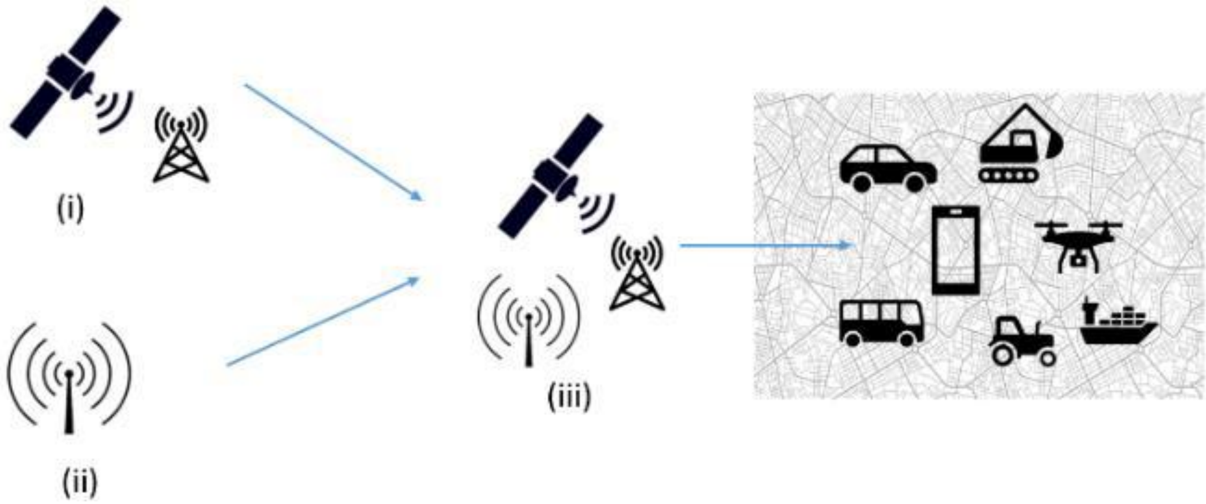
REPORT:

HyPos – Work Package 4: Hybrid positioning service



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HyPos – Work Package 4: Hybrid positioning service

Project	HyPos - Nasjonal Hybrid Posisjonstjeneste for Fremtidens Digitale og Autonome Samfunn
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Contents

1 Introduction

This report contains results and documentation for work package (WP) 4 about Hybrid Positioning service (HyPos). HyPos project goal is to explore positioning with scalable high precision GNSS positioning and real time positioning with 5G, and how these technologies can be combined to a hybrid positioning service that utilize the advantages of each technology.

The project has investigated scalable high precision GNSS positioning in work package 2, and real time positioning with 5G in work package 3. Result from WP4 is documentation and technical discussions and concept for HyPos which is based on knowledge from WP2 and WP3.

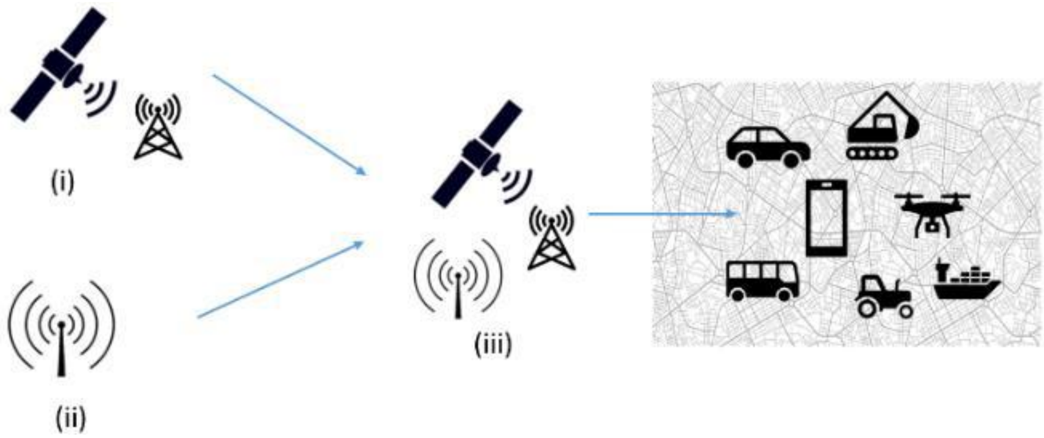

Figure 1: Concept of HyPos: (i) Scalable high precision GNSS service (ii) Positioning with 5G (iii) Hybrid positioning service and user group

Working methodology for in WP4 started with The Norwegian Mapping Authority (NMA) summarizing strengths and weaknesses for GNSS positioning, while Ericsson did the same for positioning with 5G. The project partners conducted a workshop for Hybrid positioning service with emphasis on how GNSS and 5G technology can be combined to provide a better positioning service to end users.

The report will serve as a knowledge resource for WP5 in developing business models.

1.1 Global update on use cases for 5G

5G is seen as an enabler for digitalization, especially when the use case need is beyond the simplest IoT needs, which is primarily addressed with 2G/3G/4G NB-IoT/4G LTE-M. In addition, IoT use cases are addressed with the reduced capability device types RedCap and eRedcap. With 5G, it is possible to enable low-latency communication, protected sub-network operations via network-slicing, support for wide signal bandwidths that enable high bandwidth communication. In addition, Network APIs have started to be defined, tested and even deployed, as a structured way for application functions to interact more deeply with the cellular network services.

In this context, the value-add services beyond basic communication services are seen as an opportunity for mobile network operators to provide quality, not only quantity, in their service offerings. The network APIs and service aggregators limit the number of interfaces and parties that application developers need to align, interact and test with, which is opening up for scaling the services. At the same time, many of these value add services need 5G standalone (SA), not 5G as a booster combined with 4G, 5G non-standalone (NSA), and the migration from NSA to SA is yet to happen in many markets.

5G positioning is one such value add service, but is also a component in regulatory services such as emergency call positioning and lawful intercept positioning.

1.2 Other research projects for hybrid positioning with 5G and GNSS

There are a few other research projects which study hybrid positioning with GNSS and 5G and a literature review has been conducted to understand the current state of knowledge.

1.2.1 Hyper 5G

The aim for Hyper-5G [1] were to “studying, designing and developing the algorithms and software needed to implement a precise positioning engine to jointly use multi-constellation GNSS and 5G observations”. Algorithms developed handle 5G as an additional receiver and use observations from receiver to 5G base stations as pseudo-ranges based on the time-of-arrival (ToA). When using GNSS positioning, pseudo-ranges are the raw range observation from receiver to GNSS satellite. Hence, raw observations from GNSS and 5G are merged in a Kalman filter to compute a position. Their experiment got a 2D positioning accuracy of approximately 4m for 5G positioning and approximately 1-3m for a hybrid solution in a static test. For a kinematic test the 2D accuracy were approximately 20m for 5G positioning, and approximately 1-4m for a hybrid solution. Hyper-5G project started in March 2022 and ended in February 2024.

1.2.2 5G Champion

The 5G champion project aims at the first 5G system proof-of-concept [2] and has broad perspective within 5G. Specifically the objectives work package 5 are to assess the positioning performance of mm-Wave technology, asses the gains over 5G positioning over known GNSS positioning methods and asses positioning performance of the hybridised 5G and GNSS. This study uses 5G observations for azimuth and elevation angle, angle-of-arrival (AoA) method, and add these observations to an iterative least squares method with GNSS observations. In the experiment set-up 5G base stations are used in different configurations 20m apart from the receiver and GNSS measurements are only done with GPS constellation. The receiver record and calculations are done to compute a hybrid position. The conclusions are that with one 5G antenna positioning is improved perpendicular to the vector between base station and receiver. When adding a second 5G base station positioning accuracy is further improved. Overall 5G positioning merged into a hybrid 5G and GNSS positioning are mostly applicable for urban canyons or similar where GNSS positioning struggle due to few visible satellites and reasonable short distance to 5G base station. It is also stated that 5G base station at 50m away from the receiver hardly improve the hybrid positioning [3].

1.2.3 HOP-5G

The HOP-5G project [4] aimed at hybrid GNSS and 5G positioning, where 5G is provided both via terrestrial base stations and base stations deployed on UAVs. The project started April 2021 and lasted for 18 months. Given that GNSS is good where available, but that there is a need for complements where GNSS is not available, the project investigates 5G as such a complement. The work was a mix of simulations and trials but the main target was to establish a trial system based on software defined radio components to realize the 5G complement.

2 Real time positioning with GNSS and 5G

A HyPos service is based on utilizing the strengths of GNSS and 5G positioning technology to create a better positioning service for end users. Strengths and weaknesses of each technology were investigated to set a baseline for designing a HyPos service. Details about positioning methods are given in the corresponding HyPos work package reports. Since computation of user position can happen at device or server side with 5G, a brief description of real time positioning with GNSS and 5G are given.

2.1 Strengths and weaknesses for real time positioning with GNSS

Report from HyPos work package 2: GNSS SSR [5] contains information about principles of GNSS positioning methods and distribution of GNSS corrections. This report is regarded as background information and this chapter is only a summary of strengths and weaknesses of GNSS positioning. A few terms are further explained; When using NRTK OSR positioning method via NTRIP, the user is identified by a regularly reported position, when using PPP-RTK SSR, PPP/PPP-AR or standalone this is not needed and hence the term privacy is used. Initialisation is the time for algorithms to compute the expected accuracy of the positioning method.

Strengths and weaknesses are summarized in Table **1** with different GNSS positioning techniques.

Table 1: Strengths and weaknesses with GNSS positioning

Positioning technique	**Strengths**	**Weaknesses**
Standalone GNSS	Global coverage Strong privacy 2-15m accuracy High temporal availability Free to use Low user threshold	Do not work indoors or in tunnels Vulnerable to interference
GNSS correction method: NRTK OSR	1-10 cm accuracy Distance between GNSS base stations: 20 – 100km High temporal availability	Do not work indoors or in tunnels Vulnerable to interference Highest accuracy vulnerable to vegetation and buildings 300 base stations needed in Norway Higher operating cost and user threshold compared to standalone Subscription fee for users More expensive user equipment (approx. 2000NOK to 200 000NOK) Initialisation of highest accuracy at every X km Low privacy (not relevant for telecom 3GPP standard)

GNSS correction method: PPP-RTK SSR	1-10 cm accuracy Distance between GNSS base stations: 20 – 100km No re-initialisation of highest accuracy Strong to medium privacy Scalable to more users than with NRTK OSR (3GPP is scalable for both SSR and OSR)	Do not work indoors or in tunnels Vulnerable to interference Highest accuracy vulnerable to vegetation and buildings 300 base stations needed in Norway Higher operating cost and user threshold compared to standalone Subscription fee for users possible, but not required More expensive user equipment (approx. 2000NOK to 200 000NOK)
GNSS correction method: PPP/PPP-AR	10–50cm accuracy Distance between GNSS base stations: 150 – 600km Need approximately 20 base stations in Norway	Do not work indoors or in tunnels Vulnerable to interference Higher operating cost, user threshold and temporal availability compared to standalone More expensive user equipment (approx. 2000NOK to 200 000NOK)

Some things are different when distributing GNSS corrections via the telecom standard 3GPP. 3GPP OSR and SSR corrections are distributed based on information about the device serving cell, not the device position. With 3GPP both OSR and SSR are scalable to many users and privacy is not of concern. In addition, there is a broadcast distribution option, enabling essentially limitless scalability.

To align terminology, 3GPP supports

- OSR or Network RTK since Rel 15 (2019)
- SSR phase I or RT-PPP with orbits, clocks and code bias since Rel 15
- SSR phase II or PPP-RTK with phase bias and iono/tropo since Rel 16 (2020)
- 5G broadcast since Rel 16
- GNSS Integrity since Rel 17 (2022)

2.2 Strengths and weaknesses for real time positioning with 5G

The challenge for 5G positioning right now is business development, since it will be a new service that needs to be understood and priced at a relevant level, and the expected potential income is then used to motivate network investments. The investment concerns network measurements, positioning platform, network management including site/antenna location information and potentially network element relative time difference estimation

The strengths include

- access to wide signal bandwidths, transmitted with low path loss compared to GNSS means that code phase measurements are very good – less importance to consider carrier phase measurements.
- potentially globally available for both devices and network applications via Network APIs
- network-based positioning methods, which does not require specific device capabilities beyond 5G connectivity support
- network-based positioning methods, which makes the positioning solution the same for different devices
- device-based positioning with very good scalability but with device dependency
-

The weaknesses include

- the challenge to provide required accuracy at acceptable investments matching expected income. GNSS is founded by public funding from countries and unions, while cellular network investment needs to be motivated by expected income from the service
- deployment and environment dependency on positioning availability and accuracy, where buildings can block and reflect signals to reduce positioning, and where sparser deployments in rural areas imply lower accuracy compared to denser deployment in suburban and urban areas.

Table 2: Strengths and weaknesses with 5G positioning

Positioning technique	**Strengths**	**Weaknesses**
Both technique types	Wide signal BW enabling high accuracy positioning based on code phase measurements Network API support with global reach	Accuracy deployment and environment dependency Investments in positioning needs to be motivated by expected income, not based on public funding like GNSS
Server-based	No computation on user device, which makes positioning available for all 5G devices in the same way Timestamp reflecting when the positioning measurements were made If the device is the consumer, position estimates with a delay can be combined with sensor information in realtime	Some delay of computed position both for when the consumer is the device or a network application Server and network load increase with number of users Needs network investments

Device-based	No delay of position computation if the consumer is the device Position estimates can be combined in realtime with sensor data. Scalable to unlimited number of devices	Needs investments for telecom network and devices Mobile phone providers must implement software for device positioning

2.3 Real time GNSS positioning

Simplified and brief description of alternatives of GNSS positioning.

2.3.1 Standalone positioning

When using standalone positioning a user device reads GNSS satellite signals and compute a position

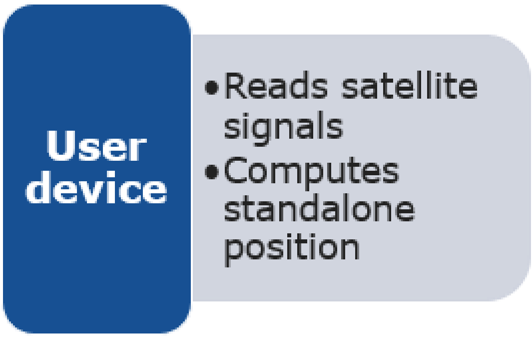

Figure 2: Standalone positioning

Assisted-GNSS (AGNSS) is a variant of standalone positioning. Broadcast satellite orbits and clocks are sent to the user device. This gives shorter time to compute a position and hence lower power consumption; in addition it can improve positioning in urban canyons.

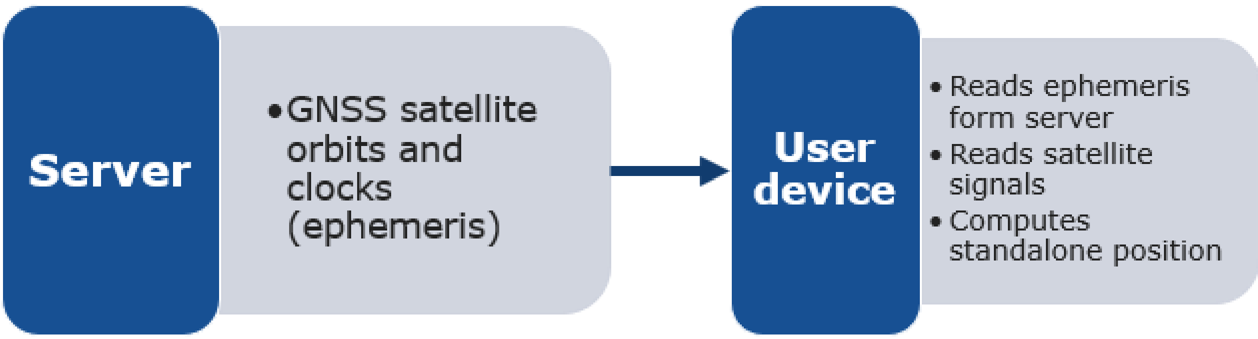

Figure 3: A-GNSS positioning

2.3.2 GNSS positioning service

A general description when using positioning service. GNSS base stations reads satellite signals and send this to a server which computes corrections for GNSS signals. These corrections are sent to user device which compute a precise position.

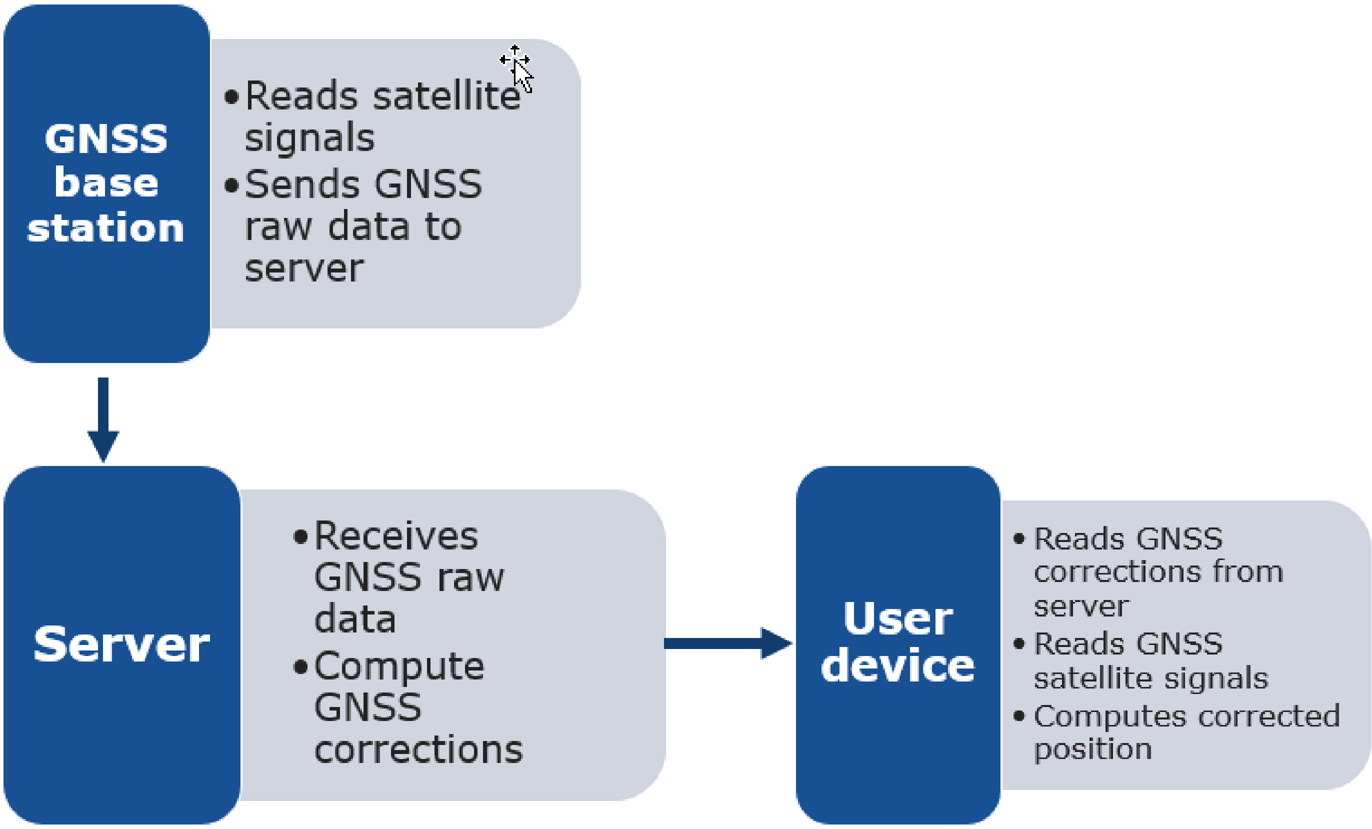

Figure 4: GNSS positioning service

2.4 Real time 5G positioning

Simplified and brief description of alternatives of 5G positioning.

2.4.1 Server-based positioning

5G base stations reads data of user devices and send these data to the server. User devices or network applications ask for their position from the server via an API.

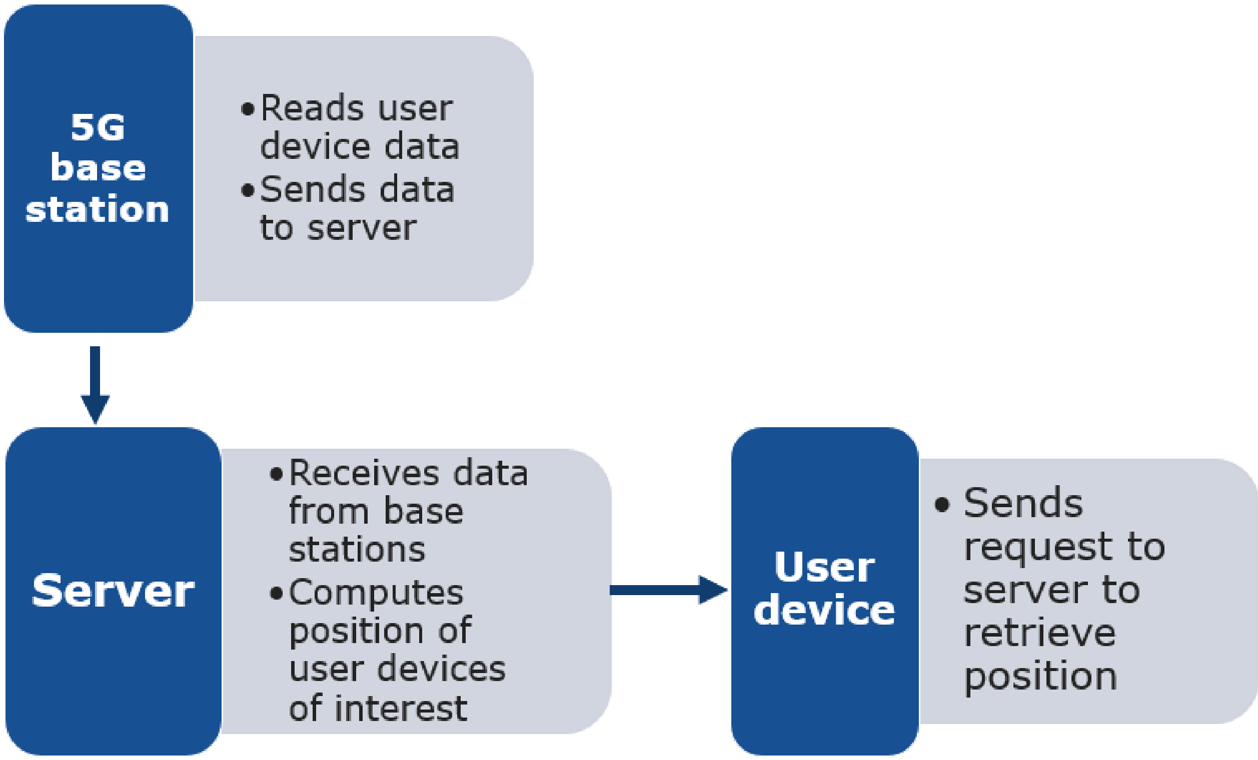

Figure 5: 5G server-based positioning

2.4.2 Device-based positioning

User device receives data from 5G base station and compute device position.

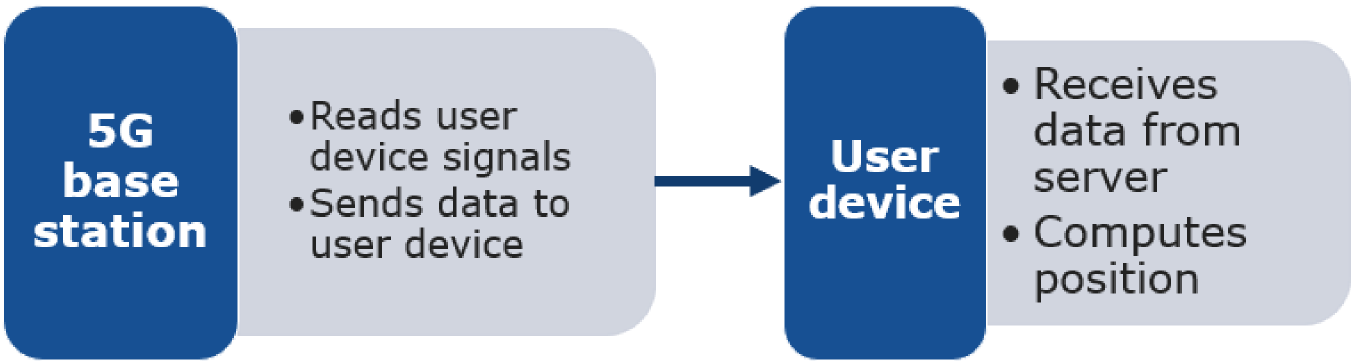

Figure 6: 5G device-based positioning

3 Concept for Hybrid positioning service

Concept of HyPos is based on knowledge acquired in work packages about scaling accessibility to precise positioning with GNSS and real time positioning with 5G. Three possible use cases were identified to be discussed in a workshop, and report summarise possible users and technical implementation.

It is worth noting that the discussed technical solutions are not dependent on a specific GNSS software or hardware, or telecom operator and therefor are methods that can be implemented in the market.

From the discussions the most feasible method to create a hybrid positioning system is to compute GNSS and 5G position separately. The GNSS position is computed at the device and 5G position is received from a server with an API. Then use the positions with uncertainties as weights to compute a combined position. I.e. if a GNSS position has an uncertainty of 2m, and a 5G position has an uncertainty of 6m, the hybrid position is close the GNSS position. It also became clear that the challenges for a technical solution will be quite similar for the different use cases.

3.1 Technical description of hybrid positioning

To determine a position with to different technologies sensor fusion is needed combine the measurements. There are two possible approaches to sensor fusion, combining raw observations or combine position estimate with uncertainties from each technology.

Statistically and mathematically the preferred solution is to use raw observations from each technology in the same algorithm. The calculations must be done at the user device. GNSS observables or raw data are available at the user device. With 5G the base stations must send time and coordinates for the base station and observables, in addition observables are needed from the chipset on the device. However, the 5G observables are not available from the chipset and this is a major obstacle which makes this approach not feasible. An alternative is that 5G observables can be sent from the base station to the user device, which is not how the 3GPP positioning reporting has been designed so far (UE-based positioning only supported with downlink measurements). It will also require an application on the user device to calculate the position that use raw observables from GNSS and 5G.

To combine positions will require that GNSS and 5G separately computes a position with uncertainties. GNSS position is computed at the user device, while 5G position is computed at 5G server and the device can subscribe to periodic updates of the position via a Network API. Onboard the user device merging of the two technologies is done. Technically this approach is possible today and the most feasible method to combine GNSS and 5G to a hybrid positioning system. One actual example is provided in this work [6], where the authors combine 5G indoor positioning based on network API and device-based high accuracy 3GPP GNSS.

3.2 Urban canyon

An urban canyon is a road or area flanked by tall buildings on both sides. This is a challenging environment for both GNSS and 5G positioning. The line-of-sight (LOS) to most GNSS satellites are obstructed and limited positioning accuracy can be expected. In an urban environment 5G base stations are located at roofs and there are a NLOS to most user at the street level.

In general, 5G position accuracy or uncertainty is degraded with NLOS. Typically, a signal from a roof will be diffracted over a roof edge, which leads to reduced distance measurement accuracy, but angle measurement will still have decent quality. Distance from base station to base station is around 2-300m in an urban environment, which gives an opportunity to determine a position with multiple angle measurements in an urban environment, in contrary to rural areas where to distance between base stations are significantly larger.

3.3 Verification of position

Verification of position is a basic integrity concept when using different technologies to determine a position. If the position with uncertainty estimate, i.e. a circle or ellipsoid, from both GNSS and 5G intersect each other the position can be trusted. This concept can be extended to first verify the position, if position can be trusted the position by using raw data from both technologies in sensor fusion to determine an even better position.

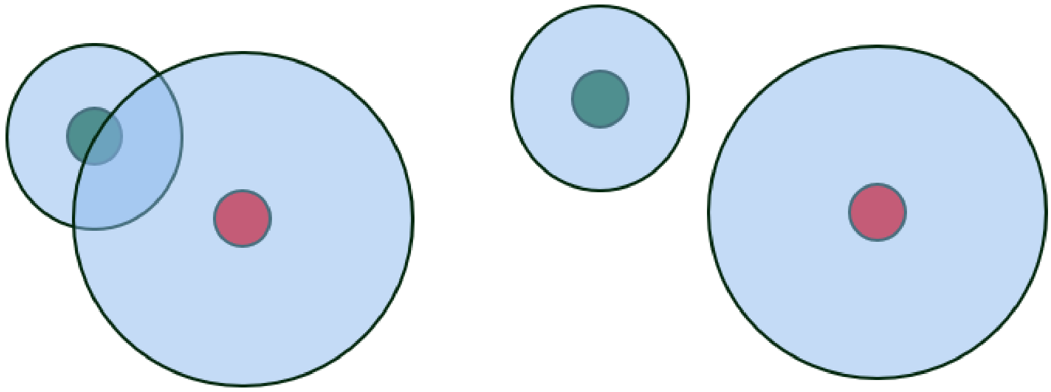

Figure 7: Left: Green and red position with blue uncertainty intersects and position is verified. Right: Position not verified. In more detail, the verification is made in consideration of position error distributions and an acceptable verification error risk.

Possible use cases are UAV which need reliable positioning, especially if the UAV operates non-line-of-sight (NLOS). Another use case is fraud protection when 5G positioning is used on the network side to verify the location of the caller.

3.4 Transition from outdoor to indoor environment

To ensure a continuous and reliable position when moving from outdoors to indoors are of interest for automated cars, or emergency calls to locate a person inside a tunnel or a public building.

From the discussions at the work shop it became clear that technically this will be like use case urban canyon. The transition from using GNSS outdoors to 5G indoors will be an abrupt event, and the challenges will be how the algorithms will handle this to give a continuous and reliable position. GNSS signals are not available indoor or in a tunnel, but the 5G signals will be the same.

An alternative for indoor positioning which is applicable for both GNSS and 5G is leaky cables.

4 Conculsions

4.1 Short term recommendations

In the short term, the most feasible path toward implementing a hybrid positioning service is to combine separately computed GNSS and 5G positions at the user device. GNSS positioning can be performed locally on the device, while 5G-based positioning—typically server-based—can be retrieved via an API. These positions, along with their respective uncertainty estimates, can be fused using weighted algorithms to produce a more reliable hybrid position, and for verification, that is not time critical services. This method is technically viable today and does not require access to raw 5G observables from the device chipset, which remains a major barrier.

To support early deployment, we recommend:

- **Pilot testing** of GNSS SSR correction services broadcast via mobile networks, leveraging existing infrastructure.
- **Development of APIs** for 5G server-based positioning to enable integration with GNSS-based systems at the user device.
- **Use-case targeting**, such as urban canyons and indoor environments, where GNSS struggles and 5G coverage is improving.
- **Stakeholder collaboration**, especially between telecom operators, GNSS service providers, and public authorities, to ensure interoperability and scalability.
- **Regulatory engagement**, particularly with NKOM, to explore voluntary or formal mechanisms for enabling access to 5G positioning data and broadcasting GNSS corrections.

The newly published national safety plan for digital infrastructure[1], 5G positioning is pointed to as an "alternative to international positioning services" and "it should be considered how 5G positioning could be established in Norway".

4.2 Long term recommendations

For long-term implementation, the goal should be full sensor fusion of raw GNSS and 5G observables at the device level. This would enable real-time, high accuracy positioning even in challenging environments such as indoors or urban canyons. However, this requires overcoming several technical and institutional barriers:

- **Access to 5G observables** from device chipsets, which is currently restricted due to commercial and security concerns.
- **Support for corrections broadcast** for GNSS to ensure scalability for high accuracy GNSS. If device-based positioning becomes realized, also broadcast support of assistance data can be considered.
- **Infrastructure upgrades**, including deployment of 5G NR features to improve positioning, and improved time synchronization across base stations.
- **Regulatory frameworks** to ensure privacy, data security, and equitable access to positioning services.
- **Market incentives** for telecom operators and device manufacturers to support hybrid positioning features.

[1] Nasjonal sikkerhetsplan for digital infrastruktur - regjeringen.no

We recommend initiating a coordinated effort involving public authorities, research institutions, and industry stakeholders to:

- Define clear societal use cases (e.g., emergency services, autonomous transport).
- Explore regulatory models similar to AML (Automatic mobile location) for enabling critical positioning services.
- Promote open standards and interoperability across GNSS and 5G ecosystems.
- Support R&D into advanced fusion algorithms and edge computing for positioning.

This long-term vision will enable a robust, scalable, and privacy-aware hybrid positioning service suitable for future digital and autonomous systems.

5 List of abbreviations

WP – Work Package
HyPos – Hybrid Positioning service
NMA - Norwegian Mapping Authority
ToA – Time of arrival
AoA – Angle of arrival
AGNSS – Assisted GNSS
NLOS - non-line-of-sight
LOS - line-of-sight
SA - Standalone

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