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1. Executive Summary

Positioning and navigation technologies have become important for the everyday life in our modern society. Much current positioning and navigation is based on satellite systems which used to be synonymous to the American Global Positioning System (GPS). Today, there are also other satellite systems available and they are referred to using the term Global Navigation Satellite Systems (GNSS) which comprises not only GPS but also the European Galileo system, the Russian GLONASS and the Chinese BeiDou (BDS). These systems are used in combination to obtain better reliability and robustness in the positioning for instance in modern smartphones.

Most applications of GNSS today are based solely on the satellite systems, these are applications which require position accuracy at the level of some metres for example the use of GNSS for vehicle navigation, and the use of GNSS for tracking of people and goods. However, for high-accuracy positioning, GNSS must be augmented and the augmentation is referred to as a positioning service. Examples of users of GNSS positioning services are precision agriculture, machine control in construction work, navigation in harbours and narrow water ways as well as the future area of autonomous navigation of vehicles, drones, vessels etc.

During recent years, many high-accuracy positioning services, ranging from global to national coverage, have been established. Operating a positioning service requires access to a network of Continuously Operating Reference Stations (CORS) which provides the observations needed to produce the correction data. Both private and public networks and positioning services exist.

In this white paper a review of the ongoing technical development in satellite-based positioning services as well as in related communication technologies is provided. Also, the status of CORS networks and positioning services in the Nordic and Baltic countries is outlined along with a discussion of current and future challenges.

There are good possibilities of cooperation between public and private services and between national agencies on data sharing and means of dissemination. Also, cooperation is beneficial in relation to some of the challenges for future positioning services such as different coordinate and height references, interference of GNSS signals, cyber threats and space weather.

National Mapping Agencies should be aware of the ongoing development and on the potential impact on the national geodetic infrastructure. The conclusion of this paper is therefore a list of recommendations for initiatives to be taken by national mapping agencies in order to be prepared for the increasing use of positioning services in the future.

It is important to be aware of future user needs and accordingly develop the geodetic infrastructure including geodetic reference frames, coordinate transformations and height systems. It is recommended to work on further development of methodologies for high accuracy positioning including the ability to provide integrity information to end users. It is recommended to increase cooperation at the Nordic and Baltic level on further development of GNSS services and also on detection of interference and jamming of GNSS signals. Furthermore, it is recommended to work for an enhanced cooperation at the European level both on GNSS positioning services and on the increasing needs for accurate and available high-quality geodata as required for autonomous positioning and navigation in the future.

2. Introduction

This white paper provides a review of the development within the field of Global Navigation Satellite Systems (GNSS) positioning services as applicable for the Nordic and Baltic countries. The purpose is to outline development trends and challenges as a basis for future work within the Nordic Geodetic Commission (NKG).

The paper reviews the ongoing development in GNSS positioning services as well as in related communication technologies. Challenges in the development of future positioning services are outlined and, finally, a list of recommendations is provided for the NKG Presidium and the National Mapping Agencies (NMA's).

2.1 Introduction to GNSS positioning methodology, definitions and terminology

A GNSS positioning service is in this paper defined as an overlay service, or augmentation service, which is used along with the GNSS-systems, i.e. GPS, GLONASS, Galileo and BeiDou. Thus, the end user equipment receives data both from the GNSS satellites and from the GNSS positioning service and use the two data types in combination to obtain a position solution.

The document has a specific focus on high-accuracy GNSS positioning services here defined as services with the possibility to provide end user position accuracy at 20 cm or better at a significance level of 68% (one sigma). Also, the document focuses on positioning in real time as opposed to post processing services which are not discussed.

All GNSS positioning services mentioned and discussed in the following require data from permanent GNSS reference stations on the ground which collect data from GNSS satellites. Such stations are referred to as Continuously Operating Reference Stations (CORS) and they exist in almost every country of the world. Originally high-quality CORS were established by government organisations as the backbone for geodetic reference frames and for use within geodynamic monitoring and modelling. However, CORS also provide an excellent infrastructure for positioning services, and many of the positioning services discussed in the following are based on government owned high-quality geodetic infrastructure. CORS are usually operated from a centralised control centre and real-time services often utilise international standardisation for the data distribution developed within the Radio Technical Commission for Maritime Services (RTCM) Special Committee 104.

GNSS positioning services providing position accuracy at the level of 50 cm to 5 metre also exist. These mainly belong to the groups of Satellite Based Augmentation Systems (SBAS) or Differential GNSS (DGNSS) services, but also a few other types of services exist.

SBAS services are developed for aviation but are also used for other applications. The services cover large regions, the size of continents. They are based on a number of ground stations, a processing centre where the SBAS data is calculated and uplink stations which uplink the SBAS data to communication satellites from where the data is distributed to users (see also Section 3.2). The SBAS augmentation data include ranging signals, corrections for some of the GNSS error sources and integrity information. Examples of SBAS systems are the European Geostationary Overlay System (EGNOS) and the American Wide Area

Augmentation System (WAAS). The systems are continuously undergoing development, and are regulated by the International Civil Aviation Organization (ICAO).

For aviation also local Ground Based Augmentation Systems (GBAS) have been developed. These are positioning services established in some airports, used for so-called precision approach and landing of airplanes, and like SBAS, the GBAS services provide corrections as well as integrity information.

DGNSS services are nowadays mostly developed for maritime applications operated by national maritime authorities following regulations within the framework of the International Association of Lighthouse Authorities (IALA). DGNSS services are based on reference stations which estimate differential corrections for the GNSS error sources and distribute these via terrestrial communication to the end users. DGNSS services are traditionally based on autonomous reference stations and are, so far, mostly utilising GPS only. Government operated DGNSS services exist in all of the Nordic and Baltic countries.

In applications of positioning and navigation, GNSS is often integrated with other sensors in a combined navigation or sensor system for use on land, at sea or in the air. In such systems, the GNSS receiver provides positions as well as timing to the navigation system. The other sensors operate in a relative sense and provide information on the location of the platform relative to previous positions (dead reckoning) or relative to external objects (e.g. road signs or other vehicles). With large amounts of data from GNSS and the other sensors, sensor fusion which integrates sensor data and information from these heterogeneous or homogeneous sensors to produce high-accuracy positioning in all situations with high reliability is in demand. Examples of sensors used in combination with GNSS for autonomous vehicles are inertial navigation systems (INS), image sensors (camera), radar and laser. In most integrated navigation systems, GNSS is used for time synchronisation of the sensors, and the importance of GNSS for time synchronisation in such systems can not be underestimated.

Integrity as a quality parameter in GNSS positioning is becoming increasingly important for many user groups, especially within the field of autonomy. Integrity is a measure of the trust which can be applied to the correctness of data from a positioning service. The integrity concept for GNSS-based positioning was originally developed for SBAS services and used as a quality parameter along with accuracy, availability and continuity. Integrity is further discussed in Section 5.2.

For users of high-accuracy services, the quality of the coordinates is also important. As coordinate quality parameter, only the term accuracy is used in this paper. Thus, no distinction is made between uncertainty, precision and accuracy because for many applications these words are used interchangeably. Also, the level of significance for measures of accuracy, such as for instance 68% or 95%, is not provided. This is a simplification made on purpose herein, because for many of the non-geodetic applications discussed, the level of significance is not known.

2.2 Development of applications and future areas of use of GNSS

According to the European GNSS Agency (GSA) Market Report from 2019 [1], the number of GNSS users globally is expected to increase from around 6.5 billion units in 2019 to 8 billion units in 2024 and more than 10 billion in 2029. Much of the increase is driven by increasing use in Asia and Africa, but there will also be an increase in Europe including the Nordic and Baltic countries.

The largest group of users will also in the future be private and personal users, where GNSS is used for Location Based Services (LBS) e.g. in smartphones, tablets, personal tracking devises and sporting equipment. Also, the number of "wearables", where GNSS receivers are integrated into clothes, shoes, watches etc., is expected to increase. A growing number of LBS applications are expected to require high accuracy such as Mobile Location Based Gaming (MLBG) and Augmented Reality (AR) for private use. For professional use, LBS applications for mapping, Geographic Information Systems (GIS) and documentation are expected to grow.

The GSA Market Report does not quantify the expected use of GNSS for Internet of Things (IoT). But IoT is a very important driver in the development of the use of GNSS in the health sector, for tracking units, in the shipping and transport sectors, in farming etc.

The second largest group of users, according to the GSA Market Report [1], will be road applications where GNSS receivers are mounted in cars, trucks etc. As mentioned by the European Radio Navigation Plan from 2018 [2], eCall will be mandatory for cars sold in Europe in the future, and smart tachographs will be mandatory in trucks sold in Europe. These regulatory initiatives will drive the development towards more GNSS units on the roads.

Focusing on professional user groups of high-accuracy GNSS services in the Nordic and Baltic countries these will most likely be machine control and machine guidance for construction work and agriculture, surveying (for building, construction, cadastral and environmental applications) and various maritime applications in harbours, inland waterways and coastal areas.

The use of high-accuracy GNSS services for navigation and positioning of drones will increase significantly, if future rules and regulations support the technical development. Increased use of drones will be within all of the application areas mentioned above.

Autonomous units on land, at sea and in the air will require high-accuracy GNSS services to a very large degree in the future, and this user group is expected to grow a lot in the coming years. For autonomy, integrity information provided as part of the high-accuracy services is crucial for the use of the services.

2.3. Development of high-accuracy GNSS positioning services

As discussed in the following, there are currently two different approaches for operation of high-accuracy positioning services namely Real-Time Kinematic (RTK) and Precise Point Positioning (PPP).

Local, regional and national high-accuracy GNSS positioning services are most often based on the RTK positioning technique, where data from CORS is used for generation of RTK correction data which is distributed to end users and applied in the positioning process. When more than one reference station is used in a network, this is also referred to as network RTK.

RTK data provides corrections for atmospheric effects on the satellite signals as well as for inaccuracies in the GNSS navigation messages (i.e. estimates of satellite position and clock errors). RTK corrections are normally transmitted to users via terrestrial communication, mostly via cellular phone networks or UHF radio. RTK services normally provide position accuracy at the level of 1–5 cm after a short initialisation of a few seconds.

PPP provides high-accuracy positioning based on global networks of CORS and data from the stations is used for estimation of satellite orbits, clock corrections, and code and phase hardware biases. The correction data is normally distributed in real time to end users by means of geostationary satellites (see also Section 3.2) or over the internet. PPP services often provide near-global coverage and are mostly operated by private companies. PPP services normally provide position accuracies at the level of 5–10 cm with an initialisation time of some minutes. PPP positioning is more vulnerable to site dependent effects and satellite signal blockage than RTK.

High-accuracy GNSS positioning services can also be categorised as based either on the Observation State Representation (OSR) or a State Space Representation (SSR) of the errors. The two approaches use different techniques to solve the problem of mitigating the spatially correlated errors in GNSS positioning in order to obtain a high accuracy.

In OSR-based approaches, the expected observed errors at the location of a user are estimated and transmitted to the user as for example with the RTK Virtual Reference Station (VRS) methodology. Conversely, in SSR-based approaches observed GNSS errors are used to model the errors across a region as a state space model, where each error source is essentially modelled separately and with separate temporal update intervals. The parameters describing the state space model are broadcasted to users. This approach is applied in some of the operational PPP services.

Currently, there is much work on combining the RTK and PPP techniques in order to take benefit of the higher accuracy and shorter initialisation time of RTK as well as the less dense network of CORS required for PPP. In the simplest way the two techniques are used separately to supplement each other, i.e. if connection to a local RTK service is lost, the user equipment can switch to using a global PPP service until connection to the RTK service is re-established.

More advanced options for combination of RTK and PPP is in the data processing of the control centre and in the end user equipment. For instance, the models used for estimating corrections for the satellite positions and clock errors can be based on the PPP methodology, whereas estimates for atmospheric errors can be based on the more local or regional RTK networks. For this to work out, the SSR approach must be applied in both the data processing, the data distribution and in the end user equipment.

International standardisation work within e.g. RTCM Special Committee 104 is ongoing, and even though SSR services to some extent does exist today, the standards are not yet finalised.

Along with the operation of a data centre for data collection, processing, storage and dissemination, the establishment and operation of CORS is also required in order to provide a GNSS positioning service. Establishing and maintaining a robust and reliable GNSS infrastructure is expensive, and, in essence, the better the infrastructure is, the better positioning performance for the end user. Many commercial service providers (for both RTK and PPP) therefore rely on data from national GNSS infrastructure for their services. See also Table 4.1 in Section 4.3.

3. Technological development

The Nordic countries have been among the early adopters of cellular communications, and the deployment of 5G networks is well underway. The development is in parts driven by the two large international providers of cellular infrastructure based in the Nordic region i.e. Ericsson and Nokia.

Modern smartphones and other similar devices such as tablets are probably the most popular means of accessing location information, and current Android devices supporting the output of raw GNSS observables are of particular interest from the perspective of accurate GNSS positioning. The amount of location-aware devices is expected to proliferate with the adoption of IoT technology [3].

3.1 Development of cellular technology

Today's cellular networks have distinct services that come with different requirements, different figures of merit etc. for each application. Localisation is one of the services which has been gaining attention for several years and is today mandatory for many applications. Ubiquitous applications that rely on accurate location information are so far limited by the best obtainable accuracy in the cellular networks themselves.

In recent standard documents, different use cases describe a requirement on localisation accuracy of less than 1 metre for a car and 0.1 metre for a robot. So far, such accuracies cannot be reached in the Long-Term Evolution (LTE) system – even when considering the dedicated Positioning Reference Signals (PRS). Therefore, the PRS pave the way for integrating localisation as a core feature which deserves an optimised waveform. In addition, the new applications (especially with a control loop inside) need to consider the time to first fix, which describes the latency of the positioning estimation process. Both of these key parameters, i.e. accuracy and time to first fix, depend on the chosen waveform for localisation. Further, the signal structure in a dense network must consider the geometrical constellation in 3D of the participating nodes as it strongly influences the performance.

The international 3rd Generation Partnership Project (3GPP) LTE positioning scope prior to 2018 was focused on support for so-called Enhanced 911 (E911) and IoT, while it is also possible to provide some GNSS correction data to connected devices on request. The positioning scope changed considerably with the recently completed 3GPP LTE Release 15, which features efficient and scalable provisioning of positioning assistance data to support high accuracy GNSS positioning. In Release 15, 3GPP has defined GNSS-RTK correction data coding that extends the LTE Positioning Protocol (LPP). The protocol can be transported between a device and a location server via either a Secure User Plane Location (SUPL) protocol or via control plane signalling in the network. The latter means that it is possible for the radio network to be aware of – and prioritise – the assistance data, such as for instance GNSS correction data, over other general traffic. In both user plane and control plane transport, the network is aware of the position of the serving base station. This means that the network has a crude position estimate of the device, enough for determining the suitable configuration of the GNSS correction data. In comparison, assistance data provisioned via Networked Transport of RTCM via Internet Protocol (NTRIP) needs the device to regularly feedback its position. The GNSS-RTK support standardised in LTE Release 15 would definitely benefit not only LTE but also 5G networks.

GNSS-RTK correction data signalling is also supported by New Radio (NR) devices as per Release 15 agreement, and dedicated NR refinements and adaptations can be part of the recently started Release 16

NR Positioning study together with NR specific positioning methods. Currently, Lantmäteriet in Sweden is working with Ericsson and other companies on procedures to enable the location server in a cellular network architecture to provide RTK corrections via the cellular network. The work is part of 3GPP Release 15 and concerns both LTE/4G as well as 5G.

Using 5G technology in itself will, depending on the density of base stations, provide positioning with an anticipated position accuracy better than 1 metre, perhaps down to 50 cm in urban areas. In such locations, and for applications which do not require high accuracy, GNSS and 5G can be used in combination for positioning of e.g. smartphones, so 5G based positioning replaces or supplements GNSS if there is too much disturbance of the GNSS signals caused by multipath and blockage.

It is worth mentioning that 4G was launched in late 2009 and early 2010 with only a handful of operators offering services within a limited territory. Although more and more 4G networks have been deployed since then, it will take until 2020 for 4G to become the most used wireless technology worldwide, and according to the GSM Association (GSMA), 4G usage will not surpass 50 percent of all subscribers globally until 2023. This means that 5G will likely still be a relatively niche technology even in 2025, with its forecast of 1.2 billion connections making up only 14 percent of the total number of cellular non-IoT connections worldwide, see Figure 3.1.

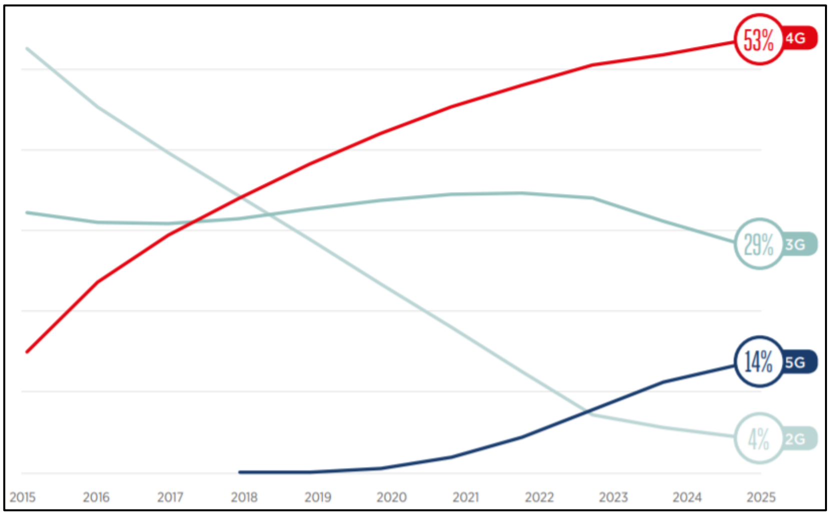

Figure 3.1: *Trend of cellular network development [4].*

Furthermore, GNSS provide timing and synchronisation for the telecommunication networks where GNSS is used for instance for handover between base stations in wireless communications, for time slot management and for event logging. Robustness and resilience in the timing and synchronisation services are key to avoid serious consequences on the operation of telecommunication, energy and financial networks. Moreover, infrastructures in the Nordic and Baltic countries are highly interwoven. Increasing the resilience of the network cannot be achieved by one country acting alone.

3.2. Dissemination of GNSS corrections using space infrastructure in the high North

Uninterrupted access to real-time GNSS correction data is difficult to guarantee in sparsely populated high-latitude regions, e.g. within the Arctic Circle. With lacking terrestrial telecommunications infrastructure such as cellular network coverage, the most cost-efficient means of data dissemination are communications satellites. Traditional telecommunication satellites are placed in Geostationary Orbits (GEO) approximately 36000 km above the Equator. Both publicly owned SBAS services and commercial PPP services base their dissemination of GNSS correction data largely on broadcast via GEO satellites. At high latitudes, however, these satellites are observed at low elevation angles above the horizon, implying that their signals are susceptible to blockage because of environmental factors such as buildings and mountains, or the user platform (e.g. the wing of a banking aircraft). In fact, at latitudes higher than 82°, geostationary satellites lie below the local horizon.

The challenges of geostationary satellites can be solved with different orbit types. One promising solution is to use satellites in inclined highly elliptical (Molniya) orbits: such satellites would spend most of their orbital period above the Arctic. As an example, Space Norway plans to launch two communication satellites in a Highly Elliptical Orbit (HEO) in 2022 in order to provide stable communication services north of 65°N. On this background, in 2018, the Norwegian Space Agency examined the possibility to equip these satellites with SBAS payloads. It turned out, however, that there was too little interest to pay for this service extension. But the European Commission is investigating the possibility of adding such payload on another satellite planned for Molniya orbit.

A different solution is to use Low Earth Orbit (LEO) satellites with a high orbital inclination, which is the approach adopted by the Iridium system. In the era of nanosatellites, a constellation of LEO tele-communication satellites could be launched at an unprecedentedly low cost.

The Galileo satellites, which are in Medium Earth Orbit (MEO), provides the possibility for dissemination of GNSS correction data, and this will be applied for the upcoming Galileo High Accuracy Service (see Section 4.2).

4. High-accuracy GNSS positioning services

In the following, global as well as regional and national high-accuracy GNSS positioning services available in the Nordic and Baltic countries are reviewed.

4.1 Global high-accuracy GNSS positioning services

One of the current challenges is to provide high-accuracy GNSS services that target the mass market applications and the traditional network RTK services are not ideal for that. This challenge is still relatively new with different suppliers pursuing different business models.

Some of the commercial services, for example, do not use an open data format and are only compatible with devices using GNSS receivers with suitable firmware. The benefit is that these can deliver a seamless, fully integrated solution, with complete interoperability (provided the region in question has good coverage). OEMs (Original Equipment Manufacturers) with customers in geographically broader markets will need to weigh this up against the benefits of positioning service providers offering open-format data.

On the other hand, Sapcorda, a recently launched joint venture between Bosch, Geo++, Mitsubishi Electric and u-blox, is creating a GNSS correction service with coverage on a global scale. Data will be distributed in an open format, customers will not be tied to a specific GNSS manufacturer, and device-makers can create the solutions their customers want. The services from Sapcorda will be broadcasted using cellular networks as well as satellite links. Also, the Sapcorda services will include integrity information which is a novel initiative in the field of high-accuracy services. Having access to GNSS services continental-wide has the potential to transform high-accuracy positioning into mainstream services, supporting various IoT applications, as well as drones and (semi-) autonomous vehicles.

In the following, some operational GNSS positioning services directed towards the global market are listed. Many of the services are not "truly global", but the service providers operate in many different countries, and the services are established so they can be expanded.

Topcon operates a PPP service, TopNET global, which is a global service mainly for Topcon-equipped platforms. TopNET live is a network RTK service available through Topcon distributers in large parts of North and South America as well as in several countries in Europe and in Australia.

Trimble operates a number of positioning services with different levels of performance. Focusing on the high-accuracy services, OmniStar-HP is a PPP service where the corrections are modelled on a worldwide network of CORS using carrier phase measurements to maximise accuracy. It is used mainly for agricultural machine guidance and many surveying tasks. The CenterPoint RTX service is a satellite-delivered global positioning service with an expected positioning accuracy better than 4 cm. The service VRS Now is based on network RTK, and is available in large parts of North America, as well as in several countries in Europe, Australia and New Zealand (see also Table 4.1).

Oceaneering International offers the C-Nav PPP service which has a global coverage and accuracy better than 5 cm horizontally.

NavCom, a subsidiary of John Deere, offers StarFire subscription. This is a PPP service with global coverage and a position accuracy typically better than 5 cm.

Hexagon AB operates a number of high-accuracy positioning services: HxGN SmartNet is a network RTK service based on CORS in Europe, North America, Australia, Russia and Kazakhstan. The service is provided in the areas covered by the stations and it relies on local actors within the service areas. Veripos is a global PPP service targeting offshore applications while TerraStar C is a global PPP service aimed at farming. The new TerraStar X operational in North America and Europe utilises a combination of PPP-based orbits and clocks with ionospheric corrections estimated from HxGN SmartNet. TerraStar X also provides integrity and authentication, and the service is aimed at autonomous driving.

Hemisphere GNSS, a subsidiary of Beijing UniStrong Science & Technology, offers Atlas which is a suite of global GNSS correction services where Atlas H10 gives a position accuracy of 8 cm.

Fugro operates several different services with global coverage. The StarFix services G2, G2+ and G4 are high-accuracy PPP services based on a global network of GNSS reference stations. The services are mainly provided for offshore applications.

4.2 Galileo High Accuracy Service (HAS)

The European Commission in 2017 [5] describes the various services Galileo will provide in the future. At that time, Galileo Commercial Service (CS) was one of the listed services and was intended for professional applications and should, against a fee, provide additional information to the position and time information of the Galileo Open Service (OS). The additional information should be developed by a service provider.

The European Commission decided in March 2018 [6] to amend the Commission Implementing Decision (EU) 2017/224 [7]. The term “Galileo CS high precision” was replaced by “Supply of high precision data in order to obtain a positioning error of less than two decimetres in nominal conditions of use”. The user will have free access to the new service – Galileo High Accuracy Service (HAS).

The service, using a combination of signals in the E6 band, consists of two parts – authentication and high accuracy. The services can be used separately, so it is not necessary to use authentication in order to obtain high accuracy. Contrary to the definition of CS, no explicit target group is mentioned in the description for HAS [8]. Beneficiaries of HAS will initially be all those who are willing to upgrade their hardware in order to receive the signals on E6. If the EC decides to make the HAS available via other media (e.g. the internet), the service can also become attractive for the mass market. This will then have an impact on equivalent services offered by commercial providers (e.g. Trimble, Fugro). The European Commission is currently finalising the relevant documents e.g. the Interface Control Document (ICD). The service is expected to be available in 2020 and fully implemented in 2022. As mentioned in Section 3.2 Galileo HAS will be available at high latitudes and in the Arctic region.

4.3 National high-accuracy GNSS positioning services in the Nordic and Baltic countries

In Norway and Sweden, the NMA's have been operating RTK services for several years. In Norway, the network RTK service called CPOS is provided by Kartverket. The CORS network of Kartverket and the CPOS service support Galileo and BeiDou. The private service providers in Norway stream raw GNSS data from the entire CORS network, meaning that all network RTK services in Norway have the same nationwide coverage. The CORS network is currently being densified along the non-electrified railways.

In Sweden, Lantmäteriet is operating the nationwide SWEPOS network of 445 CORS (December 2019) as well as the national SWEPOS Network RTK service. Galileo was implemented in the SWEPOS Network RTK service in February 2018 and the plan is to implement BeiDou in 2020. The private network RTK services in Sweden are mainly utilising data from SWEPOS stations. In Sweden, the CORS network is highly densified in a cooperation with the Swedish Transport Administration in areas with large infrastructure projects.

Table 4.1 below provides an overview of current high-accuracy positioning services which are based on the RTK technique and available in the Nordic and Baltic countries. Some of the services are operated by government organisations (the NMAs) and some services are commercially operated.

The table also provides information on whether data from the NMA services is available for free, and also if raw data from the CORS is available for free for streaming or for post processing in the RINEX format. Some, but not all, of the services have nationwide coverage.

Table 4.1: *RTK services available in the Nordic and Baltic countries.*

Country	NMA operated Service	Data from NMA service is free	Raw or RINEX data from NMA is free	VRS Now (Trimble)	HxGN SmartNet	TopNET live
Sweden	SWEPOS	No	No	Yes[2]	Yes[2]	Yes[2]
Norway	CPOS	No	No	No	Yes[2]	Yes[2]
Lithuania	LitPOS	Yes	Yes	Yes	Yes	No
Latvia	LatPos	Yes[4]	Yes[4]	Yes	No	No
Iceland	IceCORS	Yes	Yes	Yes	No	Yes
Finland	FINPOS[1]	N/A	Yes	Yes[3]	Yes	No
Estonia	ESTPOS[1]	N/A	Yes[5]	Yes[6]	No	Yes[6]
Denmark	TAPAS[1]	N/A	Yes	Yes[3]	Yes[2]	Yes[2]

Notes:
1: Governments in Finland, Estonia and Denmark operate services for science, research, testing and governmental use. None of these services can be used commercially.
2: These commercial services are streaming data in real time based on CORS owned and operated by the NMA.
3: In Finland and Denmark operated as separate services called Trimnet VRS and GPSnet.dk respectively.
4: Data from LatPos is free to use, but registration is required.
5: Not for commercial users.
6: The Estonia Land Board computes weekly positions for stations of the commercial services (if RINEX data are made available).

In addition to the services listed in Table 4.1, there are also services targeted towards specific applications, such as farming, available in some of the countries.

5. Differences and interaction between national and global services

The differences between the national and global services are mainly regarding differences in error correction models on both service provider and user side, achievable accuracy, initialisation time, dissemination means, business model (business-to-business or business-to-end user) and price of user subscriptions.

Another difference between national and global services concerns the geodetic reference frame used. National services usually utilise a national reference frame whereas global services are usually based on a global reference frame. This is further discussed in Section 5.3.

These differences are causing challenges which means that it is not straitforward to combine the two types of services. Also, there are unresolved issues in relation to standardisation and data formats used for transmission of the correction data.

The technological development on the other hand also provides opportunities. One example is a potential integration or interaction between the Galileo HAS and the geodetic infrastructure in the member states. Technically, it can be possible to stream data from the national CORS in e.g. the Nordic countries into the Galileo HAS to obtain a better positioning performance in the Nordic region. There are several political and regulatory hurdles to overcome as well as security measures. But from a technical point of view it should be possible.

5.1 Initiatives for interaction between national and global services

Integration between national and global GNSS positioning services is not yet obtained due to the reasons mentioned above. However, several initiatives have been taken in the Nordic countries as discussed in the following.

The company Sapcorda is developing a new type of positioning service as described in Section 4.1. The company has entered into agreements with the NMA's in Norway and Sweden, and has contacted the NMA in Denmark, on access to real-time data streaming from the government owned CORS. This data will be used as input to their future positioning service which will provide high accuracy and integrity on a global basis.

In Norway, Kartverket has also recently entered streaming agreements with Trimble for the inclusion of data from selected Norwegian CORS in the Trimble positioning services. Kartverket also has a streaming agreement with Veripos on data from two CORS which are used for the global services offered by Veripos.

In Finland, the Finnish Geospatial Research Institute (FGI) conducted a research project in 2013–2015 entitled *P3-Service* which investigated the provision of 0.5 m accurate positioning for mass-market devices based on corrections from the FinnRef network of CORS. Both network RTK (non-physical CORS representation) and SSR were studied. The backbone software in FinnRef is GNSMART, therefore, the SSR data were provided in the proprietary RTCM message types of Geo++. However, these messages are expected to become official RTCM standards once the standardization process is finished. Within the project, no obstacles for widespread use of these SSR formats were identified.

In Denmark, the Danish Agency for Data Supply and Efficiency (SDFE) and the Technical University of Denmark (DTU) established Testbed in Aarhus for Precision positioning and Autonomous Systems (TAPAS) in 2018. This is a not-for-profit research and development (R&D) platform for high-accuracy positioning based on the application of network RTK. The platform distributes RTK correction data using SSR, based on a high-density network of CORS. The data is distributed for free to end users engaged in R&D activities. The TAPAS platform has provided successful results in development and improvements of mobile robots e.g. for lawn moving and for cleaning of the water in the harbour of Aarhus as well as mobile robots which can be used for guidance of blind people. The TAPAS project is ongoing.

In Sweden, Lantmäteriet believes that agile techniques should be considered to enable seamless handover between network RTK services across different countries or within the same country (across different service providers, or different services for network RTK, PPP etc.), or even within the same service (when moving from one VRS[1] to another or when utilising the MAC[1] concept and moving from one cell of reference stations to another). The agile techniques use a type of handover management to process issues related to different applications or requirements. The service providers should then make use of this agility to implement smooth service hopping within very short times when moving between the stations, cells, clusters, sub-networks, networks, services or countries.

[1] VRS (Virtual Reference Station) and MAC (Master Auxiliary Concept) are two different methodologies used for network RTK.

For example, a fast handover mechanism is required in high-speed movements in order to keep the user requirements (accuracy, availability, etc.) for the application. In general, challenges for seamless transfer between the networks (service providers) or within the network itself are related to different factors such as the geodetic reference frame, the RTK methodology (VRS, MAC etc.), harmonisation of ambiguity resolution between reference stations, the communication device, communication network and communication standards used, as well as the capabilities of the GNSS infrastructure used.

5.2 Development of integrity in GNSS positioning services

Given the development in the Intelligent Transport Systems (ITS) area towards automated vehicles, the integrity of GNSS positioning will be more and more important. As an example, a service, which provides a position with errors less than 2 cm 95% of the time, is of little value for an autonomous vehicle, if the position error can be considerably higher 5% of the time and if the user is not alerted about this. SBAS systems have had an integrity functionality for a long time as they were originally developed for use in aviation, see Section 2.1.

Now there is a need to develop integrity functionality also for high-accuracy services. Several commercial companies (including Hexagon, Trimble and Sapcorda) currently do such development work for their global positioning services. For network RTK, research on integrity has also been done, but we have still not seen any implementations of such a functionality.

As a general concept, integrity functionality for positioning services is a way of securing that the position that the user equipment calculates can be trusted to a certain probability. This means that the term integrity is quite similar to the term reliability. In SBAS, integrity is obtained through a number of functions working in different parts of the value chain. For example, the processing centre determines which GNSS satellites can be used for positioning and estimates uncertainty values for the corrections. These uncertainty values are broadcast along with the corrections. This enables the user equipment to calculate confidence bounds in real time around its estimated position, often referred to as horizontal and vertical protection levels (HPL and VPL), see Figure 5.1.

The calculated position is guaranteed to be located inside the cylinder spanned by HPL and VPL with probability = 1 – integrity risk. The term integrity risk is a statistical probability illustrating the risk that integrity fails during a given time interval. The integrity risk must be very small for operational navigation systems, for instance 10^{-7} per operation for landing of airplanes.

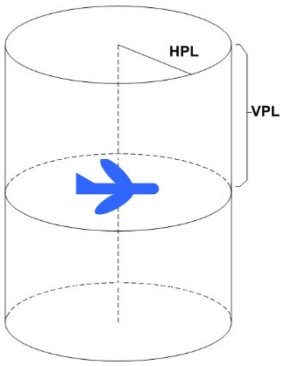

Figure 5.1: *Illustration of horizontal and vertical protection levels [9].*

5.3 Challenges with reference frames and the height component (geoid model)

As new regional and global GNSS positioning services become available in the Nordic countries, alongside the introduction of new user groups and applications, challenges with the combined use of national and global reference frames become more apparent. Without a correct transformation between e.g. ITRF2014 and the national realisations of ETRS89, the user will experience a horizontal offset of more than 0.5 metre. A future user combining high-accuracy GNSS positions with accurate geospatial datasets in real time must make sure that the reference frames are identical (or close to), or that correct transformations are applied on the fly. The new positioning services, applications and user groups will increase the need for more standardization efforts in GNSS correction data and geospatial data formats with regards to specification of reference frame (and reference epoch) and improved transformation solutions, and it will probably accelerate the implementation of global reference frames in national geospatial datasets in the Nordic and Baltic countries.

GNSS provides 3D geocentric coordinates from which ellipsoidal heights can be derived. To correct such heights to gravity related height systems like the ones used in all the Nordic and Baltic countries, a model giving the difference between these two height types or height systems is needed. Normally, such models are calculated from gravity observations and called gravimetric geoid models. When subsequently fitted to GNSS/levelling points the term fitted geoid model is often used.

The accuracy of the gravity related height obtained from GNSS is consequently depending on both the accuracy of the ellipsoidal height and the accuracy of the fitted geoid model. In the NKG region, the newest gravimetric geoid model, NKG2015, is widely used and works well for most of the area. There are exceptions, however, for instance in the western and northern part of Norway where the terrain differences are huge with deep fjords and high mountains. Also, in Sweden there are challenges with the geoid model in the vicinity of, and outside, the Swedish mainland, e.g. over the Baltic Sea. In these areas the fitted geoid model does not provide the same level of quality as in the remaining part of the region.

5.4 Other challenges for future positioning services

In the following a brief review of other challenges for future positioning services is provided.

Interference, jamming and spoofing
Interference and jamming are disturbances of the GNSS satellite signals. Intentional jamming is done on purpose to prevent someone’s ability to obtain GNSS positions. Un-intentional interference is typically triggered by broken electronic devices transmitting signals at wrong frequencies. Especially in relation to professional navigation (ships, aircraft, trains etc.) there is a great focus on reducing the risk of jamming and interference. Solutions are more resilient navigation systems based on sensor integration which can bridge short-term outages in reception of GNSS signals and/or reception of data from GNSS positioning services.

Spoofing is based on transmission of false signals that the user's GNSS equipment captures and applies in the position calculation. The purpose of spoofing is to spoof GNSS user's equipment to determine wrong positions. The solution to spoofing can be authentication. In essence, authentication techniques are based on transmission of a secret key along with the data from the GNSS satellites. When applying the key in a GNSS receiver it can be verified whether the signal is indeed originating from the GNSS satellite it is supposed to. Authentication is already applied on the military parts of the GPS signals. Galileo will be the first GNSS system to offer authentication for civilian use.

Space weather
Space weather is related to the amount of electrical activity in the ionosphere, and it is primarily driven by the solar activity. The amount of electrical activity in the atmosphere varies from day to day, and it can affect the propagation of electromagnetic waves, including GNSS signals. Essential in this context are periods of very high electrical activity caused by e.g. solar storms, which can interfere with propagation of GNSS signals to a level where it is not possible to determine a position nor to use GNSS-based timing. Research on methods for predicting space weather is ongoing, and GNSS equipment is also being developed to be more robust against increased ionospheric activity. But extreme space weather cannot be mitigated with today's technology, and the consequences can be severe for power grids and data communication as well as for GNSS-based positioning and navigation.

Cyber security
Cyber security is about minimising the consequences of internet-based crime, e.g. hacking, phishing and cyber espionage, using software solutions, advanced backup systems and deliberate work processes. But cyber security is also about building an infrastructure that is robust to the elements mentioned above and this includes infrastructure for GNSS positioning services. Today internet access is, to a large degree, provided by the cellular telecommunications network (3G, 4G, 5G), and since GNSS is used for time synchronisation in the telecommunications network, space weather and jamming of GNSS are risk factors that can affect also access to the internet. The telecommunications sector has a great focus on this, and networks in Northern Europe are quite resistant towards GNSS outages. However, wired internet is still less vulnerable than the cellular internet.

Geodata for high-accuracy positioning
Geospatial data, or geodata, is a very important element for autonomy. Almost all types of autonomous or self-driving devices (cars, drones, vessels etc.) are based on knowledge of the topography. Via data from various sensors, e.g. camera and lidar, and methods of data analysis such as artificial intelligence or machine learning, prior knowledge of topography can contribute to a more robust positioning and thus to better autonomous decision-making.

The types of Geodata which are expected to become important for autonomy are for example digital terrain models (or height models), 3D city models, road centre lines, databases with objects along the roads such as road signs and crash barriers, databases with objects along inland water ways etc. All of these objects must be geo referenced with an accuracy sufficiently good for the autonomous vehicle to perform positioning and navigation relative to the location of the objects. In essence this means that the geodata must be collected using technology which can provide a very high data quality and this will include the usage of high-accuracy positioning services for geo referencing of the objects.

The concept of High Definition maps (HD maps) is developed by the car industry for autonomous vehicle navigation. HD maps are composed of high precision geodata supplemented with other types of information which is relevant for the sensors that are used in vehicles for autonomous navigation.

Low-quality GNSS positioning services
Given the increasing importance of high-accuracy positioning services in the future, there is an increasing interest from commercial service providers with new companies being established. Many of these are reliable and robust organisations. But it is expected that some players may take the opportunity to provide high-accuracy GNSS positioning services with a reduced data quality, for instance by mounting GNSS reference antennae in less suitable locations, using poor quality coordinates for the reference antennae, performing no verification or quality control of the services etc. If such positioning services are used for geodata collection, the quality of the geodata will be reduced and this in turn may affect the use of the geodata.

The National Mapping Agencies can have an important future role in verifying data from GNSS positioning services, and also in making data from their CORS more attractive for GNSS services providers, so it becomes less likely that they establish their own stations.

6. Recommendations to the National Mapping Agencies

Through the work on this paper, the NKG Working Group (WG) on Future Positioning Services has agreed on the following recommendations.

The National Mapping Agencies in the Nordic countries should:

1. Work on developing the geodetic infrastructure in the Nordic/Baltic countries to support future needs.

2. Work for more Nordic cooperation on integration of PPP and RTK – because the mass market requires seamless new technical solutions and a new approach for dealing with end users (Section 2.3 and 5).

3. Work on how to provide integrity to users in order to support autonomy (Section 5.2).

4. Work for a joint Nordic/Baltic effort on interference detection (i.e. monitoring of the GNSS infrastructure) – because this is an increasing threat (Section 5.4).

5. Work on making data from the national CORS infrastructure technically and financially attractive to GNSS service providers - because this will reduce the probability of low-quality positioning services used as basis for geodata collection, positioning and navigation in the future (Section 5.4).

6. Consider enhanced European cooperation on GNSS – because of the advent of the Galileo High Accuracy Service (Section 4.2 and 5).

7. Consider encouraging the European Commission to establish a political institution working on future needs from autonomy for geodata (building on the work of EuroGeographics) – because requirements and needs to geodata quality will increase for autonomous applications in the future (see Section 5.4).

8. Consider the NKG WG on Future Positioning Services as a resource for the other NKG working groups in relation to GNSS user needs for reference frames, coordinate transformations and geoid models.

7. References

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