# Developing a GNSS PPP Service Delivered via Iridium

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# 1. Introduction

## 1.1 Abstract

The team at DDK Positioning Ltd. (DDK) recognised that there was a need for a truly independent Global Navigation Satellite System (GNSS) Precise Point Positioning (PPP) augmentation service that would be truly independent and truly global. The DDK team conducted market analysis and found that in order to deliver a PPP augmentation service globally from Pole-to-Pole, and remain as an independent service, they would have to deliver the service using the Iridium Satellite Communications Network.

The challenge for DDK was to develop a the GNSS PPP augmentation service transmitted to the user group via Iridium Burst.

We explore the journey of developing a disruptive GNSS PPP augmentation service delivered independently and globally.

## 1.2 References

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## 1.3 Product vs. Need

The table below maps product characteristics to addressable identified needs/customer benefits.
The current solutions for GNSS augmentation services rely on mature technology to deliver services into the marketplace (L-Band – Geostationary). Though this has been widely adopted and successfully utilised for to transmit GNSS PPP augmentation data to the customer, it does have its limitations i.e., the satellites are geostationary, coverage is not truly global and there is only a one-way communication path. The limitations of the communication link further limit the development of the GNSS products available to the markets, and result in the following:

- Long initialisation times for PPP services (15 Minutes +)
- A continuous data stream is required – the service is not able to manage network outages
- There is a limited view of satellites in Polar regions and urban canyons, plus an increased risk of masking, due the geostationary nature of the satellites
- The commercial model and cost base doesn't enable the large volume markets

The DDK/Iridium service addresses the above points, by providing the following:

- Two-way communications – enabling additional data to be supplied to specific users/regions that will reduce the initialisation times
- DDK/Iridium service is a packet-based services – that will be robust to outages of at least 10 minutes
- The LEO satellites that are used by Iridium always ensure visibility of 2-5 satellites

The GNSS market is also complex, expensive, and difficult for users to understand and deploy services into. DDK's innovative design allows us to open-up a market opportunity using the latest technology to provide a currently unavailable, global decimetre positioning solution.
DDK's product includes innovations and improvements to typical solutions by providing the ability to continue operating during prolonged network outages, provide for fast start-up and reacquisition times, and sending corrections via data packets removing the need for a continuous data stream.
The table below shows DDK's product key characteristic;

| **Identified Addressable Needs/Customer Benefits** | **Product Innovative Characteristics** |
|---|---|
| Targeted coverage cell / region/ global | Ability to deliver service to target areas via the Iridium satellite constellation – truly global coverage availability |
| Low Cost and Low Data Rates | Lower cost using packet data, no requirement for a continuous data stream |
| Expandable | Can be delivered to specific coverage areas seamlessly |
| Increased TTFF (Time to First Fix) | Instantaneous start-up time |
| QoS and status reporting | 2-way communication enabling additional benefits e.g., QoS capability, machine control |

| | |
|---|---|
| Network Robustness | Fully meshed network with redundancy built in |
| Accuracy and precision | < 10cm Positioning that can be delivered globally |
| Compatible with existing hardware | Seamless integration with Topcon line of GNSS receivers |

**Table 1: Key Product Characteristics**

# 2. System Design Journey

## 2.1 Satellite Service

The DDK GNSS PPP service is delivered over Satellite Communication link, specifically, Iridium Burst. The Iridium Burst service is available globally, delivered by the redundant constellation of Iridium satellites in Polar orbit around the Earth. Iridium holds landing rights for the service with most countries in the World and globally for oceanic regions.
Augmentation data is delivered to End User Equipment (EUE) that incorporates an Iridium modem capable of receiving the Burst service. The DDK GNSS PPP service can be supplied directly by DDK or manufactured on licence by third parties, for example GNSS hardware manufacturers. The horizontal position accuracy achievable through the service provided is:

- PPP L1: ~ 20cm
- PPP L3: ~ 5-10cm
- Global SBAS ~ 50cm

Augmentation data is sent from the DDK servers to the Iridium network and broadcast to the users who receive data at their location, which is applied to the RAW GNSS measurements in real time. The inherent latencies involved in transmission over the Iridium network, which are typically 15-20 seconds are accounted for in the construction of the augmentation data.
The availability of Iridium services has been documented at greater than 99% evaluated over an extended period. The Iridium system is now qualified as a GMDSS service provider which requires it to demonstrate an availability of at least 99.9%, or less than 10 hours down-time a year.
The Iridium Burst Service is a one-way broadcast delivery of user-defined binary payload. There is no restriction to the type of data sent and the payload size can be many thousands of bits.
The payload for GNSS augmentation data is specific to a user’s location and operational requirements.
The content of a packet scheduled for transmission depends on multiple factors:

- Geographic extent of transmission area
- Geographic centre of transmission area
- Expected time-to-live of data content
- End-User positioning requirements

To provide some indicative values, the nominal coverage area of a single Burst Global Delivery Area (GDA) is a circle 150km in diameter. This is the smallest area that can be addressed in transmission.

On average, a user in such an area will see 10 GNSS satellites (from a single constellation) at any one time.
Orbit, clock, atmospheric and calibration data is scheduled for transmission using algorithms that account for the differing lifetimes of each datatype, the allowed-for probability of missed reception of data and the positioning accuracy requirements for the delivered service.
The structure of the Global Data Burst (GDB) delivery system permits the tailoring of transmissions to include only content augmentation data appropriate for the users in a region, contrasting with the conventional delivery of augmentation data by Geostationary hemi-beam.
Please see the figure below for a comparison size between Iridium Global Delivery Areas (GDAs) and Geostationary Hemi-beam. Each red dot indicates an addressable Iridium region. There is therefore a significant reduction in data volume to the target region.

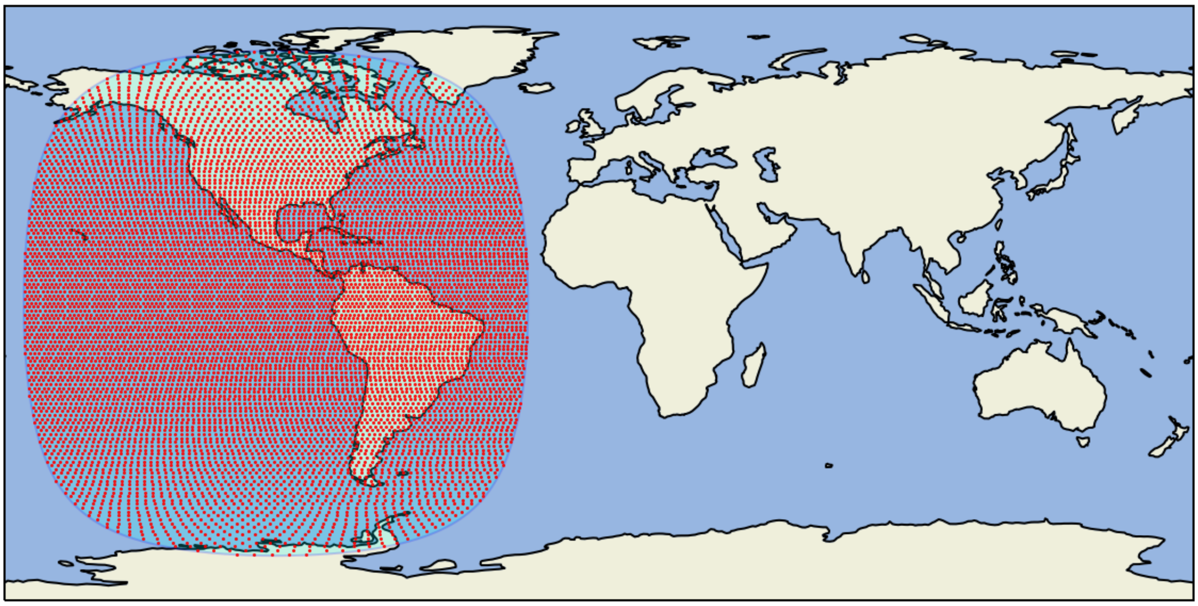

**Figure 1 – Iridium GDA v. Inmarsat Hemi-beam comparison**

## 3. Service Components

The overall system has been broken down into its various components, separated by their functionality.
The components are the main elements of the developments to be completed, enabling each element to be developed, tested, and implemented as part of the overall system.
This approach has been taken to minimise the risk of development.
The diagram below provides a schematic overview of all components for the DDK Service:

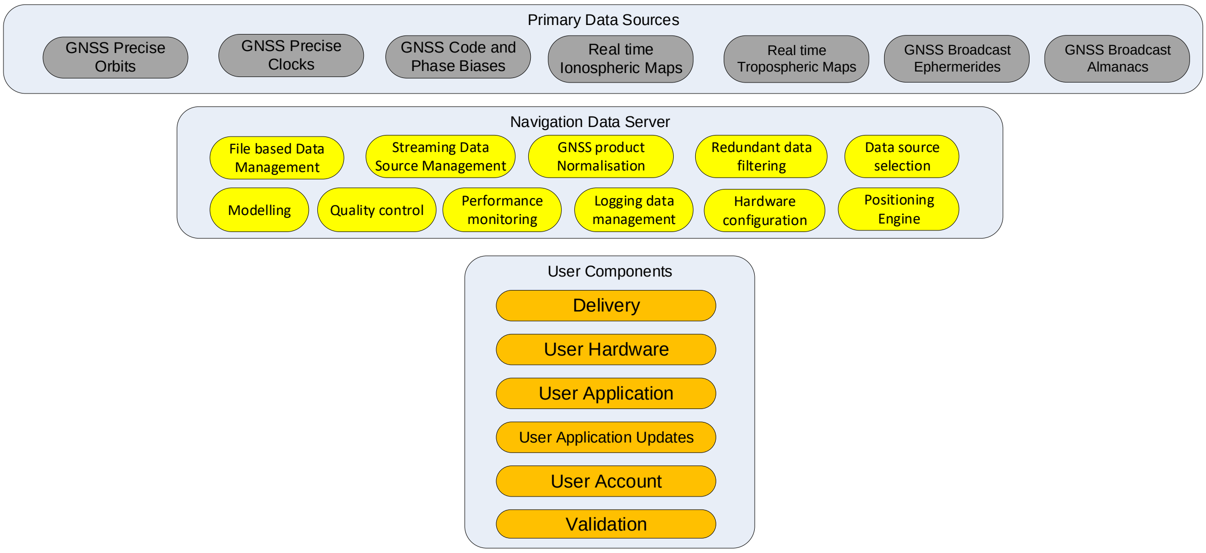


**Figure 2 - DDK Service Components**

The components of the DDK service are broken into three main areas:

- Primary Data Sources
- Navigation Data Server
- User Components

## 3.1 Primary Data Sources

Most elements common to all services relate to the management and processing of GNSS data and products.
Source data for the DDK augmentation services include:

- GNSS precise orbits
- GNSS precise clocks
- GNSS code and phase biases
- Real-time ionospheric maps
- Real-time tropospheric maps
- GNSS broadcast ephemerides
- GNSS broadcast almanacs

DDK Positioning implemented IGS corrections to generate the services during the development programme.

## 3.2 Navigation Data Server

This section will provide a breakdown of each component within the Navigation Data Server.

**1. File based Data Management for each file data source**
The main elements of the file base data management module consist of:

- Scheduled retrieval of data files
- Logging of received data
- Validation of received data
- Error reporting (outages, data errors)

**2. Streaming Data Source Management for each streaming data source**
The main elements of the streaming data source management module consist of:

- Management of data link to streaming data source (IGS)
- Logging of received data
- Validation of received data
- Error reporting (outages, data errors)

**3. GNSS product Normalisation**

Some data sources from different vendors require manipulation to allow comparisons to be properly made in subsequent processing stages.
The purpose of this module is to place all source datasets within a common frame of reference.

- Align orbits to a common frame of reference
- Align clocks to a common system time

**4. Redundant data filtering**

The DDK augmentation service operates on multiple redundant data sources. The purpose of this module is to eliminate redundant sets of identical data received from different hosts. This is a lossless process (assuming at least one source is available).

- Identify redundant datasets or files
- Discard redundant copies
- Performance and error reporting

**5. Data source selection**

For each source data type (orbit, clock, ephemeris etc) we now have multiple representations of the same value. The variations in value may be legitimate (due to variations in orbit generator algorithms for example) or otherwise (e.g., software bugs in orbit generator applications). These systematic anomalies can be accounted for in the configuration of the system, but as a practical measure such accounting is always retrospective.
This module must select the best representation of each GNSS product type for subsequent processing. The method selected depends on the source data type and the number of similar values available for comparison.
The output may be one value selected from many or may be a weighted composite of input values.
Consideration may also be made to favour continuity of source data. i.e., to keep using a certain source until there is good reason to switch.

**6. Quality control**

Quality control takes place at all stages of the augmentation process, relevant to the function of that module.

**7. Performance monitoring**

Performance monitoring metrics provide visibility at each stage in the augmentation generation process.
Performance metrics include:

- Data source availability
- GNSS constellation availability
- Historical comparison of GNSS products
- Atmospheric product visualisation
- Real-time positioning performance of DDK augmentation products
- Historical comparison of DDK and IGS final data products

**8. Logging data management**

Data is logged at all stages of the augmentation process. GNSS data is logged for historical reporting and analysis. Event logs are retained for diagnostic purposes.

Data management tasks include:

- Consistent naming of files
- Consistent treatment of diagnostic event logs
- Archiving of files to offline storage
- Implementation of an event log search and analysis system

**9. Redundant Server Pairs**

The DDK augmentation service operates on a redundant failover server pair within a data centre.

This server pair arrangement is replicated in another data centre(s). The data centre instances operate independently of each other.

**10. DDK Positioning Engine**

The DDK positioning engine is at the centre of all DDK Services. The positioning engine can generate:

- Multi-constellation GNSS solutions
- Single frequency PPP solutions
- Dual frequency PPP solutions
- Fast solution convergence
- Fast solution re-convergence

## 3.3 User Components

**1. Delivery**

Delivery covers the transfer of GNSS augmentation data between the DDK service and the end user.

Satellite (Burst)

- Augmentation data is delivered to the Iridium Gateway on a scheduled basis. An augmentation dataset is identified for each operating region at each transmission time period (currently 60 seconds) and forwarded to the Gateway.
- Augmentation datasets are assigned by Broadcast Delivery Area (BDA). The content of each dataset is restricted by the geographical extent of the BDA. A typical BDA will cover a Country (e.g., Netherlands) but the size of the BDA is determined by multiple factors including transmission data payload and geographic extent. The sum of all possible BDAs is Global.
- The Satellite Service transmits only to BDAs where there are active subscribers. Subscribers are identified to the system by use of the SBD Service (see below).
- Datasets are transmitted to the Iridium Gateway over Internet using a protocol defined by Iridium. Consideration will be given to the augmentation of this delivery method with one that provides a defined Quality of Service, such as MPLS.
- GNSS augmentation products are formatted and scheduled to maximise availability of positioning within each BDA
- Datasets are delivered to the user via the Iridium Burst Service

<u>Satellite (SBD)</u>

- Satellite SBD delivery is a bidirectional request-response process
- Augmentation data is delivered to the user device in response to an SBD MO (Mobile Originated) request.
- Requests are by proprietary protocol over the Iridium SBD Service
- User request parameters include user location, service level and available constellations
- A dataset applicable to a single user is delivered to the user device within one or more MT (Mobile Terminated) SBD messages. Typically, SBD traffic will only be generated when a user starts using the service this event will occur randomly throughout the day

## 2. User Hardware

User Hardware executes the User Application and interfaces to 3rd party equipment

- User hardware for the Satellite Service is manufactured by DDK for sale directly or via 3rd party distributors
- User hardware hosts at a minimum a PSU, embedded controller, GNSS receiver, Iridium 9602 modem, Antenna, incl. GNSS, SBD. GBD and cellular modem and antenna
- The hardware interfaces to client equipment via various interfaces (RS232, RS422, CANBus etc.)
- The User hardware is certified for use in its operating environment

## 3. User Application

The User Application is application software that:

- Executes the DDK positioning engine
- Interfaces with User Hardware
- Interfaces with the DDK Service

Features of the User Application

- User Application is embedded firmware
- Command Line Interface (CLI)
- Configuration management
- No local GUI
- Remote GUI via smartphone or desktop App
- Management of hardware modules (GNSS, Cellular, WiFi, Iridium)
- Client output configuration
- I/O interface configuration
- Data logging
- Upgrade management

## 4. User Application Updates

User Application Update describes the process of providing upgrades to User Application code running on User Hardware in the field.

- Local Update. Update is carried out locally in the field (USB or network update)

- Over the Air Update. Transmission of firmware updates via the Iridium Burst Service. Requires sophisticated management at both the server and user side for successful implementation.

**5. User accounting**

Accounting for service usage and translating usage into a billable amount to the customer's account.

- Subscription and billing to be managed in conjunction with the Iridium Services.

# 4. Results

After implementation of the prototype system and hardware discussed in the previous sections, DDK undertook a series of static and dynamic service and hardware verification trials in order to test the performance and accuracy of the service and hardware.

The DDK GNSS PPP augmentation service data is delivered over Iridium Burst. For static testing the DDK GNSS PPP augmentation service data is also delivered via Internet to enable comparison between the Iridium Burst connectivity and Internet connectivity and latency, with the Internet delivery acting as the benchmark.

The static and dynamic verification was completed using both professional geodetic grade receiver solutions and consumer grade receiver solutions. DDK used a consumer grade receiver as part of the testing to determine the level of service that was achievable using the DDK Augmentation service. The addition of this receiver enabled the testing to cover a consumer grade level dual frequency GNSS receiver that are a lower cost base compared to the Geodetic Grade receivers that have also been used throughout the project. The results shown in this section were obtained using DDK hardware with geodetic grade and consumer grade receivers.

## 4.1 Prototype BETA DDK X1 Hardware

In collusion with our manufacturing partner (Makar Technologies) DDK manufactured several BETA DDK X1 devices to use during the static/dynamic performance and accuracy verification testing. The figure below shows an example of one of the BETA DDK X1 devices used during verification testing;


**Figure 3 – Prototype BETA DDK X1 Device**

## 4.2 Static Verification

The static testing was carried out in Aberdeen (UK), Washington DC (USA), Phoenix (USA) and Livermore (USA).
Data was not sent or retrieved at the Washington site due to the COVID restrictions. Iridium Communications LLC policy is for staff to work from home, and not enter the business premises, which meant that the unit was not available for the test phase of this project.

## 4.3 Static Positioning Performance

The static positioning performance is detailed in this section. The device was configured to compute two independent real-time solutions using the same GNSS measurement set.
The first solution is a dual frequency multi-constellation PPP solution, with DDK PPP GNSS augmentation being delivered over the internet. This solution demonstrates the performance of the device using high-rate DDK PPP GNSS augmentation. The performance was measured by comparing the individual PPP positions to a static survey control point.
The second solution is a dual frequency multi-constellation PPP solution using Iridium Burst to deliver the DDK PPP GNSS augmentation to the device. This solution demonstrates the performance of the device using low-rate GNSS PPP augmentation provided by DDK Positioning. The performance was measured by comparing the individual PPP positions to a static survey control point.
The survey control point was computed using a static GNSS solution with the AUSPOS online GNSS post processing service.

## 4.4 Solution One: Augmentation Over the Internet

This position solution is dual frequency GPS + Galileo PPP in kinematic/dynamic mode. Augmentation is delivered over the Internet with a 10 second interval.
The positioning solution data provided here formed part of longer-term tests that lasted for several days. The charts and statistics are reflections of the steady-state performance of the solution after it had attained convergence.

**Note:** "Kinematic mode" indicates that the position parameters in the state vector were set for a moving object, i.e., they are large, despite the antenna being completely static. The parameters were set in this manner so that the PPP solution positions were relevant for the test being conducted and were not biased to the static scenario.

### 4.4.1 Static Performance Plots – Internet Delivery (Geodetic Receiver)

The following representative test results were obtained from observations at Aberdeen, U.K.

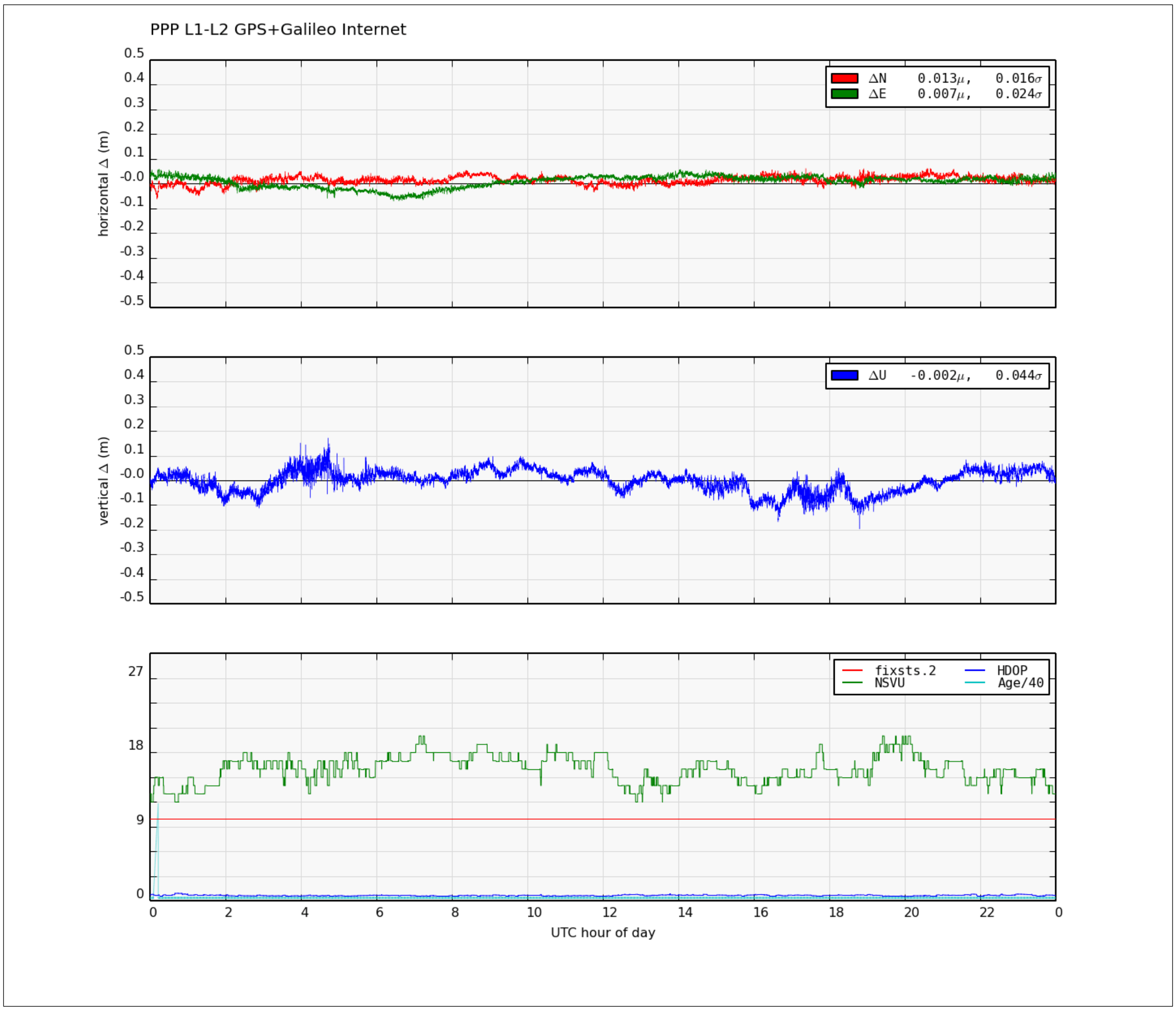


**Figure 4 – Internet Delivery: Coordinate Position Δ Values**

This position solution is a dual frequency GPS + Galileo PPP in kinematic mode. Augmentation is delivered over the Internet at 10 second intervals.
The solution set contains 24 hours of continuous positioning at a fixed point (1Hz epochs) after the solution had attained convergence.

### 4.4.2 Static Positioning Statistics – Internet Delivery (Geodetic Receiver)

| Dimension | Offset | 1-sigma (68 percentile) | 2-sigma (95 percentile) |
|---|---|---|---|
| **East** | 0.7 | 2.4 | **4.8** |
| **North** | 1.3 | 1.6 | **3.2** |
| | **Horizontal Accuracy - 2-Sigma** | | **5.8cm** |
| **Dimension** | **Offset** | **1-sigma (68 percentile)** | **2-sigma (95 percentile)** |
| **Up** | -0.2 | 4.4 | **8.8cm** |

**Table 2 – Static Positioning Statistics Using a Geodetic Receiver (Internet)**

### 4.4.3 Availability

Augmentation data availability measured as the ratio of received to transmitted augmentation data frames was greater than 99% over the positioning interval.

### 4.4.4 Latency

Clock correction latency, measured as the age of correction at the time of arrival at the device, has a mean value of 14 seconds over the positioning interval.

### 4.4.5 Convergence

Convergence testing and analysis is performed in offline mode. This allows for resets of the navigation algorithm under varying visibility, geometry and atmospheric conditions and so generate representative values for the horizontal and vertical convergence of algorithms.
One of the aims of the development was to achieve accelerated convergence using additional information from precise real-time atmospheric (ionospheric and tropospheric) information.
Unfortunately, real-time atmospheric data to the accuracy and resolution required to produce accelerated convergence was not available within the test period, and this aim was not realised.

## 4.5 Solution Two: Augmentation Over Iridium Burst

This position solution is a dual frequency GPS + Galileo PPP in kinematic mode.
Observations included in the solution are as follows:

- GPS L1 (C/A) and L2 (P2 or L2C) range and phase as iono-free combination.
- Galileo E1 (C) and E5b (Q) range and phase as iono-free combination.

**Note:** "Kinematic mode" indicates that the position parameters in the state vector were set for a moving object, i.e., they are large, despite the antenna being completely static. The parameters were set in this manner so that the PPP solution positions were relevant for the test being conducted and were not biased to the static scenario.
The solution set contains 24 hours of continuous positioning at a fixed point. The PPP positions were logged at 1Hz epochs.

### 4.5.1 Static Performance Plots – Iridium Burst Delivery (Geodetic Receiver)

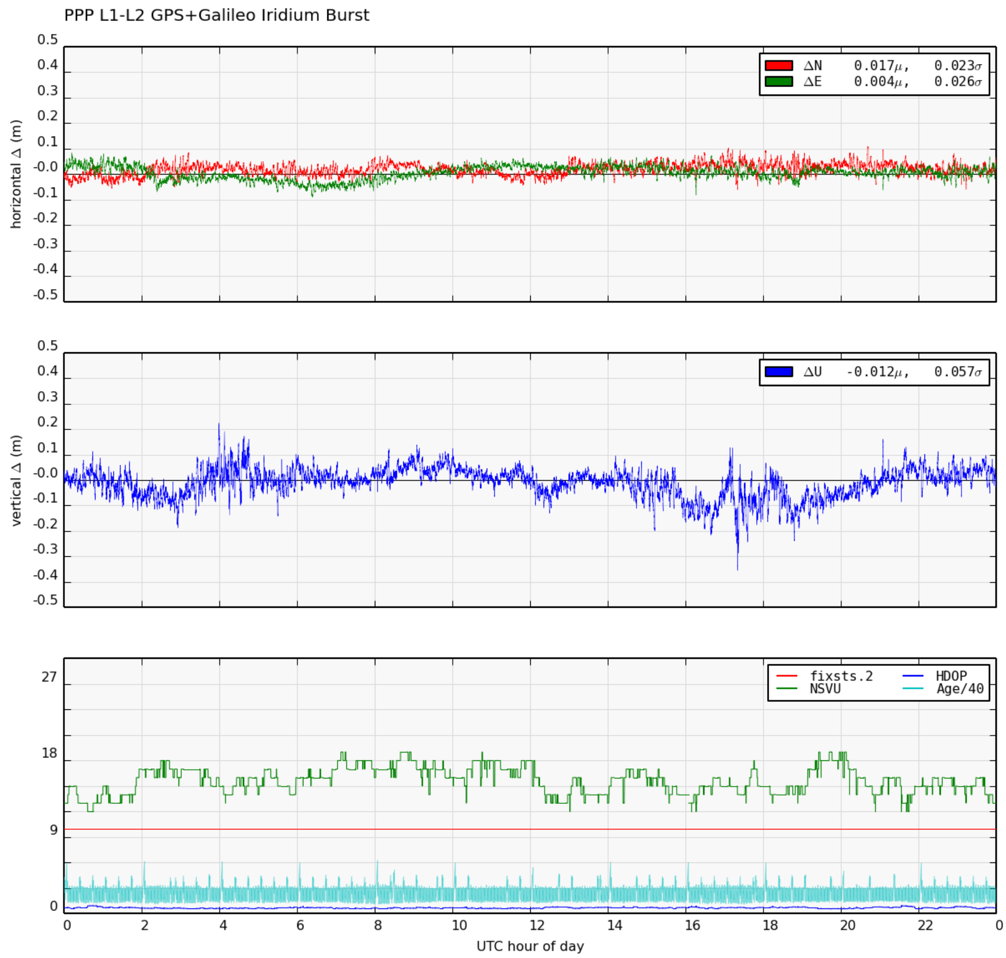


**Figure 5 – Iridium Burst Delivery: Coordinate Position Δ Values**

### 4.5.2 Static Positioning Statistics – Iridium Burst Delivery (Geodetic Receiver)

| **Dimension** | **Offset** | **1-sigma 68 percentile)** | **2-sigma (95 percentile)** |
|---|---|---|---|
| **East** | 0.4 | 2.6 | **5.2** |
| **North** | 1.7 | 2.3 | **4.6** |
| | **Horizontal Accuracy - 2-Sigma** | | **6.9cm** |
| **Dimension** | **Offset** | **1-sigma (68 percentile)** | **2-sigma (95 percentile)** |
| **Up** | -1.2 | 5.7 | **11.4cm** |

**Table 3 – Static Positioning Statistics Using a Geodetic Receiver (Iridium Burst)**

### 4.5.3 Availability

Augmentation data availability measured as the ratio of received to transmitted Iridium Burst data frames was greater than 99% over the positioning interval.

### 4.5.4 Latency

Clock correction latency, measured as the age of correction at the time of arrival at the device, has a mean value of 28 seconds over the positioning interval. This represents an increase of 14 seconds over the direct (internet) solution.
The maximum age of correction recorded in this solution set is 240 seconds.

### 4.5.5 Convergence

Convergence testing and analysis is performed in offline mode. This allows for resets of the navigation algorithm under varying visibility, geometry and atmospheric conditions and so generate representative values for the horizontal and vertical convergence of algorithms.
One of the aims of the development was to achieve accelerated convergence using additional information from precise real-time atmospheric (ionospheric and tropospheric) information.
Unfortunately, real-time atmospheric data to the accuracy and resolution required to produce accelerated convergence was not available within the test period, and this aim was not realised.

## 4.6 Dynamic Verification

### 4.6.1 Dynamic Verification Equipment

The following test harness was used for the dynamic testing, this was used to enable multiple GNSS receivers to be used simultaneously, with the same GNSS antenna as a reference point.

| Item | Description | Number |
|---|---|---|
| 1 | Iridium Antenna c/w cable and mounting bracket | 1 |
| 2 | Tallysman GNSS Antenna c/w cables, mounting bracket and splitter | 1 |
| 3 | LTE Antenna c/w cables and mounting bracket | 1 |
| 4 | Geodetic GNSS Receiver – RTK Rover (to act as the base data for comparison) | 1 |
| 5 | Geodetic Receiver (DDK MAX) | 1 |
| 6 | Consumer GNSS Receiver (DDK CORE) | 1 |
| 7 | DDK X1 c/w ARM64 CPU, Iridium Modem and LTE Modem | 1 |
| 7 | DDK PPP GNSS Augmentation Data: Over LTE | 1 |
| 8 | DDK PPP GNSS Augmentation Data: Over Iridium Burst | 1 |

**Table 4 – Dynamic Positioning Equipment**

### 4.6.2 Dynamic Verification Route

The route taken for the dynamic validation is shown in the figure below. The route covered enclosed streets with vegetation cover, driving at various speeds and with various manoeuvres. The vehicle speed varied from between 0 km/h whilst stationary, accelerating to 10 km/h whilst making tight circular manoeuvres and 60 km/h on straight roads, the mean speed was 30 km/h. The speeds and manoeuvres are representative of the type seen in both marine and agricultural sectors.

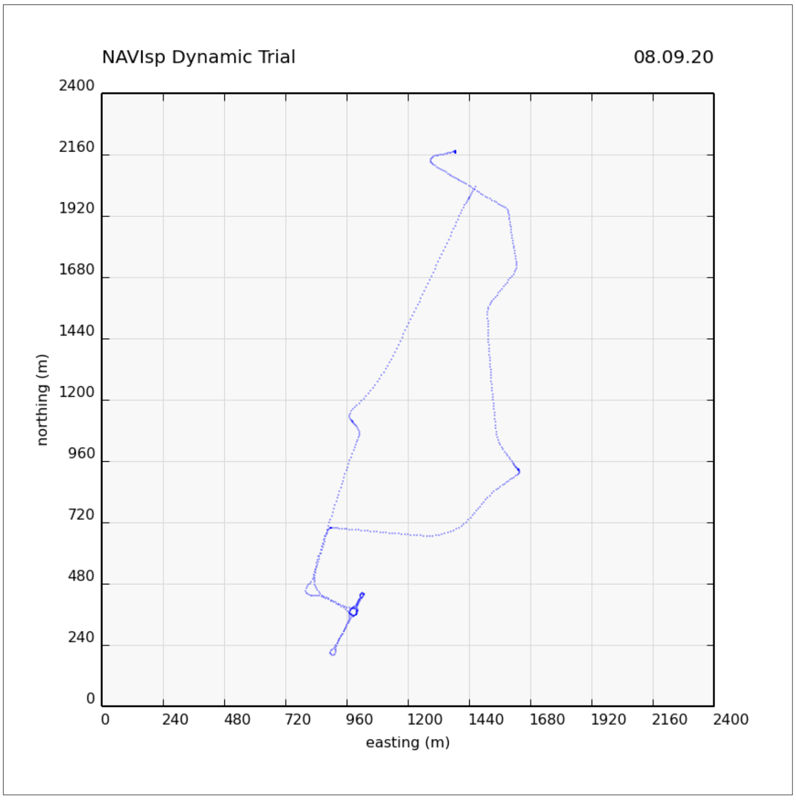


**Figure 6 – Dynamic Validation Route (Aberdeen, UK)**

### 4.6.3 Burst Availability

Over the duration of the trial 30 Iridium Burst messages were received with a mean latency of 20 seconds. There were no losses.

### 4.6.4 Dynamic Performance

| **Dynamic Performance Results (Geodetic Receiver)** | |
|---|---|
| **East (1σ)** | 4.7cm |
| **North (1σ)** | 1.9cm |
| **Vertical (1σ)** | 4.9cm |
| **Horizontal (2σ)** | 10.1cm |
| **Vertical (2σ)** | 9.8cm |

**Table 4 – Dynamic Positioning Results (Geodetic Receiver)**

| **Dynamic Performance Results (Consumer Receiver)** | |
|---|---|
| **East (1σ)** | 3.8cm |
| **North (1σ)** | 4.5cm |
| **Vertical (1σ)** | 12.0cm |
| **Horizontal (2σ)** | 11.8cm |
| **Vertical (2σ)** | 24.0cm |

**Table 5 – Dynamic Positioning Results (Consumer Receiver)**

The position log from each receiver is first differenced against the position log of the reference receiver and then summary statistics calculated over the trial period interval.

# 5. Conclusions

## 5.1 Static Verification Conclusions

The static verifications were carried out over several months. The positional performance met the requirements set out at the start of the project.
Though the static DDK PPP GNSS results are compared to a static GNSS survey control point, each epoch is a computed solution and is not smoothed or changed to fit a static state. This provides the real-world view of the performance, and each epoch represents the actual level of performance. The static verification did highlight some longer-term sinusoidal waves that are seen over several days at the test locations. This could be a result of orbit errors, or even tidal uplift in coastal zones, these are areas to be investigated further, but would not be witnessed during dynamic tests. One possible explanation of the long-term sinusoidal errors is a mismatch in the application of solid earth tide modelling used in the generation of the GNSS orbit/clock augmentation and that employed in the positioning solution.

| Description of Result | Horizontal Results - 1σ [cm] | Horizontal Results - 2σ [cm] |
|---|---|---|
| Mean | 3.3 | 6.5 |
| Target Value | <5 | <10 |
| Target ± Δ to Mean Value | -1.7 | -3.5 |

**Table 6 – Summary of Static Performance Results**

This summarised mean result of 6.5cm confirms the compliance with the Project Goal of <10cm horizontal accuracy. The static tests met the requirement set out as part of this project.

## 5.2 Dynamic Validation Conclusions

During dynamic testing it is more difficult to determine the performance, due to the challenge of determining the 'Truth'. For the DDK service, 2 approaches were used to establish the truth:

1) Using an RTK solution from a separate GNSS receiver, from the same GNSS antenna
2) Process the logged raw GNSS data from the GNSS receiver used for the PPP solutions, and post process using final orbit and clock data

Using both aforementioned methods enables the truth solutions to be cross referenced and then used to check the performance of the dynamic DDK service.
The dynamic vehicle was used to test the service in open and urban locations in and around Aberdeen, UK. The vehicle speed varied from between 0 km/h whilst stationary and accelerating, 10 km/h whilst making tight circular manoeuvres and 60 km/h on straight roads, the mean speed was 30 km/h. The speeds and manoeuvres are representative of the type seen in both marine and agricultural sectors.
The Augmentation data was sent over the Iridium Burst and over an IP link via LTE. This approach provided consistency in the data communication link.
The Dynamic testing revealed the level of communication available on the Burst service in various scenarios including high vegetation (trees) and urban areas. The Burst service was always available and thus there was no impact to the overall service performance.
The service operated within specification, i.e., the horizontal and vertical position performance was within 10cm and 20cm respectively 95% of the time throughout the test period.

The dynamic testing was successfully delivered, and summary of results can be seen in the table below.

| **Dynamic Performance Results (Geodetic Receiver)** | |
|---|---|
| **Horizontal (2σ)** | 10.1cm |
| **Vertical (2σ)** | 9.8cm |

**Table 7 – Dynamic Positioning Results (Geodetic Receiver)**

| **Dynamic Performance Results (Consumer Receiver)** | |
|---|---|
| **Horizontal (2σ)** | 11.8cm |
| **Vertical (2σ)** | 24.0cm |

**Table 8 – Dynamic Positioning Results (Consumer Receiver)**

## 5.3 Closing Statement

The main aim of the project was to design and develop a GNSS PPP augmentation service that is delivered over the Iridium Burst service, as well as the various components including the hardware required to test and validate.

This report provides a summary of the work carried out, the results achieved and reports the findings of the validation process.

The project enabled the design, development, and validation to be completed for each section of the service, ensuring each component of the service was validated against the initial objectives set out at the beginning of the project.

The aims of the project were then met, with the key elements being as follows:

- System design for all components (PDS), (NDS), Prototype hardware and User Positioning Engine
- Development of the elements set out in the system design
- Integration of Service within Iridium Burst Service
- Verification of the Service

Beyond the individual component testing, the accumulation of the end-to-end system validation resulting in final positional performance was achieved in both static and dynamic environments. The positional performance achieved for both tests met < 10cm accuracy levels. Other measurements of the performance that met the requirements were Iridium Burst availability, network outages, multi constellation and delivery of augmentation as a packet-based service to accommodate the Iridium Burst architecture.