onocoy: Enabling mass adoption of high precision GNSS positioning using web3

White paper
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Abstract

While Global Navigation Satellite System (GNSS) technology has become omnipresent in consumer, automotive, and industrial applications, the adoption of high precision GNSS technology continues to be inaccessible to the mass market due to the lack of a global, dense and optimally distributed GNSS infrastructure network facilitating improvements of positioning to the sub-centimeter level. Such a network would represent the basis to serve an existing market of €6.7B and facilitate novel applications benefiting humanity such as early tsunami warning systems, crustal deformation monitoring and space weather monitoring, on a larger and more accurate scale than previously possible.

onocoy incentivizes the transparent construction of such a network in a decentralized way with blockchain-based tokens, open standards and hardware that includes all stakeholders of the ecosystem including existing competing actors and users of their services. In this way, community-powered and decentralized GNSS infrastructure as a commons is created that benefits everyone by fostering accessibility, collaboration, and innovation.

Keywords GNSS · Blockchain · DePIN · RTK · web3

1 Introduction

Global Navigation Satellite System (GNSS) technologies use satellite constellations, orbiting Earth, to provide position, navigation, and timing (PNT) information to users on the Earth's surface and in its immediate vicinity. GNSS enables users to determine their location, velocity, and time by the trilateration of signals from multiple satellites. The first and most well-known GNSS is the Global Positioning System (GPS), developed and operated by the United States. Other constellations include the Russian GLONASS, Chinese BeiDou, and European Galileo; besides these, there are some regional navigation satellite systems such as the Japanese QZSS and the Indian NavIC, designed to provide improved PNT over their respective regions.

GNSS has a wide range of applications which are growing beyond its use in positioning and navigation for users at the Earth's surface, which is well-understood by retail consumers, it is also used in determining the position of both aircraft and spacecraft. The use of GNSS is fundamental for determining geolocation in critical situations such as emergency and disaster responses, and search-and-rescue operations, where other methods of positioning can be inadequate: GNSS is necessary when trying to achieve highly accurate, real-time positioning. The importance of its use in timing is less recognized by the general public. GNSS is important in determining precise times for financial transactions and telecommunications, and synchronization of scientific experiments and network infrastructure. In its relatively short history, GNSS has become an essential technology in many aspects of modern life.

The following paragraph introduces the different approaches used, and performances achievable, when providing positioning services using GNSS. Single Point Positioning (SPP) is the basic positioning principle used with GNSS. It estimates the user's coordinates and clock error through a trilateration of the satellites' position and signal. At meter-level accuracy, the precision of SPP is good enough for many use-cases, but it is limited; various sources of error, such as

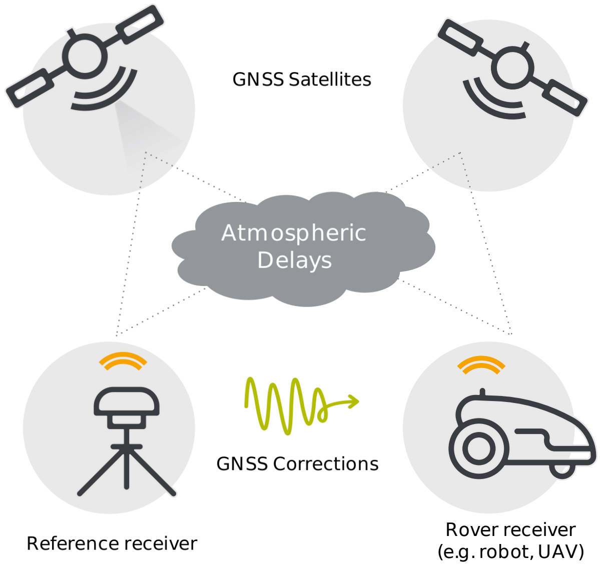

Figure 1: A geographically close GNSS reference receiver is fundamental to improving the positioning accuracy of a rover receiver from a meter to a (sub)centimeter accuracy.

satellite orbit errors, atmospheric effects, and multipath, i.e. the appearance of multiple signals caused by reflection off surfaces, all contribute to deterioration of precision [Teunissen and Montenbruck, 2017]. For applications that require higher accuracy and precision, High-Precision Positioning techniques like Real-Time Kinematic (RTK) corrections and Precise Point Positioning (PPP) are required. These systems are capable of achieving centimeter to millimeter-level positioning accuracy by primarily mitigating atmospheric effects and resolving carrier-phase ambiguities. Applications of high-precision positioning include surveying and mapping, precision agriculture, construction, and geodesy. High-precision GNSS is also used in monitoring of the Earth's vibrations and movements, allowing for the measurement of the movement of tectonic plates, monitoring of the melting of glaciers, and development of early tsunami and earthquake warning systems.

While some of the benefits above can be realized with the use of either RTK or PPP, only RTK is able to deliver instantaneous centimeter-level positioning in real-time. The convergence time to centimeter-level accuracy with PPP is primarily due to the estimation of the residual atmospheric errors, which typically takes tens of minutes. RTK, however, relies on a ground-based Continuously Operated Reference Station (CORS) that provides the observed GNSS measurements. Assuming the CORS is within 20km by differencing the measurements between the rover and CORS, all major error sources are eliminated, in contrast to PPP where the unmodelled errors are mitigated through estimation. RTK enables high-precision positioning for objects in motion, as shown in Fig. 1.

With the benefits of RTK having been made clear, what prevents its global realization is a combination of factors: high costs, redundancies, and proprietary standards all play a role. While one may install a CORS to cover an area of interest, the coverage will be limited to a local area. The alternative is then to build a network of reference stations, but the conventional build-out of such a network results in high investment and maintenance costs and gaps in coverage, since central entities focus on only the most profitable areas of coverage. The result is a patchwork of networks and disorganized single-station owners: increased costs, and redundant and patchy coverage. The desired solution is one in which the local model can be scaled globally, so that coverage can be delivered to any region where it might be economical and redundancies may be limited to the amount needed for robustness. Such a network would result in lowered costs and increased performance.

We at onocoy have created the solution to these problems described above by implementing a GNSS reference station infrastructure that is decentralized and efficient. The enabling technologies are those of web3, which is a collection of technologies that incorporate the World Wide Web, distributed ledger technologies, and tokenized economics to enable new kinds of decentralized economies. In particular, ours is a decentralized physical infrastructure (DePIN) project[1], i.e., a web3 project aimed at networked physical infrastructure.

[1]For an overview of decentralized physical infrastructure networks (DePINs), see Kassab [2023].

In the onocoy network, any operator of a CORS is able to stream its correction data to the onocoy platform in exchange for tokens which give access to governance in the system. The token is therefore a form of equity that empowers its holders, and reference station operators in particular, to behave as owners and stewards of the onocoy network.

Beyond using tokens, the onocoy network implements other tools that continue to enable decentralization, the most important being open standards; onocoy does not require proprietary standards. RTK technology has existed for decades and has an established practice around its use. onocoy has taken a conscious step to support the existing RTK infrastructure so that we may complement the existing ecosystem. With this comes a challenge: since standards are open, one has to differentiate between real and fake data; since the network monetarily incentivizes data collection, there is an incentive for prevarication of data. This implies that the network must check the validity of incoming data before determining a reward. Fortunately, and in contrast to other DePIN application contexts [Chiu et al., 2024], such checks are possible due to the physical nature of the data; there are multiple techniques to verify GNSS data, relying on detecting anomalies within data streams that deviate from our understanding of physics and statistical behavior. In a sense, the onocoy validation scheme provides a non-cryptographic likelihood estimate of physical work having been done. Compared to other projects in web3, this is quite novel, as most web3 projects focus on definitive cryptographic proofs, such as those obtained in Bitcoin's proof-of-work scheme. Since onocoy relies on open standards, and cryptographic protocols are not standard within GNSS, this is not possible to implement.

Nevertheless, what is possible is the implementation of all mechanisms described above as decentralized schemes. In the onocoy network, tokens are held within users' wallets, i.e., they are associated with a public cryptographic key whose private keypair is held by an individual user and not accessible by the network. Validation is done by decentralized validators; these are validation schemes implemented in combination with smart contracts, or code running on the blockchain, so that the network may provide trust in its functioning.

The current status of onocoy is an early product rollout on the Solana blockchain mainnet. In this stage, data is provided to paying customers, and reference station owners earn test tokens that may or may not be converted to the actual token at launch. Other aspects of onocoy, such as the decentralization of validators remain off-chain.

The rest of the white paper is structured as follows: onocoy's unique positioning in the GNSS market is illustrated in Section 2. The cryptoeconomic design facilitating an efficient and resilient co-operation of stakeholders within the onocoy network is then given in Section 3. This is followed by introducing onocoy's IT architecture and its approach to validating the correctness of GNSS measurement streams in Section 4. Finally, a summary and call for action is given in Section 5.

2 onocoy's unique positioning – a GNSS market perspective

In this section, we show how onocoy has positioned itself to create and leverage synergies within the GNSS ecosystem. In Section 2.1, we present the existing GNSS market and its challenges with regards to creating a global and dense network of CORSs. In Section 2.2, we then illustrate how onocoy overcomes these challenges with its unique positioning as a community-owned and shared infrastructure. In Section 2.3, we conclude how this ultimately enables novel applications in the service of humanity.

2.1 Existing GNSS market and its challenges

The biggest markets for real-time high-precision are currently those of machine control, agriculture and logistics. Growth is driven primarily by automation and autonomous vehicles, e.g., last-mile geofenced transportation/ delivery services, and is expected to result in a total available GNSS market of €43B in 2028 with a 7% CAGR [EUSPA, 2022]. The market is served by about 20 companies; these are correction service providers that operate CORS, compute correction data, process the data and provide highly-precise positioning to their customers. For this, they rely on a subscription-based business model, charging between $200 and $50,000 per year per device. Besides these commercially operating reference station networks, there are free and open networks such as those operated by universities or governments, typically providing coarser coverage and lower-quality data.

The high costs associated with building and maintaining dense CORS networks have limited their adoption to regions with a sufficiently large and affluent customer base – predominantly dense urban areas and regions with highly automated, large-scale agriculture. Markets outside of these regions, particularly in emerging and developing countries, continue to be under-served and, as such, there does not exist a global, high-density CORS network. Moreover, in regions where sufficient network infrastructure exists to the point of redundancy, the redundancy is not leveraged to the benefit of providers, such as providing backup if one station goes down, and thus does not increase the resilience of the infrastructure.

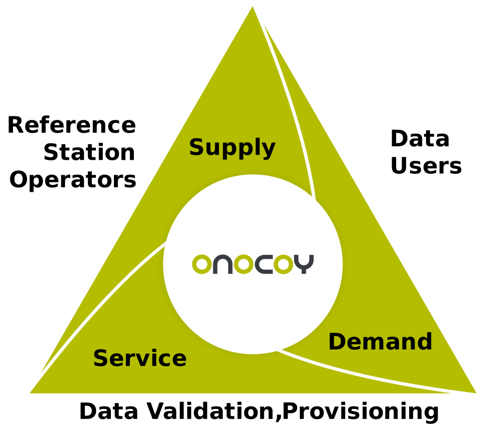

Figure 2: onocoy's three-sided market that enables users to receive validated reference data from station operators

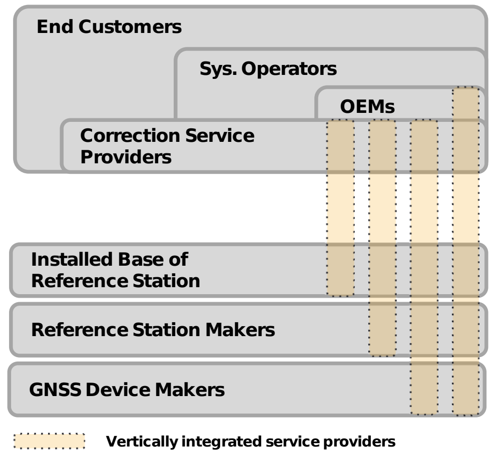

Figure 3: Service providers are vertically integrated, resulting in high reference station infrastructure costs.

CORS networks need to be regularly updated with new hardware as new signals and constellations become available but much of existing infrastructure gets outdated due to the investments required. Typically, network growth is slowed down because building up a dense global service is costly. Simultaneously, revenues are only realized once it is fully deployed, making it difficult for service operators to roll out dense networks quickly and globally.

Even where sufficient coverage and quality is available, infrastructure is often inadequately exploited. Commercial reference station networks rely on proprietary solutions and communication protocols, restricting their use to specific niches and limiting interoperability across vendors. Due to this fragmentation in this segment, the the number of customers served is limited, hence service costs of each vendor remains high.

For instance, correction service providers utilize business models made for high-end niche markets (e.g., oil tankers) and typically do not pursue a fit with mass markets (e.g., autos): Correction services are often bundled with receivers (see Figure 3), making it hard for users to select the best receiver and the optimal service for their application. It also creates an undesired lock-in with vendors' offerings. Additionally, providers often impose use-case limitations on their customers. This regionally-fragmented correction service landscape makes selling products globally a challenge for hardware producers (OEMs as well as tier 1 and 2) and service operators.

As a result, GNSS correction service costs have not fallen at the same rate as the cost of the required hardware. This impacts the entire industry, with limited adoption of high precision GNSS technology in many mass market applications holding back sales and depriving end-users and entire economies and regions of the technology's benefits.

2.2 onocoys unique positioning – benefiting all stakeholders

To overcome the challenges described above, onocoy positions itself as a three-sided platform (Figure 2) following Gomes Jr. [2022] between station operators, data users (clients), and data validation and provisioning. Using open standards and protocols (i.e. NTRIP RTCM3 MSM), data is received from reference stations and relayed to users via validators that continuously monitor reference station data quality and alert station operators in the event of performance degradation.

This approach affords the strategic positioning of onocoy in the existing GNSS industry as a shared infrastructure commons, complementing and bringing together existing GNSS market stakeholders and new joiners (e.g. crypto miners who want to operate reference stations), and providing synergies and benefits for all (see Figure 4).

By separating the operation of reference stations from the provision of value-added correction services, reference stations can be shared among service providers via open communication protocols and hardware, avoiding redundancies in the reference station infrastructure except those desired for robustness. By engaging communities to set up and manage reference stations and validators, investments and operational costs for a network can be spread over a large number of people, enabling the creation of a global and dense network, as in the case of the Helium network [Jagtap et al., 2021].

Already today, onocoy offers publicly accessible, pay-per-use single-base RTK streams, thereby democratizing access to correction data for mass markets and mitigating the effects of vendor lock-in. In particular, by focusing on single-base

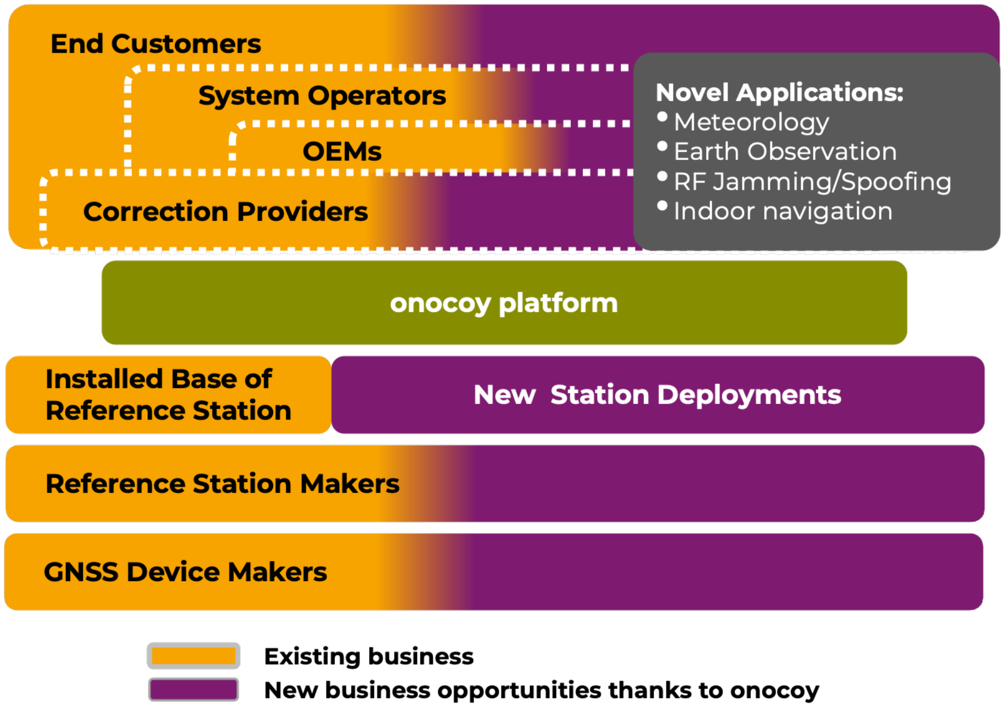

Figure 4: onocoy's strategic positioning in the existing GNSS market as a shared infrastructure benefiting all stakeholders.

RTK, onocoy is not in competition with existing correction service providers that focus on value-added service on top of their streams (e.g., VRS, PPP, PPP-RTK; see Section 4.1 for details on these technologies). In fact, onocoy reduces both the capital and operating expenses for these stakeholders and provides an opportunity for them to grow into regions currently not covered by their services, such as Africa, South America, and Asia. Furthermore, these stakeholders can contribute their existing installed base of reference stations to onocoy and gain additional revenue.

Thus, business models suitable for mass-market applications become possible as there is a straight-forward per-use charge and no limitations on market segments are imposed.

In summary, the advantages across the value chain are evident. They are:

- *Reference station manufacturers* get access to a mass market that would not exist without onocoy's community-powered network.
- *Reference station operators* gain new, or additional, distribution channels. Throughout a station's lifetime, they may sell data to onocoy for rewards, with upside potential based on data usage in the proximity of their station (see onocoy's rewarding concept in Section 3.3). Moreover, they benefit from real-time data quality monitoring and reporting, guaranteed by onocoy validators.
- *Providers of value-added correction services* profit from cost-effective coverage expansion and additional revenues from their existing network. Instead of needing to make vast infrastructure investments, they utilize onocoy's network and gain access to high-quality stations worldwide, taking advantage of a risk-free path to network expansion and economies of scale.
- *Product manufacturers (OEM)* benefit from a larger addressable market. Worldwide availability of affordable reference station data and correction services allows for mass adoption and hence increased hardware sales. Furthermore, onocoy's global coverage gives ease-of-use in scaling products and services.
- *System integrators and operators* can expand into new applications and services, with correction data becoming affordable and available everywhere, be it single-base RTK or added value correction services.
- As a result of all of the above, *end customers* gain access to improved and/or new products, applications and services.

onocoy's strategic positioning results in a value proposition that complements existing value-added services in the GNSS industry such that a mass market for high-precision positioning can be formed, built on a global, shared and common CORS infrastructure.

2.3 onocoy enables fair access to novel humanity-serving applications

The creation of a global and dense CORS network will provide cost-effective access to the technology's benefits and enable novel humanity-serving applications: Currently, as illustrated, correction services are only available in high income areas, e.g., Europe and North America, and in niche markets, e.g., precision agriculture, at high cost, thus preventing a large part of the global population from accessing the benefits of applications built on it, e.g., autonomous navigation in South America.

Worse, these barriers prevent the emergence of novel, humanity-serving applications facilitated by a global and dense network such as i) improved weather monitoring and forecasting, ii) long-term climate measurement [Guerova and Simeonov, 2021], and iii) large scale tsunami warning systems [Blewitt et al., 2009] that would be of great value to large parts of the world population by, amongst others, mitigating and addressing the risks of climate change. For instance, I) the ability to monitor weather more effectively and II) long-term climate measurements will improve humanity's ability to assess climate change mitigation actions by providing real-time feedback on countermeasures (required for a complex system such as our society to self-organize [Ballandies et al., 2024a]), resulting in accelerated learning cycles.

3 onocoy's cryptoeconomic design – efficient and resilient co-operation via web3

The design of the onocoy cryptoeconomy follows a value-sensitive design science research methodology [Ballandies et al., 2024b]. This is a principled method that considers stakeholder values explicitly during the design and construction of IT systems [Friedman et al., 2013, Van den Hoven et al., 2015]. Since a lack of consideration of stakeholder values in the construction of a software artifact can result in technology rejection [Helbing, 2021], the failure of including the values of onocoy's stakeholders could prevent its mission of creating a community-powered global RTK reference station network. Therefore it is important to identify the values for the onocoy network. The four most important ones are:

- *Participation*: The team, investors, and community members must all participate in the project's growth
- *Progressive decentralization*: The platform's elements must become distributed over the long run
- *Economic sustainability*: onocoy must be a non-profit organization that generates sufficient funds to achieve its mission
- *Value sharing*: Investors and contributors must have an attractive return/reward

These values are secured via web3 in onocoy's platform by using i) *blockchain-based tokens* for interest realignment among all stakeholders and to crowdsource investment cost into the global and dense reference station network; ii) *smart contracts* to instantiate cost-effective and transparent mechanisms to handle large amount of micro-transactions in a pay-per-use business model covering all world regions; and iii) a *decentralized distributed ledger* to secure and robustify the network.

Utilizing the conceptual architecture introduced by Ballandies et al. [2021], the main parts of the onocoy system are illustrated in Figure 5. These parts are the i) core economy, ii) off-chain governance, iii) investors, iv) on-chain economy, and v) tokens. In particular, onocoy is a 2nd layer (L2) system built on top of an established blockchain, utilizing smart-contract capability to facilitate on-chain governance and token issuance and transfer. onocoy is therefore a decentralized application (dApp) built on a blockchain maintained by a third-party (community) which is utilized for data storage and computation; this effectively removes the complexity and cost of maintaining one's own blockchain while increasing the transparency and trustworthiness of code/ mechanisms utilized.

At system initialization, some actions occur off-chain - that is, they are not stored on or executed by the blockchain. For example, the management of funds received from early investors. Nevertheless, by following the value of progressive decentralization, onocoy commits itself to over time move as much as reasonably possible on-chain to increase the transparency and trustworthiness of the platform. The core economy that relies on both system tokens is the sharing of GNSS measurements by continuously operating reference stations (CORS), also referred to as miners in web3, with system users.

In this section, we detail the onocoy cryptoeconomic design (CED). In Section 3.1, we describe the token flows. In Section 3.2, we describe the token design. In Section 3.3, we illustrate the rewarding concepts. In Section 3.4, we describe the tokenomics and in Section 3.5 we present the governance of the onocoy system.

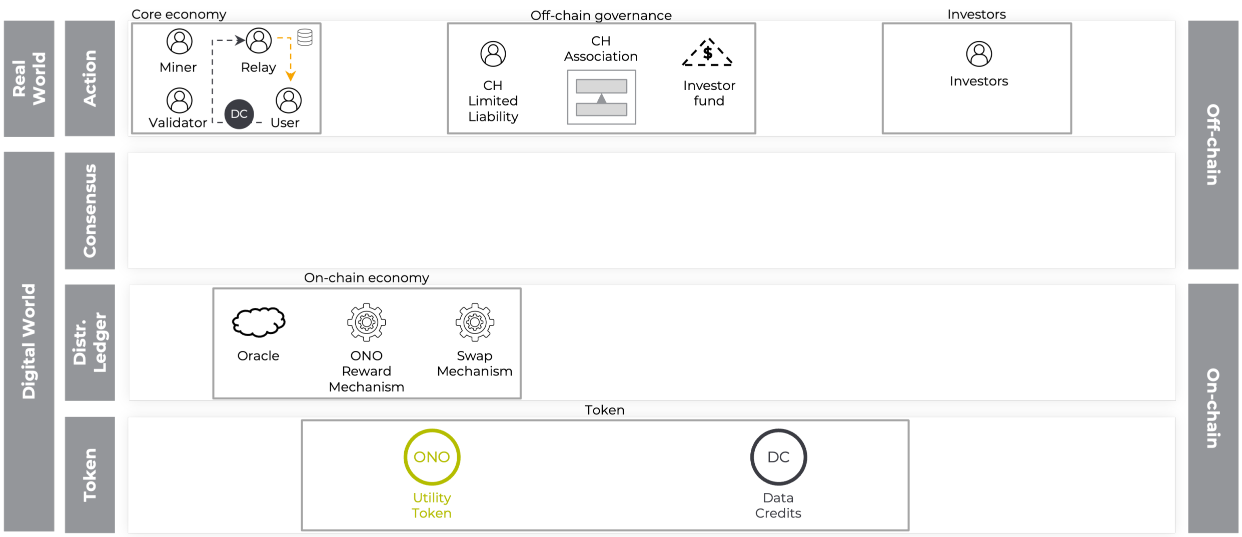

Figure 5: A presentation of the main elements of onocoy's cryptoeconomic design, utilizing the conceptual architecture introduced by Ballandies et al. [2021]

3.1 Token flow and core economy

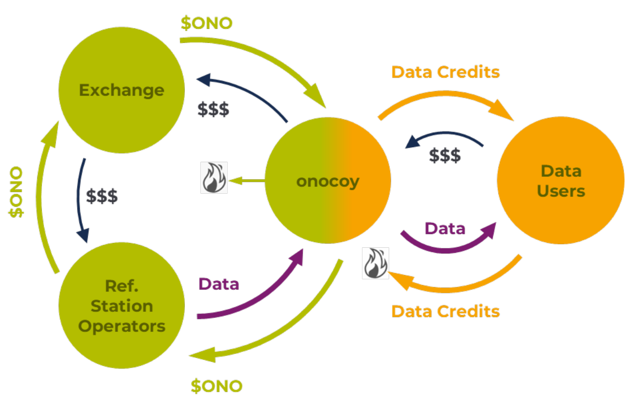

Figure 6: onocoy's two-token *deflationary* model: ONO is utilized in onocoy's governance and incentive design; Data credits are obtained with Fiat (e.g. Dollar) and provide access to correction data; Fiat is used to finance operations (i.e. platform development, operations and ecosystem development) and may be used for buy backs and burn

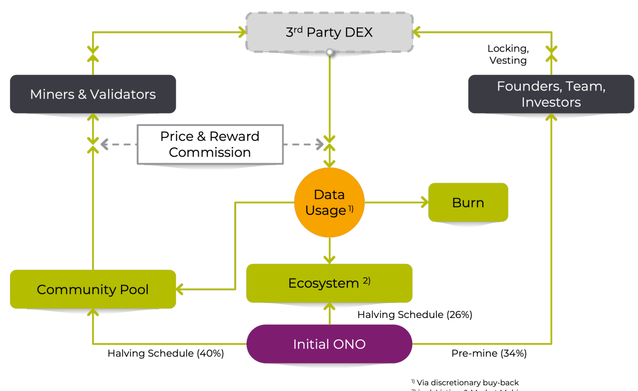

Figure 7: ONO token flow: ONO are released via halving schedules and lock and vesting contracts; users can acquire ONO to access system services, in turn financing onocoy's operation

Figure 6 illustrates the onocoy token model: a deflationary token model that facilitates the tying of system revenues with ONO token value via the onocoy association and aligns the diverging needs of data users and reference station operators. This facilitates stable FIAT prices for data access with the non-transferable data credit, while leveraging the advantages of cryptoeconomic tokens for incentives [Ballandies, 2022] via the freely-tradeable ONO token. This ONO token is a utility token that can appreciate in value which is traded at exchanges and contributors to the project are rewarded with it (e.g. miners: owners of CORS that provide GNSS measurements to the system). Data credits are issued to data users in exchange for Fiat (e.g. Dollar). Data user utilize these credits to access system services, which are burned once utilized. The Fiat is used to finance operations (i.e. platform development, operations and ecosystem development) and may be used to buy back, redistribute or burn ONO via the onocoy association (Figure 7). If and when a buy

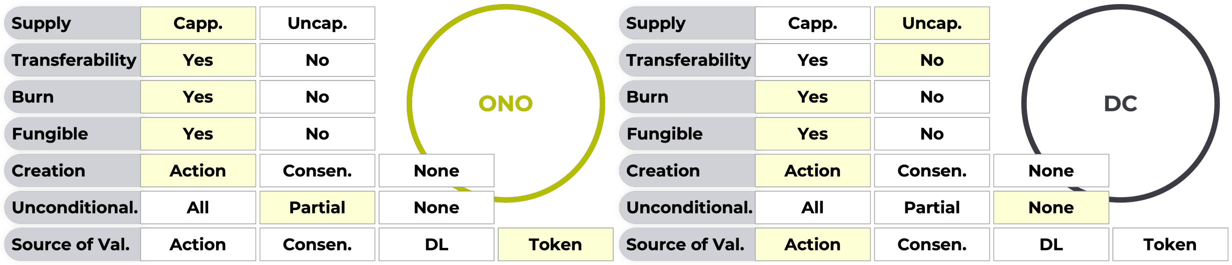

Figure 8: ONO (left) and data credit (right) token design in the categorization scheme of Dobler et al. [2019]

back occurs, the ONO units are split between a reward pool that incentivizes system contributors and an ecosystem development pool that finances maintenance and development of the onocoy system (see Figure 7). Data credits are used to pay for the onocoy service. System service costs are denoted in FIAT, enabling customers to predictably know how much system service they can access with their data credits. This solves the challenge of fluctuating token values often observed in web3 to which traditional and risk-averse stakeholders from the GNSS industry are not accustomed to. Data credits are burned when the service is consumed and are non-transferable. Thus, data credits can only be utilized within the onocoy system[2].

3.2 Token design

onocoy's deflationary token model facilitates stable fiat prices for web3-agnostic customers while retaining the advantages of having its own (value-gaining) blockchain-based token that can incentivize the setup and maintenance of a global and dense physicial infrastructure network. In the following the ONO token and the data credit are illustrated.

3.2.1 ONO token

Figure 8 illustrates the ONO token design. The ONO token is a utility token that is used for governance in the onocoy system (see Section 3.2.2).

The supply of ONO token units is capped (see "Supply: Capped" in Figure 8). Assuming an increasing demand for ONO over time, keeping ONO supply fixed will create an upward price pressure on it. Also, should a buy back occur, a part of the ONO token units are burned (see "Burn: Yes" in Figure 8), thus reducing the amount of available ONO which creates a further upwards price pressure on the token by reducing its supply.

In order to guarantee incentives for service providers, i.e., miners, and to deploy and maintain a global and dense reference station network, new ONO token units in the onocoy system are continuously released to providers subject to a halving schedule (see "Creation Condition: Action" in Figure 8). In particular, onocoy chose a deflationary factor of 16% per year[3], which results in a four-year halving schedule of newly created token units until no new tokens come into existence (Figure 7), which is similar to the mechanism applied for block rewards in the Bitcoin system (not accounting for token unit burns).

In order to function as a meaningful investment, the ONO token is transferable to enable a cash out by selling token units (see "Transferability: Yes" in Figure 8). This also guarantees that stakeholders are not locked-in to the system. Moreover, the ONO token is fungible to guarantee censorship resistance by preventing the discrimination of specific token units (see "Fungible: Yes" in Figure 8).

3.2.2 data credit

Figure 8 illustrates the data credit design. The data credit facilitates the functioning of onocoy's core economy: By burning data credits, users obtain access to RTK correction data streams. Data stream prices are nominated in data credits, which provides value to the token (see "Source of value: Action" in Figure 8). Thus, by retaining data credits, users can predictably know for how long they will be able to access correction data streams. New data credit units come into existence by performing the action of buying it with Fiat (e.g. Dollar) from the onocoy association (see "Creation condition: Action" in Figure 8). In particular, the data credit value is pegged in this way to a FIAT currency, i.e.,

[2] Note that, because the data credit is non-transferable and cannot be swapped back to ONO, no third-party market can form on data credits and hence it cannot function as a stable coin.

[3] Each year the amount of newly available ONO token units are reduced by 16 %

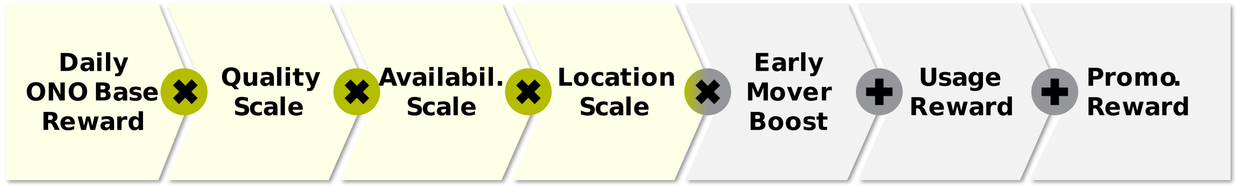

Figure 9: Miners' rewards in the onocoy network consist of three components that are added together: i) a (possibly boosted) base reward, ii) a usage reward, and iii) a promotional reward.

the USD, which makes data credit stable in relation to those currencies, a prerequisite for risk-averse GNSS industry to accept it as a payment standard. In order for the data credit to **not** be a stable coin, it is non-transferable[4] (see "Transferability: No" in Figure 8). In particular, data credits cannot be swapped back to Fiat. Thus users can utilize the data credit only within the onocoy system for accessing data streams.

In contrast to the ONO token, the data credit supply is uncapped (see "Supply: Uncapped" in Figure 8) to account for a potentially unlimited amount of users accessing an unlimited amount of data streams. In order to function as a unit of account (of potential time to access correction data streams), the data credit is fungible (see "Fungible: Yes" in Figure 8).

3.3 Rewarding concept

Several forms of rewards are provided to contributors of the onocoy system. In this section, we describe the rewards scheme for miners. Other forms of rewards, e.g. a bounty program for bug identification, grant schemes for network development or validator staking for network security and decentralization are discussed and may be introduced in the future.

3.3.1 Miner rewarding

onocoy incentivizes network rollout and maintenance by rewarding data contributors, also referred to as data miners. The amount of received rewards is scaled according to multiple factors such as: i) signal quality, ii) signal diversity, iii) station availability, and iv) location context. Also, special incentives are utilized for early adopters, targeted network expansions and upgrades.

Figure 9 depicts the miner rewards scheme: The *Base Reward* is the reward that miners receive irrespective of the usage of their data and consists of four components:

The *Daily ONO Base Reward*, representing the maximum base reward a miner can earn per day. The value is set by the rewards commission[5] (see Figure 7) based on a target fiat amount[6], modified with an *Early Mover Boost* that is initially set at 5. Both the Base Reward and the Early Mover Boost are periodically set to be updated by the rewards commission, with the intention that the base reward doesn't change too frequently and the boost decrease over time. For the initialization, the choice of Base Reward reflected a fair yearly amortization for a typical reference station and the boost reflected a risk premium for miners that takes into account an already existing base load of reference stations. The *Quality Scale* represents the type and quality of GNSS measurements submitted to the system and is decomposed into "Supported Signals" and "Signal Quality". The *Availability Scale* represents the availability and continuity of the GNSS measurements to the clients/customers (e.g. uptime). The *Location Scale* motivates the optimal distribution of CORS by penalizing overpopulated areas.

The *Usage Reward* incentivizes sharing the success of the onocoy service within certain regions. The usage reward considers the actual utility (number of data streams in use) and the potential utility (improvement in signal quality) of a particular region which are shared among all miners of a region. Thus, miners of a particular region are incentivized to work together to increase the usage of their data, with the goal of the emergence of a regional community spirit. Furthermore, this incentive is designed as a feedback mechanism for miners to identify valuable spots for reference station deployment such that onocoy results in a self-regulating and self-organizing system [Ballandies et al., 2024a].

[4]If the data credit would be transferable, an external market for data credits could form with potentially another exchange rate between data credit and FIAT then the one facilitated by the onocoy system. Hence, onocoy would be required to employ mechanisms that would stabilize data credits around the desired exchange, making onocoy a stable coin project.

[5]The rewards commission consists of members of the association.

[6]Having fiat-fixed rewards for miners has been shown to be required to adequately reward them [Kalabić et al., 2023].

Pool	**Percentage of all Tokens**	**Release**			
		once	*contin.*	*lock/ vest.*	*halving*
Team	10%	x		x	
Ecosystem	32%		x	x	x
Community	40%		x		x
Investors	14%	x		x	
Listing & Market Making	4%	x			

Figure 10: Distribution and release schedule of the 810 million ONO token units among the different stakeholders

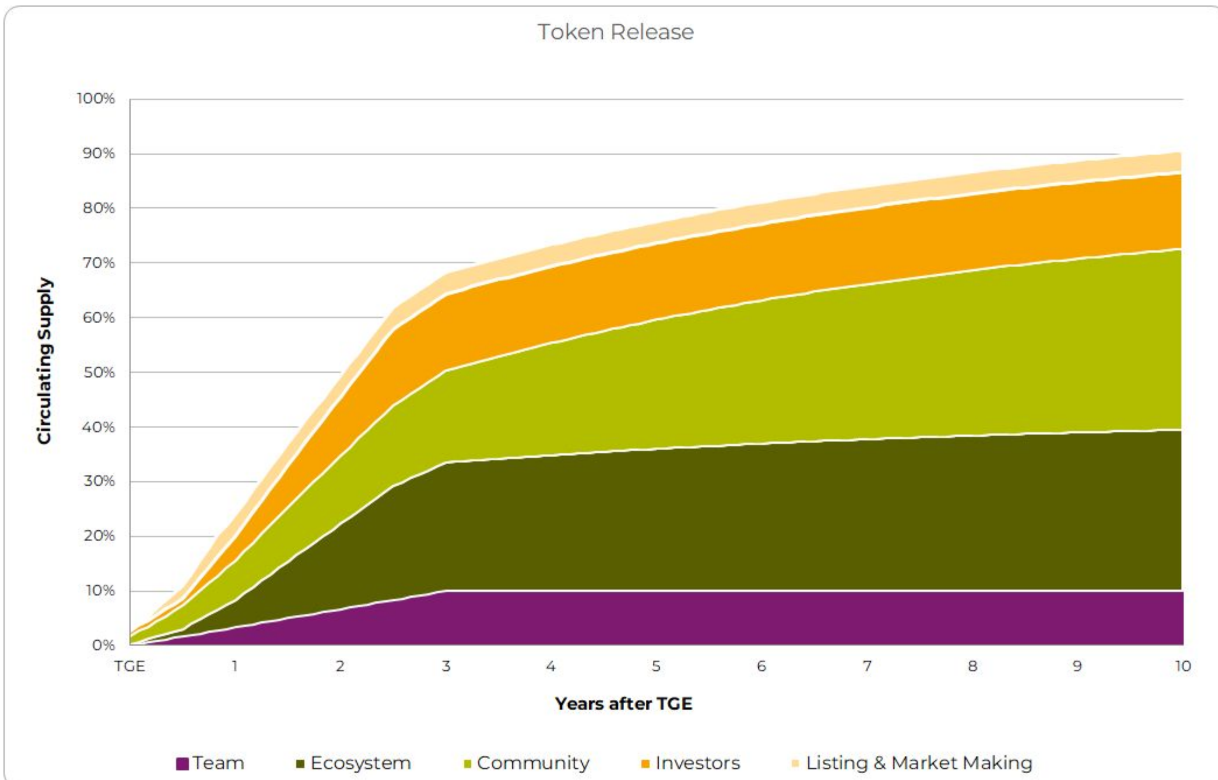

Figure 11: Dilution of the ONO token over time

3.4 Tokenomics

The ONO token is distributed among the stakeholder groups as shown in Table 10. For both founders and investors, tokens are vested with linear monthly vesting in equal instalments; this reduces downward price pressures on the ONO token via token sales while facilitating a commitment of the team and investors to the network. In contrast, the community and miners continuously receive their token units as rewards for their delivered service. The vesting of the team's and investors' tokens ensures continued engagement, while the tokens of the other groups are immediately available, providing a timely return for them in order to i) encourage network growth in the early days and ii) account for an appreciating value of the ONO token over time. The token units released to the miners and the community are subject to a four-year halving schedule, following recent findings that a deflationary factor is required in DePIN token models to have a stable economy [Kalabić et al., 2023].

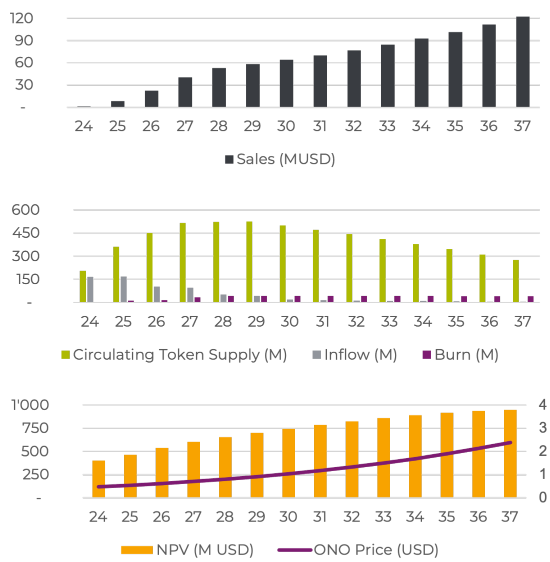

Figure 12: Results of our simulation showing expected revenues, token supply and derived value appreciation of the ONO token.

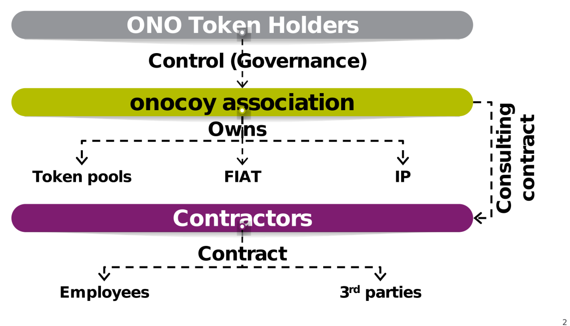

Figure 13: Legal setup of onocoy's off-chain governance: A decentralized autonomous association governed by ONO token holders which eventually merges the on-chain concept of a DAO with the legal representation of an association.

This token release schedule manifests into a continuous and decreasing release of tokens over time as depicted in Figure 11.

A rigorous analysis of ONO's value appreciation has been performed by using Kalabić et al. [2023] and approximating onocoy's deflationary token model model as a discrete-time, full-information, dynamic game. In this game, all participants are aware of future revenue, so there is no need for speculation and an optimal policy for each participant can be derived. Figure 12 illustrates results from our base scenario assuming a realistic growth in revenues (see the top image in Figure 12) taken from the European Commission report [EUSPA, 2022]. Based on these numbers and the illustrated token dilution schedule (see Figure 11), the circulating token supply (see the middle image in Figure 12) and the value appreciation of the ONO token (see the bottom image in Figure 12) are derived. The result is a lower, i.e., worst-case, bound on the token price since the only factor considered is the value derived from data revenue. Novel applications like indoor navigation could be facilitated by the platform that would create a further demand for onocoy services as illustrated in Figure 14, which is not currently considered in the simulation.

3.5 Governance

The purpose of onocoy's governance is to i) enable participation of all stakeholders; ii) enable autonomous improvement; and iii) prevent power concentration by any one stakeholder or a group of stakeholders. These elements, in combination, facilitate onocoy's collective intelligence, which can manage the network successfully in a rapidly changing and complex environment [Ballandies et al., 2024a]. To enable all of the above, the governance follows the value of progressive decentralization. In the long run, governance should be decentralized.

Initially, the system utilizes on-chain majority voting with one ONO token unit equaling one vote facilitated via Realms[7] as its community decision mechanisms. However, in the future, different voting mechanism[8] may be employed to improve the alignment of the vote result with community sentiment [De Tocqueville, 1838, Helbing et al., 2023].

In order to facilitate the progressive decentralization of the system, we have chosen to establish onocoy as a not-for-profit Swiss association, following the best-practice approach of *decentralized autonomous associations* (DAAs) [Ganzoni, 2022]. The association is controlled by its members in accordance with their voting power based on the square root of the tokens represented (e.g., 1 vote power equals 1 vote, but 4 vote powers equal 2 votes, 9 vote powers – 3, and so on). The association owns the intellectual property and system funds, and contracts third parties to develop and maintain

[7]https://www.realms.today

[8]e.g. such as such as Borda count or approval voting combined with a square-root voting to prevent power concentration

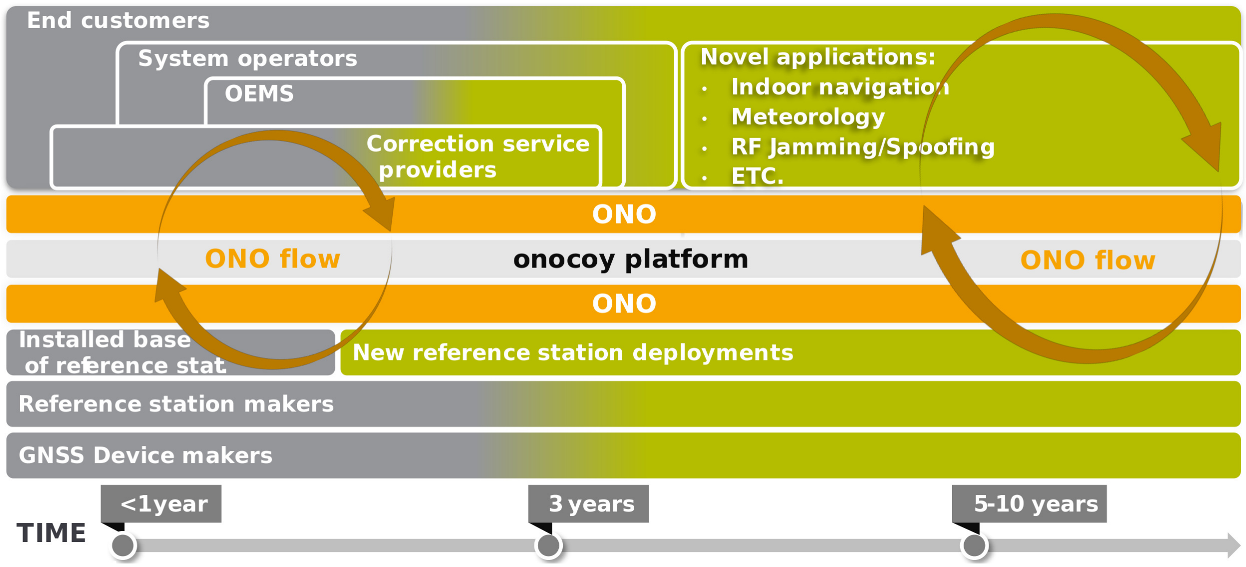

Figure 14: Over time, novel applications are emerging which create a further upward pressure on the token price, besides the one illustrated in Figure 12.

the onocoy system (see Figure 13). One of these third parties is the onocoy Services AG in which some of the initial team members have been organized. The goal is to nurture a rich ecosystem of such third-party companies and services. The core team is organized as a Teal[9] organization [Laloux and Wilber, 2014] that is based on, among other things, contributor autonomy and peer relationships.

In summary, onocoy has established a Swiss association as a legal entity with the following characteristics:

- It is not-for-profit
- Its purpose is the development, deployment and promotion of the onocoy platform
- It establishes a vibrant ecosystem around the platform
- It can pursue its purpose by performing the necessary task itself or by outsourcing them, e.g., to onocoy Services AG
- It will issue tokens for initial financing and to fund growth
- It may hold interests in additional legal entities
- It is kept as lean as possible
- It adopts supplementary regulations stipulating that strategic decisions are made on the basis of ONO token shares via quadratic voting

4 onocoy's IT infrastructure and validation

onocoy's mission is to develop a dense and globally distributed network of independent miners that delivers low latency and high-quality GNSS measurements to a diverse base of clients via onocoy's decentralized platform. The platform is currently divided into three components: i) a blockchain, which implements the economics and governance presented in Section 3, ii) the validator, which utilizes a variety of GNSS processing techniques to determine the quality of reference data streams (see Section 4.1), and iii) a real time communications network, which connects all components such that low latency of the real-time critical data is ensured. (see Figure 15 for a depiction).

At the time of writing, onocoy's economic component has been deployed via smart contracts on the Solana blockchain, whereas the validator, caster, MQTT communication network and database are still centrally managed by the onocoy association. onocoy's backend is based on a 3 layer architecture:

[9]Teal organizations are based on an organizational theory of workers' self-management.

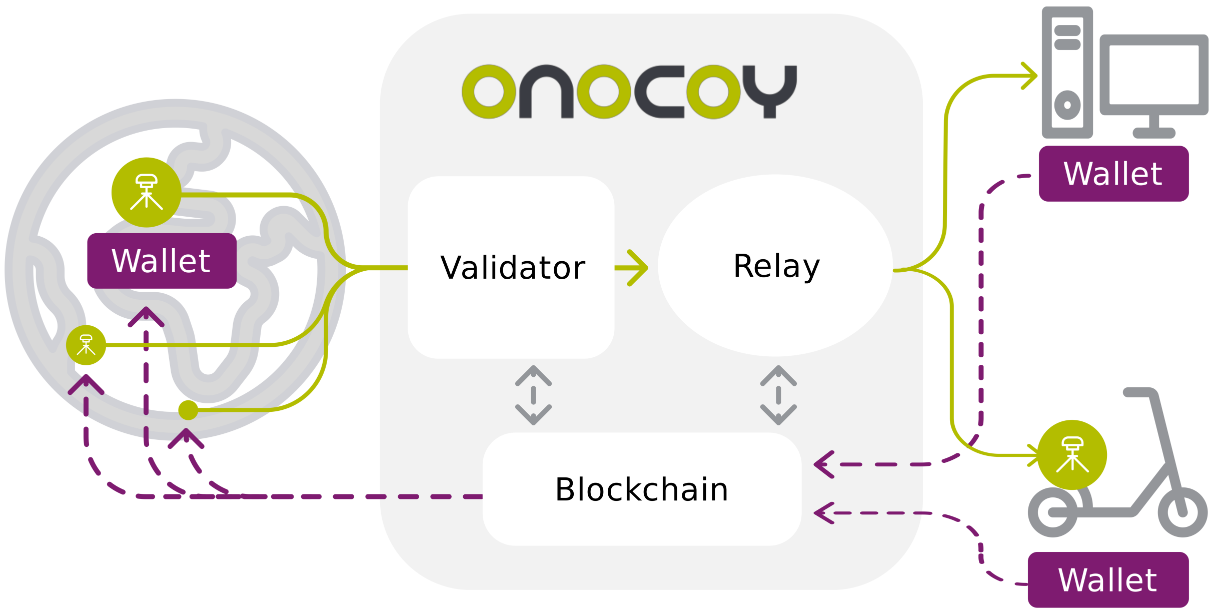

Figure 15: onocoy's IT infrastructure

- Frontend services (NTRIP caster endpoints, console UI)
- MQTT backbone (communication network)
- Backend services (api, validator, database)

To interface both with the external CORS stations and Clients, onocoy uses open industry standards to exchange data (RTCM 3.x and NTRIP 1.0/2.0 HTTP) by implementing the caster functionality. This to maximize compatibility and realize the objective to become a shared platform for the GNSS industry that is inclusive to all existing and new stakeholders.

onocoy's system architecture is designed with scalability in mind. System critical components can be replicated to accommodate demand and increase redundancy. Multi-region scalability can be achieved by replicating the cluster and bridging the MQTT brokers across geographical regions.

This modular design, using loosely coupled components, enables the system to accommodate changes and updates without significant disruption. It allows for integration of new components or functionalities and enables the system to evolve as needed.

By following the principle of progressive decentralization that facilitates resilience and robustness of the onocoy platform, all of these components will eventually be decentralized. The validators may use a proof-of-stake-type algorithm to determine consensus on the quality of data streams, while the caster and MQTT implementation will be expanded with additional technologiesas needed in order to simplify further decentralization of those.

In the following, we present information regarding validator framework (Section 4.1) and the base reward function (Section Section 4.2). Further details regarding decentralization of the caster and communication network and the other types of rewardings in onocoy are forthcoming.

4.1 Validator framework

GNSS measurements submitted by miners are the raw data that a GNSS receiver observes from the signals transmitted by GNSS satellites. These measurements typically contain the time of transmission of the satellite signal and a coarse distance measurement - the pseudorange measurement. Additional measurements captured by the receiver include the carrier-phase and Doppler measurements, where carrier-phase measurements are critical for attaining centimeter-level real-time performance.

The GNSS measurements submitted to onocoy's system are rigorously assessed via the validators to guard against the submission of spoofed and synthetic GNSS measurements. While spoofed GNSS measurements are intentionally deceptive, synthetic GNSS measurements are not typically classified negatively as they provide value-added service in the form of correction data. At onocoy, submission of synthetic GNSS measurements is considered fraudulent as it is seen as an attempt by the miner to emulate authentic GNSS measurements, which leads to undeserved rewards.

In the following, an overview of spoofing and synthetic measurements is presented in Sections 4.1.1 and 4.1.2, respectively. Section 4.1.3 then gives an overview of onocoy's strategy to ensure authentic GNSS measurements are accepted by the platform.

4.1.1 Spoofing

Spoofing refers to the deliberate manipulation or falsification of signals or data in order to deceive or mislead a receiver or system [Jafarnia-Jahromi et al., 2013]. The spoofed GNSS measurements are intentionally generated to deceive a GNSS receiver. Spoofing involves broadcasting fake GNSS signals that mimic accurate GNSS signals but with intentionally modified parameters that cause a receiver to calculate an incorrect position or timing solution [Humphreys et al., 2008].

Spoofing attacks can be carried out using various techniques, such as signal generators, software-defined radios, or replay attacks [Humphreys et al., 2008]. A spoofing attack usually aims to gain unauthorized access to a system or disrupt its operation. Spoofing attacks can have serious consequences, especially in applications that rely on high-precision positioning, such as aviation, maritime, or military applications. Spoofing attacks typically cause receivers to calculate a false position or time, resulting in navigation errors, collisions, or other safety risks. GNSS systems typically use techniques such as encryption, signal authentication, and anti-jamming measures to prevent spoofing attacks [Humphreys et al., 2008].

4.1.2 Synthetic measurements

Synthetic GNSS measurements are artificially generated measurements that are not ordinarily intended to deceive a GNSS receiver but provide additional or augmented measurements to complement actual GNSS measurements. Synthetic GNSS measurements can be generated using a variety of methods. However, the most common method is generating correction data for augmentation purposes. One common source of synthetic measurements is from correction service providers that transmit correction data using an Observation Space Representation (OSR). The alternative representation of correction data is using State Space Representation (SSR), where the correction data is de-correlated into their respective state terms. OSR synthetic measurements are, by design, in a similar format as the GNSS measurements. It is also possible to convert SSR-formatted correction data into an OSR format by transforming the correction data from the state-space domain into the observation-space domain [Seepersad, 2018].

4.1.3 Validating of GNSS measurements

At onocoy, we have deployed a multi-level GNSS measurement processing scheme to guard against the submission of spoofed and synthetic measurements. We examine GNSS measurements over varying time scales using different processing techniques and adjustment methods. We focus on comparing the consistency of the estimated receiver, signal and satellite-dependent state terms across different processing techniques. In Figure 16, we present an overview of the different GNSS measurement processing techniques, which include Single Point Positioning (SPP), differential GNSS (DGNSS) code, Real-Time Kinematic (RTK) and Precise Point Positioning Ambiguity Resolution (PPP-AR). At onocoy, real-time processing is performed using the SPP, DGNSS code and RTK techniques. Daily PPP-AR ensures the miner's location is determined in a global reference frame. More importantly, within the context of fraud detection, PPP-AR ensures global consistency of satellite carrier-phase biases. Post-processed relative baseline solutions are determined against trusted Tier 1 and Tier 2 reference station infrastructure. The varying time scale of the post-processed solution is primarily due to the delayed access of sub-networks of Tier 1 and Tier 2 infrastructure in addition to the utilization of precise orbit and clock products on longer baseline processing. A critical step in our fraud detection is the generation of atmospheric delays and satellite biases from a network solution to ensure consistency amongst a network of miners. Network solutions will be compared against products generated for scientific application to ensure reliability from an independent data source.

As previously mentioned, by design, onocoy opted for an ecosystem that accepted hardware from various GNSS manufacturers as the focus is on developing a community-powered and shared initiative. The GNSS measurement validation framework in Figure 16 has shown high resilience to various attacks examined thus far.

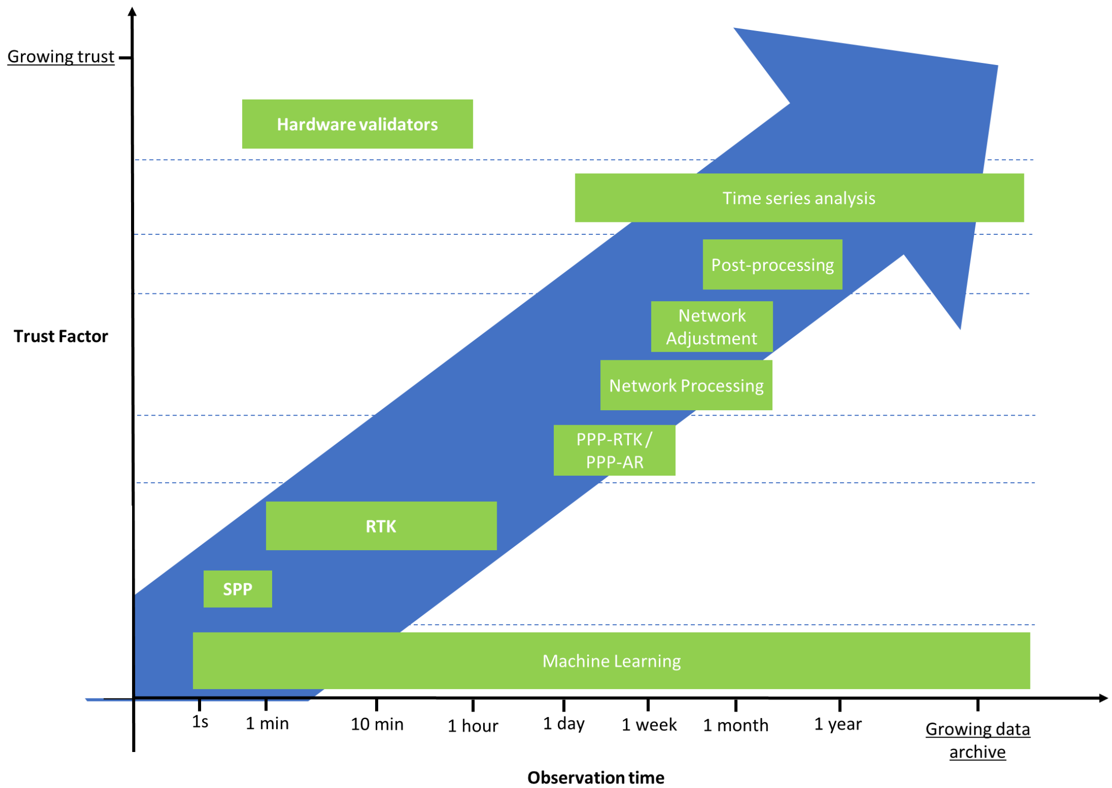

Figure 16: GNSS measurement validation framework

4.2 Measuring the base reward components

Using the validator framework (see Section 4.1), the scales of the miner's base reward are calculated (see Figure 9). The following sub-section details the calculations of the location scale, quality scale, and the availability scale.

4.2.1 Quality scale

The quality scale refers to the supported GNSS measurements submitted by the miner as well as the quality of the measurements. Supported GNSS measurements and the measurement quality are determined by metrics derived from the different GNSS processing methods of Figure 16. Supported GNSS measurements consider the major GNSS (GPS, Galileo, BeiDou and GLONASS) and RNSS (QZSS and IRNSS) constellations. Table 1 presents the reward rate assuming all major GNSS and RNSS were visible. A miner located in Eastern America is expected not to see both QZSS and IRNSS, as such, the reward rate would be updated to exclude these two constellations. GLONASS is given lower importance relative to GPS, Galileo and BeiDou due to the measurement quality of Frequency Division Multiple Access (FDMA) measurements in contrast to the Code Division Multiple Access (CDMA) [J.A Ávila Rodríguez, 2011][10]. Lower importance is given to QZSS and IRNSS due to their regional coverage.

Each constellation transmits a variety of different frequencies and modulations [J. Sanz Subirana and Hernandez-Pajares, 2011]. Priority is given to the number of available nominal frequencies. Table 2 shows the scale factor with respect to the number of nominal frequency bands that are available.

To determine the quality of the measurements, a variety of different metrics are utilized. These metrics include cycle-slip-free epochs, GDOP, measurement availability, pseudorange and carrier-range post-fit residuals, solution position error as well as the ambiguity resolution fixing rate. In the near term, the metrics would be expanded to include position repeatability. Table 2 shows the optimal range of values per metric to attain the full-scale factor. These ranges are expected to be further optimized in the near-term to ensure miners are compensated fairly based on the variety of different hardware qualities that are submitted to the onocoy network.

[10] Note that onocoy anticipates equal rewards for GLONASS once its modernization efforts attain operational status.

Constellation	Scale factor
GPS	0.263
GAL	0.263
BDS	0.263
GLO	0.132
QZSS	0.039
IRNSS	0.039

Table 1: Reward-rate per constellation availability

Frequency Bands	Scale Factor
L1 or L5 only	0.08
L1+L2 or L1+L5	0.32
L1+L2+L5	0.8
L1+L2+L5+L6	1

Table 2: Reward-rate per frequency band availability.

Measurement quality performance metric	Optimal conditions to earn full reward
cycle-slip-free epochs	> 80%
measurement availability	> 60%
pseudorange post-fit residuals (rms error)	< 0.5 m
carrier-range post-fit residuals (rms error)	< 0.02 m
solution position error	< 1 cm horizontal and < 3 cm vertical
ambiguity resolution fixing rate	> 80%
GDOP	< 5

Table 3: Optimal conditions to earn full measurement scale factor

4.2.2 Location scale

Conventional single-frequency RTK performance is limited to baselines of less than 15km, as longer baselines may not effectively account for errors within the GNSS measurement. The objective of relative positioning is to reduce or eliminate error sources by mathematically differencing simultaneous GNSS measurements from multiple receivers. Accuracy in conventional single-frequency RTK is correlated with baseline length and amounts to approximately 0.1 to 1 ppm for baselines up to some 100km and then less for longer baselines [Euler and Schaffrin, 1991]. In Seepersad et al. [2015], baselines were extended up to 50 km under optimal ionospheric conditions, and altitude differences were limited to 400 m due to differences in tropospheric effects. These findings, which are well documented in the literature [Tobias et al., 2011, Rothacher, 2002, Euler and Schaffrin, 1991], highlight two important factors in the spatial distribution of miners which include sensitivity to varying baseline lengths in 1) the horizontal component, and 2) elevation difference.

The goal of the location scale is to

- incentivize spatial distribution of infrastructure
- ensure necessary infrastructure redundancy
- encourage the installation of higher-quality miner infrastructure in areas with low-quality miners (in availability and signal quality)

The current version of the location scale issues a penalty to miners within a defined radius of each other (initially set to 50km). To allow infrastructure redundancy, nearest neighbours are excluded from the calculations. The amount of nearest neighbours which are excluded will be revised regularly and depends on the evolution of the network. A full penalty is applied to non-excluded neighbours within a close radius (initially 15km) as no additional information is gained once we have established the necessary infrastructure redundancy. To minimize clustering during the rollout of the network, a less stringent penalty is applied to those > 15 km and < 50 km.

The implementation is performed as follows.

1. An inner and an outer radius for distances is defined based on the 3D distance, where the inner reward radius is 15 km and the outer reward radius is set to 50 km.
2. For each base station, all nearby base stations are listed ordered by distance ascending where distance represents the 3D baseline distance between the current station and the neighbouring station. The current station has an index equal to 0 and neighbouring stations range from 1 to N where N is the total number of stations within the outer radius.
3. The first X neighbours are ignored from further calculations, where X is the designated infrastructure redundancy value.
4. The distance penalty for miners within the search area is determined, where the distance penalty is a value between 1 (full penalty) and 0 (no penalty). If the distance is less than the inner radius, the distance penalty will be set to 1. Between the inner and outer radius, the distance penalty decreases quadratically from 1 to 0.
5. The distance penalty based on a shared factor is determined, where the shared factor is defined as the ratio of the grades (quality and availablity) of both stations. The shared factor is a value linear between 0 (no rewards) and 1 (full rewards).
6. The location scale is determined by multiplying all reduction factors.

4.2.3 Availability scale

The availablity scale represents the completeness of a data stream during a given time period. Next to the connection duration, also measurement availablity is monitored, as a RTCM station is expected to send a full data set every epoch/second. A dynamic system grant is added to the measured availability to cope with potential system/network errors. The value of a station regarding its availability is not a linear function as a continuous stream is key for the data consumers. Therefore data availability below a threshold (initially 80%) is set to a scale of 0, and an exponential function (initially quadratic) is used to model the availability scale between measured data availablity between 80% and 100%.

5 Call for action

onocoy is on a mission to provide a dense, high-quality GNSS reference station network to unlock the enormous potential of high-precision positioning all across the globe. To do so, it relies on cutting-edge web3 concepts including smart contracts, community participation, and blockchain technologies.

onocoy's unique approach decouples GNSS reference station infrastructure management from correction service provision. Token-based incentives and the systematic use of open standards allows onocoy to tap into the existing installed base of mass market GNSS reference stations and, when required, bring about targeted infrastructure development, quickly and efficiently closing gaps in geographical coverage and technological capabilities. onocoy is the most efficient way to solve the ecosystem problem of creating a global and dense GNSS reference station network.

Our vision is to build this network as a decentralized, and transparent system to ensure inclusive, discrimination-free access to and use of GNSS high-precision technology across all borders.

To achieve this ambitious goal, we require the skills, contributions and visions of each and every one of you – GNSS experts and enthusiasts, web3 hodlers and builders, IT specialists and hackers, ROI miners and idealists –

We require **you**.

Join us.

We are on a mission.

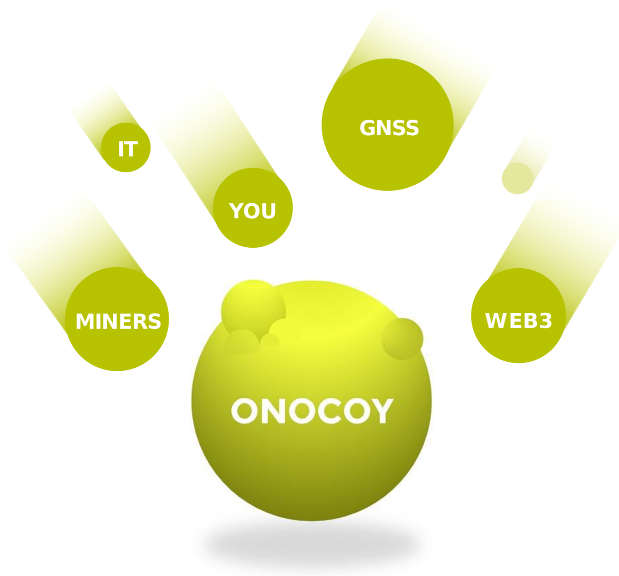

Figure 17: Let's unite – for a future that brings high-precision positioning to earth and beyond.

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