Geodnet

Global Earth Observation Decentralized Network

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***Abstract*—This technical whitepaper explains some design and architecture decisions around the Geodnet network and the GeoDAO decentralized autonomous organization. It covers the motivation of the network, the capabilities of current and future reference stations, the blockchain and GEOD token mechanics, and how the network powers applications from climate change monitoring to centimeter accurate positioning.**

I. Introduction

The use of GNSS receivers to collect real-time Solar and Space Weather observations is well known. For the last twenty years, small and medium sized networks of GNSS receivers have collected multiple signal measurements enabling important industrial and scientific applications. However, despite these networks' demonstrated benefits, today there are no openly-accessible global and dense GNSS receiver networks [1]. Furthermore, GNSS receiver signals are easily jammed and spoofed, yet there is no public, cryptographically secure GNSS receiver network to help protect the ~$1T in location aware applications. ***Geodnet,*** a public blockchain-based and token-incentivized network is planned to fully address these challenges.

II. Definitions

The following background terms are used in the whitepaper:

- **Space Weather:** Changes in the ionosphere and troposphere caused naturally by Solar activity but also other factors such as air pollution. Space Weather can be tracked via changes to GNSS signals.
- **Ground Motion:** Movement in the surface of the Earth caused naturally by tectonic plate motion but also other factors such as climate change, rising sea levels and desertification.
- **GNSS:** Global navigation satellite system is the general term for satellite navigation systems that provide autonomous geospatial positioning with global coverage including, e.g., GPS, GLONASS, Galileo, Beidou systems.
- **Base (also Base Station or Station):** A GNSS receiver permanently installed at a known fixed location. A Virtual Base is a base created by blending data from multiple bases.
- **Rover:** A GNSS receiver whose location is not fixed, e.g., a smartphone with built in GNSS receiver. The accuracy of the rover can be improved with data from a base or a network of bases and a positioning engine algorithm.
- **RTK:** Real-Time Kinematic positioning is a technique to locate a Rover using nearby Base data to centimeter accuracy in a global coordinate frame. The method uses differences in the satellite observations of a base and nearby rover to remove common errors, including the influence of Space Weather.
- **PPP, PPP-AR:** Precise Point Positioning (optionally with Ambiguity Resolution) is an alternative method for centimeter-accurate positioning that relies on data derived from a network of global stations instead of a nearby Base (or Virtual Base).
- **GeoDAO:** The Decentralized Autonomous Organization which governs the Geodnet network.
- **GEOD Token, Blockchain and Wallet Address:** GEOD Tokens are issued to a Wallet Address based on *Proof of Location and Proof of Accuracy* for GNSS Miners, and *Proof of Stake* for Service Validators nodes. Transaction records are stored in the Geodnet blockchain.
- **Data Credits:** To facilitate users' purchase of Geodnet data products without cryptocurrency tokens, Data Credits purchased in USD or other fiat currencies are utilized.
- **Interplanetary File System (IPFS):** A protocol and peer-to-peer network for storing data and sharing data in a distributed file system. Geodnet stores collected data using IPFS.
- **Smart Contract:** A smart contract is a self-executing contract with the terms of the agreement between buyer and seller being directly written into lines of code.

Benefits of Blockchain for CORS Networks

A. *Blockchain Project Characteristics*

Blockchain protocols are the backbone of secure permissionless and decentralized networks. Blockchain projects encourage open standards and open-source development while economically rewarding participation in network development. Large communities have developed around blockchain and cryptocurrency projects as evidenced by the emergence of Bitcoin and other tokens as a ~$2T asset class and the more than 68M verified accounts on Coinbase as of its Initial Public Offering [2]. The ability of a successful blockchain project to rapidly deploy distributed infrastructure makes it an excellent candidate for a global, dense, and secure GNSS receiver network.

B. *Related Example: HELIUM*

The Helium network is an existing example realization of these principles. Helium is now the world's largest wide-area low-power wireless network implementing the LoraWAN standard. Within two years of the public availability of Helium miners (hotspots), more than 200,000 hotspots are online providing dense and inexpensive LoraWAN coverage in many of the major cities of the world. Geodnet's goal is to provide a similar benefit for access to secured GNSS measurement observation streams [3].

C. *Why now?*

Several trends favor the immediate development of ***Geodnet***. These trends are:

- Mass-market applications for precise location service
- Availability of low-cost high-precision multi-band multi-constellation receivers
- Success of related cryptocurrency and blockchain projects

As a result of these trends, a community-initiated, decentralized network of high-accuracy GNSS receivers can quickly scale to "mine" Space Weather data. The network effect created from a token incentive (GEOD token) will drive rapid and cost-effective global deployment.

III. Space Weather GNSS Miners

High-quality yet affordable Space Weather (GNSS) Miners utilize affordable components with state-of-the-art GNSS receiver hardware. For use on Geodnet, these designs must be certificated and secured. GeoDAO approved miner hardware are sold globally for installation on homes and buildings with clear sky visibility and stable Internet connections. An example of such an installation is shown in Figure 1.

Figure 1: Example Installation at Residence in Perth, AUS

The Geodnet network depends on the delivery of *honest* GNSS data, and several steps are taken in the protocol design to prevent fake or simulated GNSS data from entering the network, while simultaneously rewarding stable high-quality installations.

Reference designs that include additional Ground and Atmospheric sensing modalities are encouraged. Examples include meteorological sensors (i.e., temperature, pressure, humidity), acceleration sensing for strong motion measurement, visual or infrared sensor for celestial imaging, LiDAR for spatial information capture, and software defined radio for tracking LEO signals of opportunity and RF spectrum measurement.

Additional communications interfaces such as inclusion of Helium LoraWAN network compatibility and TDOA measurement is contemplated.

A. *Receiver Hardware:*

The hardware architecture of a miner is shown in Figure 2. The GNSS chipset is secured, and authenticated data is transferred as described in the next section. The miner may provide Ethernet, WiFi, and/or cellular communication for the transfer of data to the Internet. The miner shall meet the following minimum requirements:

- Dual-Frequency GNSS Signal Tracking
- GPS, GLONASS, Galileo and BeiDou Constellations
- > 50 Channels
- < 10W Total Power Consumption
- GNSS chipset shall have an SDK Available for Custom Secure Firmware
- Cryptographically-Secure Key Storage

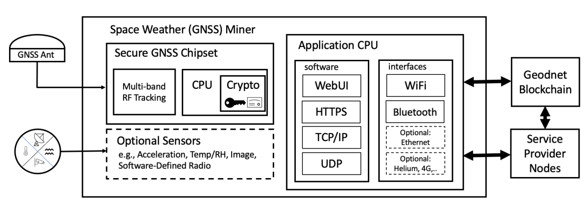

Figure 2: Space Weather (GNSS) Miner Architecture

Miners communicate data to service provider nodes using UDP for continuous real-time space weather data, and via TCP/IP to validators for configuration and oversight. To ensure reliable real-time transmission, the number of Service Provider connections per Miner is limited by Geodnet. Miners may be differentiated in the ecosystem based on channels received, additional functionality, and price.

B. Secure Receiver: Cerification and Encryption

Hardware miner designs and manufacturers are first approved by the GeoDAO. Upon approval, the manufacturer creates a root X.509 ceritified by GeoDAO. Each miner device receivers a unique private and public key pair which is signed with the manufacturer's root certificate. The miner's private key is stored securely within the device and used to authenticate all communication and data from the miner.

Certification and data encryption secures Geodnet against obvious fake miners, simulated observation data, or use of data relayed from other base station networks. Authenticating the hardware platform ensures miner hardware meets minimum quality standards, and securing the entire receiver processing and communication path protects the GNSS observation data from manipulation and guarantees authenticity.

A GNSS Miner is uniquely associated with a Wallet Address. The manufacturer is also required to spend ("burn") a fixed number of data credits for each miner that joins the blockchain. These items are stored on the blockchain. Miners who do not have an interest in GEOD tokens or are unable to receive tokens can transfer earned tokens to the Wallet Address of the GeoDAO or alternative destination.

C. Proof of Location (POL)

An initial GNSS Miner validation occurs after a series of successful validation messages are received within time threshold $t_{validation}$. This process is referred to as *Proof of Location.*

GNSS Miners are invalidated and removed from Geodnet after failing to deliver timely validation.

Proof of Location prevents a dishonest space weather miner from utilizing simulated RF data e.g., installation indoors and connected to a GNSS RF simulator. For a miner to remain joined to Geodnet and eligible for token rewards, the miner must deliver periodic validation messages to the validator nodes within a threshold time $t_{validation}$ as shown in Figure 3.

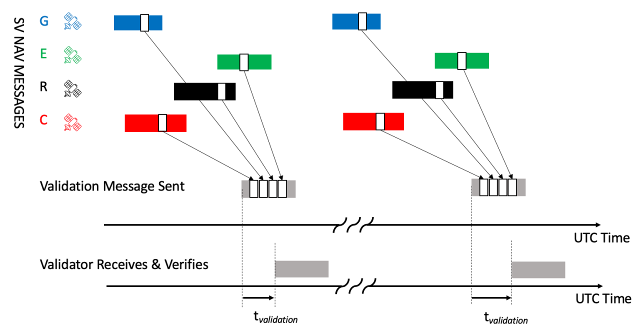

Figure 3: Proof of Location Validation Messages

The validation message is a pseudo-random code derived from a combination of datum in each of the four major constellation's navigation messages. The navigation messages are updated regularly but without advance public notice. An RF simulator attempting to generate dishonest GNSS measurements must first receive current navigation messages from actual Satellite Vehicles and then replay them. In general, the reception and replay of the navigation data will incur a delay greater than the threshold time, resulting in detection of dishonest GNSS data. The validation message checks are combined with differential pseudo-range and carrier phase analysis as part of the proof of location protocol. This limits observation errors if a sophisticated Security Code and Estimation Replay (SCER) attack is attempted [4].

D. Proof of Accuracy (POA)

Validated GNSS Miners are rewarded in proportion to the formula:

$$Q = \frac{\alpha \ln(1+d)}{e^{\gamma(1-R)}}$$

Q: *Proof of Accuracy Metric*

d: *radial distance from nearest Miner in km divided by 10km*

α: *signal quality weighting computed from number signal received meeting carrier-to-noise threshold.*

γ: *reliability weighting factor*

R: *30 day rolling reliability computed as number of expected messages divided by number of received messages*

These parameters are computed by the validator node described later in the whitepaper with the results stored in the Geodnet blockchain.

E. Gensis Miners

To bootstrap the global development of the Geodnet network, a global network of more than 40 survey-grade GNSS stations is installed with a target of 100 stations prior to the end of 2021. Figure 4 shows the installation as of September 2021. The location of these Genesis Miner stations is evenly spread over the surface of the Earth providing a baseline network capability to produce the data products necessary for PPP and PPP-AR algorithms. PPP's global capability bootstraps the functionality of the network at a global level.

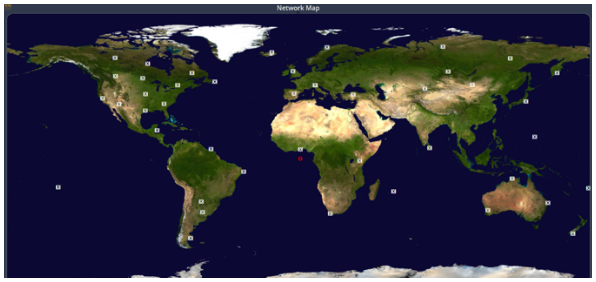

Figure 4: Genesis Miners

IV. Network Architecture

The Geodnet network consists of Space Weather Miners, Validator Nodes and Service Provider Nodes as shown in Figure 5. Service Provider Nodes face the end-user and utilize the blockchain to select which miner stream or combination of streams to utilize.

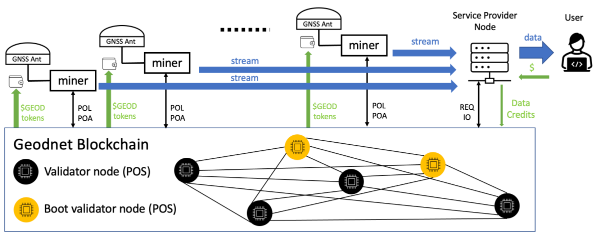

Figure 5: Geodnet Architecture: Miners, Validators, and Service Providers

Validators are Internet connected instances that are staked with the GEOD token and participate in a Proof of Stake consensus protocol to validate Geodnet blockchain transactions. In the initial phase the number of Validator Nodes will be limited to 64 with a minimum of 20 to launch the main net. When a new Space Weather Miner first connects, it will communicate with a validator boot node. The validator boot node will assign the Miner to a primary validator. If the assigned validator leaves the network, the process repeats. After the validator confirms the miner's security certificate, the miner begins signed data transmission and the initial validation process. After the initial validation is complete, the validator continues to receive Proof of Location validation messages, and at random intervals requests observation data from the miner to compute the Proof of Accuracy. Sample data is stored along with the Merkle-proof. The consensus protocol will determine which node generates a new block at a particular time point. If a miner provides fake or in-accurate data, it will be spotted, and the proof is also included in the block.

A. *Proof of Stake*

Proof-of-Stake (POS) is a consensus protocol widely used in recent blockchain projects. In Geodnet, validator nodes (v-node) stake tokens to participate in system consensus. Each v-node will have its chance to produce blocks based on the BLS algorithm weighted by the staked token.

Geodnet uses the BLS algorithm for fast and reliable BFT-like (Byzantine Fault Tolerant) consensus [5]. Multiple parties use threshold signature to reach an agreement on a blockchain proposal. The staking will also improve economic security by punishing any misbehaving validators. Anyone who owns Geodnet token can bond (or delegate) their GEOD tokens and become a validator, making the validator set open and permissionless.

B. *Data Credits*

Data Credits (DCs) are central to the Geodnet Blockchain and Network. DCs are used to assert new Space Weather miners and their identity, as well as pay for real-time geospatial data service such as virtual reference station (VRS) corrections. Every 1 second of data streamed from a Geodnet costs 1 DC which is fixed to 1e-5 dollars ($.00001). Service Provider nodes receive requests from Applications and Users and utilize Data Credits to pay for the required streams to service those Applications and Services. GEOD tokens are convertible to Data Credits. Service Provider nodes can run algorithms to compute VRS streams, Precise Clock/Orbit streams, or other processing methods based on external market demand.

C. *Software Stack Service Provider Node*

The service provider runs a GeoDAO provided stack written for Node including several libraries and APIs to interact with the blockchain and receive real-time data streams from Miners. These libraries and APIs are extendable by the operator of a Service Provider Node, and include hooks to connect code written in other programming languages.

D. *Software Stack Validator Node*

The validator runs an open-source GeoDAO maintained stack that is the backbone of the blockchain. The Geodnet blockchain provides benefits over existing Proof of Work (POW) and Proof of Stake (POS) protocols.

Most POW blockchain systems only offer probabilistic finality. Probabilistic finality refers to the fact that theoretically, some nodes with overwhelmingly high computation power can build an alternative branch and eventually replace the original one. Also, POW consumes a lot of energy to perform the brute-force search for the required hash function input [6].

Proof-of-Stake (POS) is a consensus protocol that uses stake as the criteria to vote on new block generation. Unlike POW, POS is a closed system, which means tokens are created without any external entropy. Thus, the POS system will likely suffer from centralization in initial token distribution and reward system. Another drawback of POS consensus protocol is that the

POS system itself can be easily cloned, equivalent to an unlimited token supply [7].

Geodnet takes an approach that merges the desired features of POW and POS. External resource consumption (External Entropy) is critical to the system's security and decentralization. However, instead of using the unbounded energy consumption as in Bitcoin or most other POW protocols, Geodnet uses geospatial information as the unique and unforgeable resource to be part of the consensus process. Geodnet Consensus Protocol uses both geospatial data input (POL, POA) and staked token (POS) to determine the block generation efficiently.

Each base station miner forms a verifiable geospatial span. Each validator provides the geospatial span proof with staked power to perform block proposal and generation. An additional advanced algorithm such as the BLS algorithm is used to optimize the network efficiency. The protocol will also improve economic security by punishing any misbehaving validators.

In this way, Geodnet will be the first and unique network that utilizes limited Earth surface as the resource, which provides enormous value for the network. Additional services such as localization, high-definition mapping, and autonomous navigation are just natural derivatives of this network.

V. GeoDAO

GeoDAO is the Decentralized Autonomous Organization which governs the Geodnet network.

A. Organization

A Decentralized Autonomous Organization (DAO) is best described as an effective and safe way to work with like-minded individuals around the Globe. GeoDAO is an organization dedicated to a decentralized blockchain-based network of environmental and space weather collection stations for utilization by the Geospatial community and industry.

GeoDAO is organized around a ERC20 SmartContract, a piece of code that describes the creation and distribution of native GEOD tokens. The SmartContract shall be registered on public blockchains such as Ethereum and BNB, pegging the GeoDAO and the token distribution logic into well-established public chains for added security. Additionally, in March of 2021, the State of Wyoming (USA) passed a bill to provide a registered DAO legal status as a limited liability corporation (LLC) providing the substantial limited liability and double-taxation benefits of a traditional LLC entity. GeoDAO is registered under this statute [8].

B. Token Supply

The total token supply growth rate halves every two years. The dependence of the token supply over time t could be written as:

$$\boldsymbol{M(t)} = \boldsymbol{M0} + \int \boldsymbol{I0} * \boldsymbol{exp}[-\boldsymbol{ln2} * (\boldsymbol{t}/\boldsymbol{T})]\boldsymbol{dt} + \int (\boldsymbol{m(t)} + \boldsymbol{\Delta(t)})\boldsymbol{dt}$$

M0 is the initial token supply. The first integral part is the staking reward in terms of time t. The second integral part is the mining reward. The miner number will change over time, as displayed in the previous graph. $\boldsymbol{m(t)}$ is the current Base Station number, and $\boldsymbol{\Delta(t)}$ is the expected miner growth.

C. Software Development

GeoDAO developers will deliver a baseline set of open infrastructure necessary to bootstrap the community. These deliverables include initial miner reference designs, validator and service provider reference code, as well as user-facing tools.

User-facing tools includes the Geodnet website, a user-facing web console application, and a mobile GEOD wallet application with miner registration features. GeoDAO will contribute other tools as the need arises.

D. Ecosystem Outreach

GeoDAO conducts community education and outreach thru popular online and social channels, as well as traditional conferences and publications.

VI. Applications

A public, secure, and dense global reference station network will transform numerous scientific and commercial applications.

A. Climate Monitoring

High-accuracy geodetic position data from dense and diverse global locations helps scientists predict the effects of rising sea levels and changing precipitation patterns. The monitoring of shoreline changes, forest fires threats, desertification, and air quality have all utilized data from existing CORS networks [9,10,11].

B. GNSS Spoofing and Jamming Detection

The European GNSS Agency estimates the global installed base of GNSS receivers is 6.5B units; however, commercial GNSS receivers are easily spoofed and jammed. In the United States, 14 of the 16 critical infrastructures depend on GPS[12]. Current consumer receivers provide little to no protection against well documented attacks utilizing easily acquired low-cost hardware. A dense network of secure GNSS receivers can provide an important alert and warning capability of localized GNSS attacks [13].

C. Geodeformation Hazard Warning

According to the EU Commission on Science, more than one in three people live in areas exposed to earthquakes. While Geodnet cannot prevent Earthquakes or other natural geohazards such as sink-holes and landslides, real-time and accurate data helps predict disasters and identify at-risk infrastructure [14,15].

D. Precise Positioning and Timing

Many of the existing networks of GNSS receivers are maintained to enable precise positioning and timing services on rover devices. Trimble and numerous other companies have supplied receivers used for survey, farming and other precise GIS applications for more than twenty years. Both the Rover receiver and the GNSS data correction services for these applications have traditionally been quite expensive; however, recently a great deal of enthusiasm has emerged for lower-cost rovers for Autonomous Automobiles, Drones, and even Mobile Phone applications. These applications are driving a growing need for low-cost highly available correction streams. A large decentralized network can meet this need with secured global data at a fraction of the cost of alternatives.

VII. Next Steps and Roadmap

The Geodnet architecture was first introduced at ION GNSS+ 2021, and the initial response has been favorable. On-going discussions with receiver manufacturers, software developers, and users will drive a first public facing testnet by the end of 2021. The goal for fully operational service by the end of 2022, and 100,000 stations within three years. Within 10 years, the goal is to reach ~1M stations.

Date	**Milestones**		
	Event	***Description***	***Miners***
2022.1	Testnet launched	Initial Token Distribution and Test Net Running	100
2022.6	Mainnet	Staking Ready	1000
2023.1	Operational PPP-AR & Regional RTK VRS Services	End-User Service Model Operational, Beta Dev API	10000
2023.6	Mainnet 2	Dev API Fully Operational	30000
2024.12	Global RTK Available	RTK on-demand globally. Largest single network WW.	100,000

Geodnet (https://geodnet.com) regularly posts new information regarding project status and provides links to additional resources regarding Geodnet.

Decentralized infrastructure promises a scalable and rewarding way to tackle high-precision measurement at Earth scale.

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