FOAM Whitepaper

05.01.2018

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FOAM — The Consensus Driven Map of the World

FOAM is an open protocol for decentralized, geospatial data markets. The protocol is designed to empower users to build a consensus-driven map of the world that can be trusted for every application. As technology evolves and changes, maps need to change too. FOAM secures physical space on the blockchain, harnessing the power of Ethereum with a cryptographic software utility token used to provide computational work and verification to the network.

The component elements of the FOAM protocol are designed to provide spatial protocols, standards and applications that bring geospatial data to blockchains and empower a consensus-driven map of the world. Token mechanisms and crypto-economics underpin the elements of FOAM and empower the distributed users to coordinate and interact in a decentralized and permissionless fashion.

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Elements of FOAM

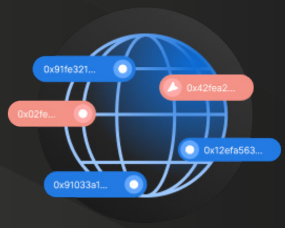
The thinking behind FOAM is that users should own their personal location information, controlling when and with whom they choose to share their location. FOAM is committed to solving this need by providing spatial protocols, standards, and applications that offer a higher level of security and resiliency than conventional geospatial technologies and location-based services.

Location-based services have augmented both urban and rural life, changing how people get around and how products get to people. In the future, the world’s collective critical infrastructure will rely even more heavily on spatial information, from stock exchanges to autonomous vehicles and the internet of things. Blockchains have emerged to enable cryptographically secure transactions and distribute risks through peer to peer networks without the need for a trusted third party. Blockchains have the potential to enable secure and self-regulating emergent infrastructures of the future.

New applications driven by smart contracts will need consensus-driven geospatial data that can be verified and trusted. Previous attempts to create an open source map that is legible to humans, verifiable, and readable by machines, have been crippled due to a lack of funding for open source projects. This document explains how the FOAM protocol allows a grassroots user base to efficiently solve this infrastrucutre development problem around open communication standards for maps.

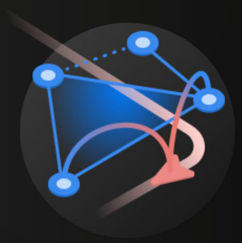
Crypto Spatial Coordinate Standard

An open and interoperable standard for location in Ethereum smart contracts.



Spatial Index and Visualizer Webapp

A general purpose visual blockchain explorer that enables users to understand, engage and act with spatial data.



Proof of Location

Consensus on whether an event or agent is verifiably at a certain point in time and space.

Problems:
Location Encoding, User Experience and Verification

There are three problems in relation to existing spatial protocols that FOAM sets out to solve which are intended to assist users and developers of blockchain, smart contract and location-verification based projects and services. **These problems relate to (i)location encoding standards, (ii) user experience for spatial applications, and (iii) secure verification about the authenticity of location data.** Each of the component elements of FOAM is designed to address its corresponding problem, (a) Crypto-Spatial Coordinates, (b) the Spatial Index and Visualizer, and (c) Proof of Location.

Location Encoding

Currently, there are no established standards for embedded locations, physical addresses, or coordinates in smart contracts. Further, there is no open way to verify geospatial data. For smart contracts to remain interoperable, they need a shared language for them to reference and index the physical world. Additionally, location standards today are an unsolved problem. Throughout history, there have been many ways of encoding physical locations into addresses — from longitude and latitude all the way to the more recent geohash. While autonomous car companies are racing for more accurate location data, the fact remains that most of the Earth's surface lacks an address. According to the United Nations, 70% of the world is unaddressed, including more than half of the world's sprawling urban developments.[1]

Maps and addressing systems are at the foundation of our lives, and have played a major role throughout history. From the earliest forms of navigation, cartographers' work has been a vital tool upon which commerce and development rely. We have gone from hand drawn maps and non-standardized measurement tools like footsteps, to centralized cartography projects of ordnance surveys, to the most recent high-tech developments in digital cartography that rely on the work done by satellite imaging, geographic information systems and even street view cars. Currently, Google dominates consumer mapping, followed by HERE, a company jointly owned by the largest German automotive companies, and TomTom, known for standalone Global Positioning System (**GPS**) units, lagging behind.[2] And that's a problem, since whoever controls the map defines how we navigate the world. Even more so for applications that require consensus-driven and verifiable geospatial data.

Alternative addressing systems have attempted to increase human memorability, verifiability and machine readability. Notable examples are What3words and Open Location Code. However, attempts to create a broadly accepted standard around them have failed to materialize as these systems are either proprietary, like Google, and/or open source projects lacking economic incentives. What3Words uses unique three-word addresses to divide the world into a grid of 3X3 m^2 squares. In its system, an address such as Banana.Radio.Scent could describe an area within a field for example. Though What3Words may hope to become a global standard, it is still a centralized addressing system that charges a license fee.

Other location standards have suffered from similar problems. See 'An Evaluation of Location Encoding Systems' for an overview of these.[3]

	example	unique	not pro-prietary	deter-ministic	veri-fiable	crypto-spatial
postal	Times Square, Manhattan, NY 10036	no	yes	no	no	no
long/Lat	40.758895,-73.9873197	yes*	yes	yes	yes	no
GEOHASH+ETH	XrCNFltAaz5xlHUw6o5GLbtMDqclNn4xqX	yes	yes	yes	yes	yes
CSC	5AH71r9wTRp9eHsqR	yes	yes	no	yes	yes
geohash	dr5ru7k	yes*	yes	yes	yes	no
what3words	rocky.silver.funded	yes	no	no	no	no
xaddress	2399 OUT CASTS	yes	no	no	no	no
open location code	Q257+H3	yes	yes	yes	yes	no
makaney code	WWJT-89GN	yes	yes	yes	no	no
what3emojis	🐒🐀🌛	yes	yes	yes	no	no

https://github.com/google/open-location-code/wiki/Evaluation-of-Location-Encoding-Systems

OpenStreetMap (**OSM**) is an alternative to Google and other proprietary mapping data, as an open source and collaborative mapping project which is free to use and created by millions of participants around the world. OSM is gaining traction on Google, and is currently used by Mapbox, Apple Maps, PokemonGO, Foursquare, and Craigslist among others. As the crowdsourced and open map gets better and better, the value of licensing proprietary mapping data from Google plummets rapidly. But what OSM currently does not do is make it easy to enforce agreed-upon truths. This is an inhibitor to potential blockchain infrastructure development, as it needs a location standard for blockchain applications that is free, open source and interoperable so that protocols can securely connect offline spaces to online assets.

User Experience

Similar to a need for a location encoding standard, there also needs to be able to interact, visualize and reason about the data with an advanced user experience. Examples of such interfaces exist for centralized geospatial data sets, which are not compatible with open blockchain infrastructure. Additionally, there are no open user experience standards for visualizing geospatial data from a blockchain.

Numerous blockchain projects' use cases have or will need visual mapping tools for smart contracts such as:

- Supply Chain
- Energy Markets
- Real Estate
- Mobility
- Location-based games

For any of these blockchain applications a map or visualization component is crucial. Currently there are no blockchain tools for geospatial data. FOAM aims to provide a solution to this.

Location Verification

Currently there is no reliable and trusted location verification service. It is problematic to rely on GPS and it is not a viable tool when a smart contract needs to execute autonomously on spatial information. A backup for GPS is needed because it can be easily spoofed, jammed, or falsified. This means that there is currently no truly secure way to verify location in blockchain-based smart contracts or decentralized applications.

The Vulnerabilities of GPS

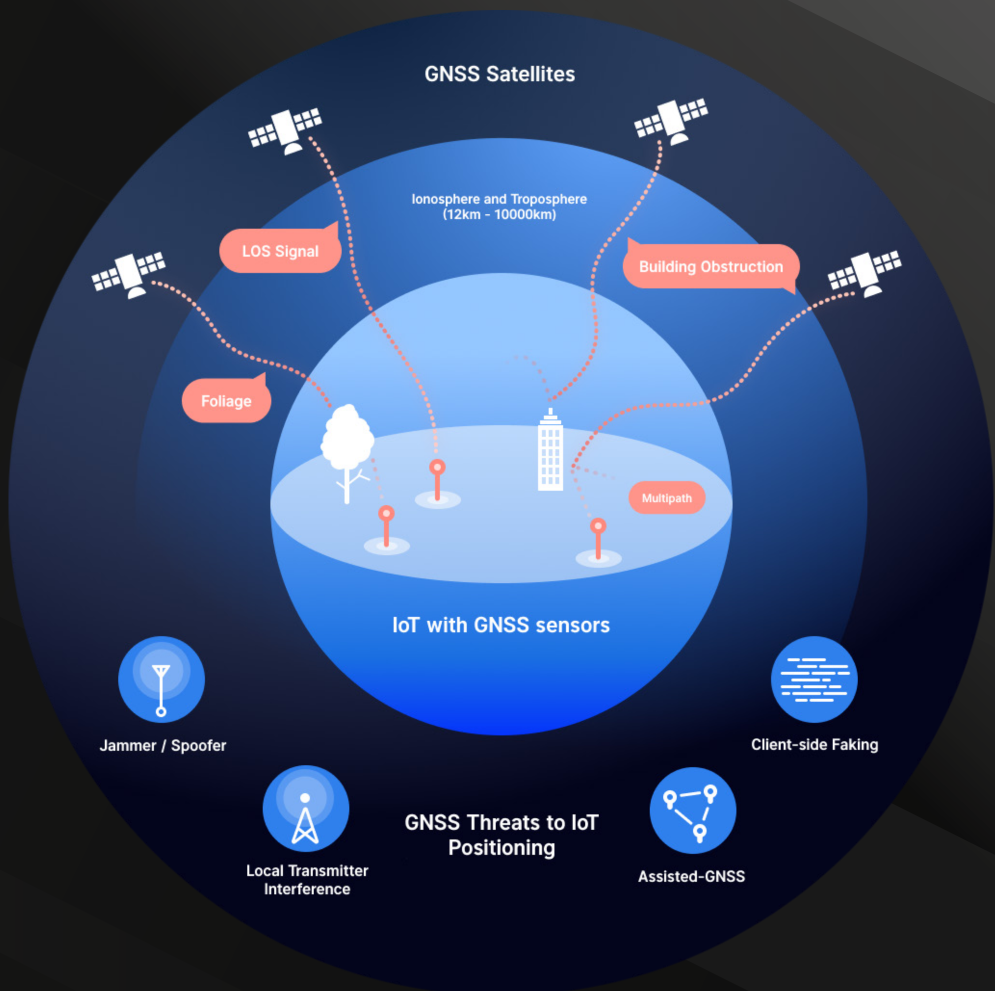
GPS is the world's premier Global Navigation Satellite System (**GNSS**), consisting of 31 satellites launched by the U.S. military and made available for civilian and commercial use. GIPS has become a ubiquitous tool, recently dubbed as "The Technology That Envelops Our Cities — and Brains" by Alphabet's Sidewalk Labs. What may not be immediately apparent, is that GPS technology works through time as much as it does space. Inside each satellite is a high-precision atomic clock, which sync regularly to master control stations on the ground. GPS receivers, common in today's smart phones, must pick up time-stamped signal data from a minimum of four overhead satellites. By using time stamps to calculate the time of arrival, a receiver can calculate a triangulated position.

Ordinarily, GPS is reliable, such that society has collectively come to depend on a functioning geopositioning system. However, its problems, vulnerabilities and limitations have become increasingly evident. This reliance is evident in a number of industries, including much of the global financial system. The New York Stock Exchange uses GPS to time automated computer trades and ATMs and credit card transactions require location data. The electrical grid relies on GPS synchronized time stamps to deliver electricity without causing power surges, as well as obvious use cases relating to transportation, navigation, and mobility.[4]

Civil GPS is unencrypted, it has no proof-of-origin or authentication features, and despite dire warnings first raised in 2012, the system remains extremely susceptible to fraud, spoofing, jamming, and cyberattack.[5] Operational Control System (**OCX**), the putative next generation of GPS "will be the first satellite control system designed after the advent of significant jamming and other cyber threats." However, the project has been continuously delayed, with a scheduled launch date now in 2022. Even so, the OCX design fails to address vulnerabilities, "GPS competitiveness as a worldwide civil system will diminish."

The limitations of GPS require at least four beacon signals to be overhead, which makes indoor localization nearly impossible. Urban density and skyscrapers also cause difficulties in receiving four messages and the issue of multi-path signals occurs within the vicinity of high rise buildings. Further, for a device, it can take multiple minutes to acquire an accurate coordinate. When it comes to power consumption, GPS is a drain on battery and is not feasible for low-powered Internet of Things (**IoT**) devices.

The goal of Proof of Location is therefore to provide consensus on whether an event or agent is verifiably at a certain point in time and space while accounting for the above vulnerabilities inherent in GPS.



Solutions: Crypto–Spatial Coordinates, Spatial Index Visualization, Proof of Location

Crypto–Spatial Coordinates — the open location standard on Ethereum

The FOAM Crypto-Spatial Coordinate (**CSC**) is a starting point for this shared location standard, allowing any smart contract to make an immutable claim to an address on the blockchain and a corresponding location on the map. Crypto-Spatial Coordinates are Ethereum smart contract addresses with corresponding addresses positioned in physical space that are verifiable both on- and off-chain. This allows for physical addresses in the built environment to have a corresponding smart contract address that is accessible for decentralized applications. The protocol uses the geohash standard as a basis for this construction because of its conceptual and mathematical simplicity. Another benefit of the geohash standard is that it is in the public domain.

The CSC standard can be adopted by any smart contract to make a claim to, or reference, a location in the physical environment. If adopted across projects and use cases, the CSC allows smart contract transaction activities to take on a spatial dimension. The CSC can act as a reference point for spatial events that works for any kind of transaction on Ethereum or other Ethereum Virtual Machine compatible blockchain. Since geohashes are intrinsically hierarchical, it also means that a contract referencing a building, and a contract referencing an IoT device located within that building, automatically have a spatial relationship.

Properties of the CSC

The protocol encodes a CSC as a hash with inputs consisting of:

1. A geohash.
2. A corresponding Ethereum address.

A key property of the CSC is that it is verifiable both on- and off-chain. This means:

1. A smart contract can make an immutable claim to a specific location and receive a unique identifier, a CSC, which contains permanent information about both location and the blockchain address.
2. Any user can verify off chain if a CSC is where it claims to be by visiting the location, and verifying the information on the blockchain.
3. Any other smart contract is able to reference the registry of all CSCs and determine any particular contract's physical location and blockchain address.
4. Two smart contracts should be able to compute their location and spatial relationship between themselves on-chain with the data provided by the CSC standard.

The approximate resolution of a CSC is one square meter. This resolution allows for a maximum of approximately 500 trillion unique locations.

The CSC Functionality

1. For geographical input, the protocol uses a geohash represented by a value 10 characters in length in a format based on the base32 encoding standard. The alphabet used is the standard geohash alphabet as defined here.[6] This amounts to approximately 50 bits.
2. For the Ethereum address, the protocol uses a 160 bit standard, associated with the address of a contract.

base32, 48 bits	base16, 160 bits
drrehu19f	0x7d551397f74a2988b024afd0efe4ee802c7721bc

base16, 256 bits
0x3b0556fae1e228878fb35b24e0a5f9c4f13b59035ff899e03f56c0a13250616

base58, 96 bits
6UwLL9Risc3QfPqBUvKo

For ease of visual human reference, the protocol displays the first 8 characters in this representation and the shorter a CSC address is, the larger the area it represents. Longer addresses represent more specific claims to locations, a similar hierarchical concept to telephone area codes or ZIP codes.

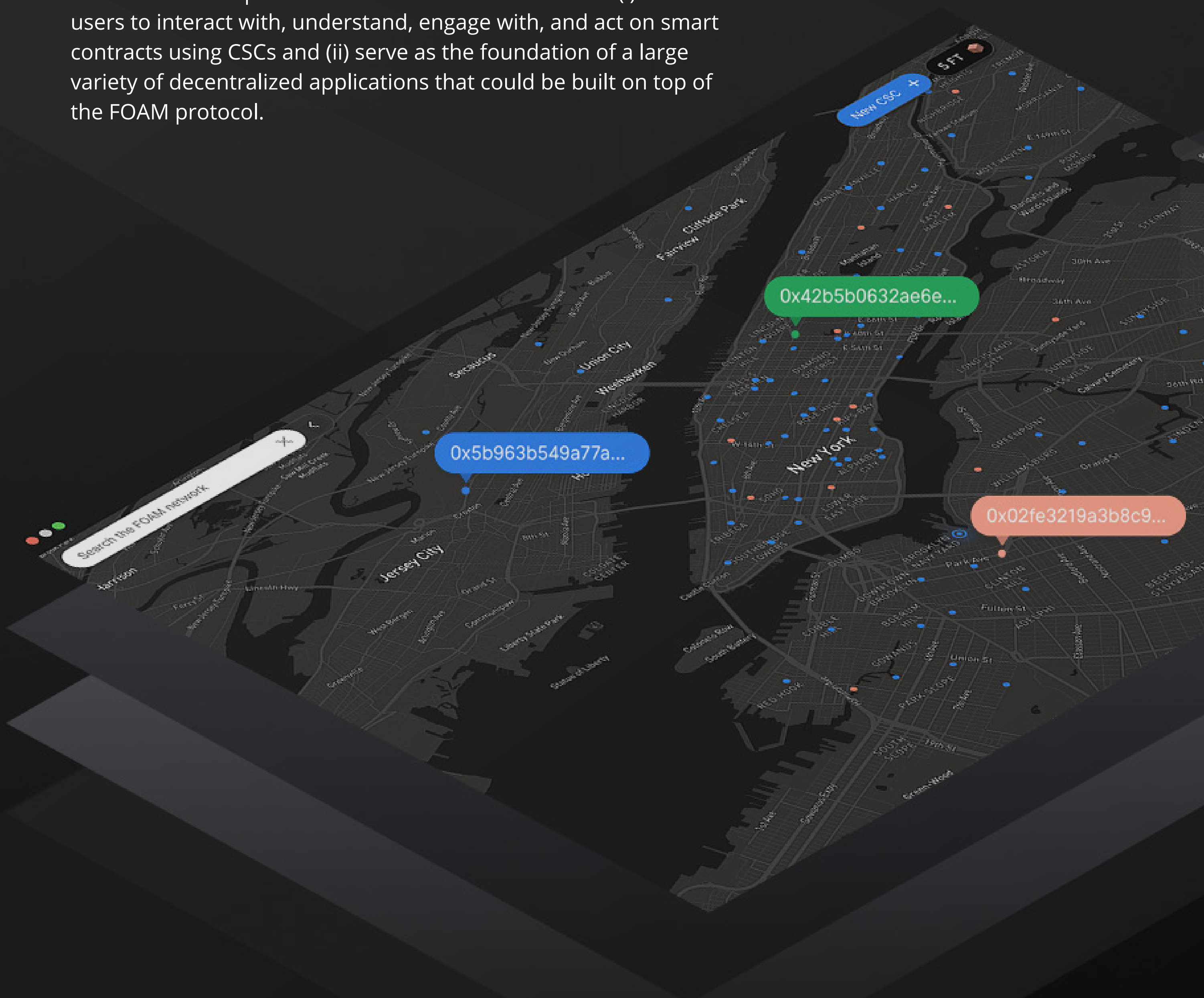
In conclusion, the CSC is effectively a human readable paired representation of a geohash and an Ethereum address, together with an immutable pairing of the two on the blockchain. It is possible to verify the CSC of a contract and its associated geohash. The protocol allows the CSC to be mapped back to the original geohash and address on-chain using the registry for any smart contract to utilize and reference.

The Spatial Index and Visualizer

A General Purpose Visual Blockchain Explorer

The Spatial Index and Visualizer (together, the “**SIV**”) can serve as the front-end interface for any decentralized application that needs to visualize smart contracts on a map.

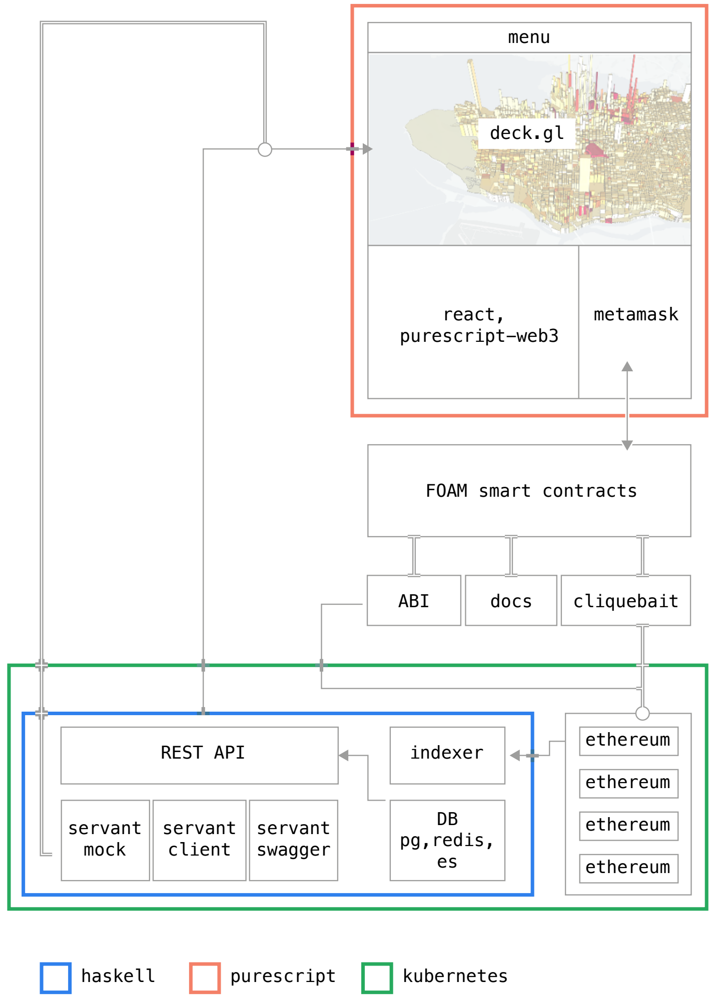
CSCs enable the blockchain to act as a reliable reference point of spatial-related smart contracts using CSCs and, by extension, allow spatial-related smart contracts using CSCs to be queried and displayed on the SIV. As an open-source web-app, the SIV is a visual user experience interface that is intended to (i) allow users to interact with, understand, engage with, and act on smart contracts using CSCs and (ii) serve as the foundation of a large variety of decentralized applications that could be built on top of the FOAM protocol.



Properties of the Spatial Index and Visualizer

The SIV is an explorer for geospatial assets on the Ethereum blockchain.
The full architecture of the application consists of:

1. A front-end interface application that is a visual explorer written in purescript coding language
2. Interactive visualization components that can be used to visualize network activity usage leveraging Mapbox as a base map.
3. Interactive elements with independent identity solutions Metamask and uPort for secure transaction signing and authentication.
4. The ability to interact with the Spatial Index through the common internet protocol Representational State Protocol (**REST**) application programming interface (**API**), allowing other services to use the Spatial Index.
5. The ability to perform queries on the indexed log of Ethereum address states produced by the Spatial Index of CSC referenced smart contracts with ElasticSearch functionality.



The REST API could utilize the data store of the spatial index for FOAM-based proof of location applications, and also act as an open API for other applications seeking access to data generated by CSC referenced smart contracts.

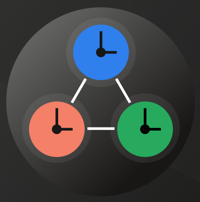
The SIV explorer displays the data from the REST API in meaningful ways, including by reference to Mapbox as a base map. In addition, the Visualizer allows the user to interact with SIV referenced smart contracts in an ordinary web browser via independent identity solutions Metamask or uPort.

Independent project Metamask allows users to access Ethereum decentralized applications (**dApps**) such as the Spatial Index right in their browser without running a full Ethereum node. MetaMask includes a secure identity vault, providing a user interface to manage your identities on different websites and sign blockchain transactions. The MetaMask add-on is in Chrome, Firefox, Opera, and the new Brave browser.

uPort is an independent self-sovereign identity system that is designed to allow people to own their identity, fully control the flow of their personal information, and authenticate themselves in various contexts — both on and off the blockchain. uPort is fully integrated into the SIV. The uPort integration means you can now use your uPort identity wallet to deploy CSC referenced smart contracts and sign transactions directly through the web application functionality of the SIV.

The main achievement and contribution of this design would be allowing users to interact with the Ethereum blockchain and deploy smart contracts with geospatial parameters from within a web browser. The architecture of the SIV forms a smooth loop of events, from web-app, to blockchain, to the Spatial Index indexing function, and back to the app. The protocol uses some of the most advanced and novel software available for the task, including the languages, the data processing units, and container-based cluster protocol that supports all of it.

The SIV functionality



1. Navigate CSCs:

Spatially-specific CSC-referenced smart contracts are displayed directly in the application. Users could apply filters to display CSCs according to each use-case.

2. Deploy a Smart Contract:

A CSC is deployed as a smart contract directly referenced by the Spatial Index by using Metamask or uPort.

3. Visualize new CSC-referencing smart contracts within the Spatial Index:

The Spatial Index protocol checks when a new CSC-referenced smart contract is deployed, and automatically visualize it in the SIV.

The general design of the SIV is to enable a vast number of potential applications across different markets, for example a user interface for a decentralized ride-sharing ecosystem that empowers drivers and passengers to transact without middlemen, a control panel for blockchain-based supply chain management, or a spatial bounty game that may have similar elements as Ingress, Pokemon Go and CryptoKitties. While these applications may not yet exist, the goal of CSCs and the SIV is to provide a necessary utility layer to enable their further development. Although the CSCs and the SIV do not require the FOAM Token to function, they exist as necessary underlying architecture to allow the use of the proof of location function, described further below.

Proof of Location

Verifiable and Secure Proof of Location

The goal of the Proof of Location solution is to provide the framework and infrastructure to support a decentralized, privacy preserving, highly accurate, censorship resistant alternative to GPS. FOAM is a shared and open protocol that is not rent seeking and does not charge or receive any centralized fees. Location is a fundamental infrastructure protocol needed to achieve the full vision of a decentralized 'web3' economy and can foster an ecosystem of applications built on top of a verified location standard.

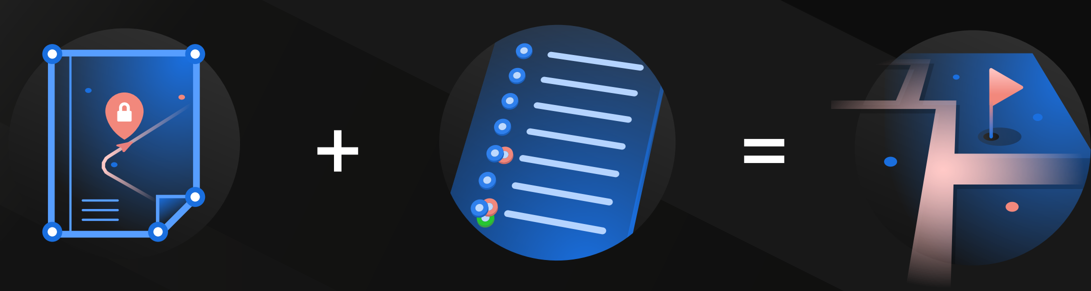
Proof of Location is the primary utility arising from use of the CSC and SIV elements discussed above. Proof of Location will inherently be an iterative process which involves the use of token curated registries by users to contribute, verify and determine Proofs of Location.

Properties of the Proof of Location Protocol

Token Curated Registries for Geographic Points of Interest

As outlined above, the CSC standard is a registry that enables the blockchain to act as a registry of spatial contracts and, by extension, allow spatial contracts to be queried and displayed on the Spatial Index Visualizer. Token Curated Registries (**TCRs**) are a crypto-economic model for curating human readable lists with intrinsic economic incentives for independent token holders to curate the list's contents. The content of the list is backed by staked FOAM Tokens and FOAM Token holders vote on additions to the list with the goal of raising the value of their token by producing a valuable list, as described in more detail below. The theory and thinking behind TCRs is somewhat comparable to private maps and locally curated points of interest — the contributors are incentivized to ensure a high-quality result, for economic or reputational reasons.

CSCs and TCRs together make a powerful combination for a new form of mapping and maintaining what are known as Points of Interest (**POI**). In this light, FOAM users can be the contextualized successors to the work of cartographers throughout history that maintained geographic data about everything from topography to dense urban streets. However, FOAM takes this history a step further by granting control over the registries of POI to locally-based markets and community forces, allowing the information provided to be validated by those who contribute to the relevant locality.



CSC TCR POI

Historically, maps were created and maintained by centralized entities, usually a government, and were sometimes slow to update and always prone to human error or deliberate censorship. Not until the recent boom of digital cartography have maps become meaningfully democratized. Maps have never been so readily and easily available to the public. However, one of the most valuable aspects of the map are the Points of Interest. In today's terms that translates to where are the stores, cafes, restaurants and malls, where a fleet of vehicles in a ride sharing program like Uber should be anticipating if demand is shifting or surging, or which traffic bottlenecks drivers should avoid on an app such as Waze.

POI data is notoriously closed and proprietary. Foursquare is a leader in this field, collecting data from user check-ins, however Google remains the ultimate leader, with a competitive "moat" around its innovative data-sets. It algorithmically generates "Areas of Interest" out of its own proprietary data sets. For Google, POI data is not collected but created out of Street View and Satellite View data which allows an unprecedented quality, coverage, and scale that is substantially ahead of any competitor.

The output of a TCR is a list/registry, and the result for any CSC is binary—it is either in or it is out. The list/registry is curated by FOAM Token holders that are incentivized to generate a valuable list of integrity, with the value of the registry ultimately being determined by how useful it is and if it acts as a good focal point of information about the world. However, whereas the concept of a TCR in the abstract is often thought of as subjective (i.e. participants may develop TCRs about inherently subjective lists/registries such as the best movies, beaches or whiskies), in the case of FOAM, the TCR is objective and location-based. The entity applying to be on the list is either physically there or not—there can be no subjectivity with respect to CSC candidates. As a result, a POI list curated by FOAM Token holders can serve as a social Proof of Location for smart contracts that represent fixed places. From a location point of view, for a business or any POI there could be great benefits in the form of foot traffic, customers and exposure for being listed on particular registries/maps that may develop. Of course notwithstanding the objectivity of location based TCRs generally, it is possible users may also deploy TCRs for subjective uses also, such as a list of the best coffee shops in a particular area.

The FOAM TCR has three kinds of actors: **Consumers** that want to utilize the list, **Candidates** that want to be on the list and **Cartographers** (i.e. FOAM Token holders) that curate the list. The crux of the incentive game is to include reputable information and exclude faulty information to ensure a reliable and useful TCR is maintained. This is done through staking tokens to the information on the list. Let's look at an example location TCR for FOAM:

1. Location Candidates submit a FOAM Token deposit in order to add a Point of Interest to the registry with a corresponding CSC.
2. In doing so, they have to wait out a challenge information to ensure a reliable and useful TCR is maintained. If honest and reputable, none of the Cartographers should dispute this Candidate and the POI will become part of the list after the completion of the challenge period. The deposit is then locked through the TCR smart contract, and the tokens are staked to that POI's listing.
3. During the challenge period, if another current Cartographer feels that this proposed POI will degrade the quality of that particular registry, they can issue a challenge, by submitting an equal amount of tokens to the proposed listing Candidate's deposit. This initiates a voting period among the Cartographers.
4. Because POI data is objective, voting Cartographers have the ability to verify the Candidate in person.

5. Cartographers then proceed to vote whether to include or deny this Point of Interest to the registry. Any current Cartographer can then vote, the result of which is based on the quorum of FOAM Tokens voting.
6. After the voting period, if the challenging Cartographer succeeds, the proposing Candidate's staked token deposit is distributed to the challenging Cartographer and the winning Cartographer voters as a reward for helping to curate the registry.
7. If the challenge is unsuccessful and the Candidate's proposal is affirmed by a majority of Cartographer voters, a percentage of the challenging Cartographer's deposit is forfeited to the Candidate whose Point of Interest was affirmed. In addition, a certain percentage of the losing challenging Cartographers' staked tokens, by reference to each losing voter's token proportion to all tokens staked for this particular challenge within the TCR, is transferred to the winning voting bloc, again by reference to each winning voter's token weight within the TCR. The FOAM TCR is interacted with through the SIV.

Cartographers will be able to vote and change the modular parameters of the FOAM TCR, such as the window of time in which a Cartographer can challenge a Candidate or in which Cartographers can cast their votes. Multiple TCRs could also be developed by different communities or users, allowing for potentially different registries of business types or maps dedicated to particular purposes.

Signaling

A further potential use of the FOAM Token by Cartographers is to stake their tokens to **Signal**. Signaling is a mechanism designed to allow Cartographers to incentivize the growth and geographic coverage of the FOAM network. To Signal, a Cartographer stakes FOAM Tokens to a Signaling smart contract by reference to a particular area. These staked tokens serve as indicators of demand, and are proportionate (i) the length of time staking (the earlier, the better), and (ii) the number of tokens staked (the less well-served areas, the better). In the context of the Dynamic Proof of Location utility discussed further below, these indicators are the weighted references that determine the spatial mining rewards.

Cartographers will Signal where location services are needed, and in doing so increase the eventual block reward (the FOAM Tokens received through the mining process described below) of that location. This incentive mechanism is to coordinate Cartographers, in a grass roots fashion, to operate the protocol and further incentivize Cartographers to potentially operate Dynamic Proof of Location Zones themselves. While the goal of the Signal function is to incentivize the growth of the FOAM network and the increased adoption of the dynamic Proof of Location functionality described further below, there is no guarantee that those incentives will work as intended or result in predictable outcomes. While the Signal smart contract is designed to develop and grow the network, it is always possible that other economic incentives and behaviors could disrupt or alter the expected operation of the Signal function in unforeseen ways, up to and including possible negative outcomes for FOAM Network adoption, participation and utility.

Dynamic Proof of Location

While the Proof of Location utility is currently achieved through the TCR process described above, it could be strengthened through the Signaling process and the strengthening of the network further through the process described here.

All Cartographers should be mindful that the FOAM Token exists to provide functionality with respect to the FOAM TCR only at launch, which is intended to provide Proof of Location functionality for static objects, and the Signal function. What follows is the potential outline of an expanded form of Proof of Location which is intended to supplement the TCR, potentially providing Proof of Location functionality to transitory things. It is described here for illustrative and descriptive purposes only and on a non-promissory basis. Dynamic Proof of Location's ultimate adoption would depend on a variety of factors, including FOAM user adoption, the organic community-driven expansion of the network and the requisite addition of radio hardware by, and at the expense of, individual FOAM users. As such, if or when it is adopted cannot be stated with any certainty. As described above, the Signal function is intended to assist in that development but there is no guarantee that it will achieve its goal, in whole or in part, or operate as intended.

However, FOAM hopes that the Cartographers and users will contribute the necessary individual work, resources, and effort themselves to contribute to the ongoing community-driven growth and supplement this important cartography project. With the addition and use of necessary radio hardware, as described in more detail below, Proof of Location could be expanded to further prove location status through a time synchronization protocol intended to ensure continuity of a distributed clock, whereby specialized hardware can synchronize nodes' clocks over radio to provide location services in a given area, called a **Zone** (the nodes providing such services being Verifiers and Anchors (collectively, the **operators**)). Just as GPS can determine location through the difference in time and distance of radio signals, time difference of arrival, with a high-precision clock signal, the FOAM network can use the relative geometry between beacons to compute a node's distance, thereby enabling a secure, spatially distributed location system. In that context, the FOAM token would be used as a form of protocol participation deposit for Zone operators, which is needed to enable operators to provide the necessary work of time synchronization to the network and serve as collateral that the rules of the protocol will be followed. If the rules of the protocol are not followed by the Zone operators, their license would be revoked by the FOAM protocol and their staked FOAM tokens forfeited to other Zone operators in accordance with the FOAM protocol. Zone operators are rewarded in new tokens for providing their work, in the form of time synchronization services, to the network.

Verifiers are computers that check Zones for fraud and compute location algorithms from the time data. Together the work provided by the Verifier and Zone allow them to mine triangulations. Their collective output result in data that can be computed for triangulation and in return for this process these actors are eligible for newly issued tokens from the FOAM protocol as a [reward for this output]. In return for a Zone operator providing this service, they may receive a fee from customers who wish to verify their location through the protocol. The denomination of this fee would depend on the preference of the Zone. Proof of Location can therefore provide consensus on whether an event or agent is verifiably at a certain point in time and space producing a digital authentication certificate that is fraud proof, called a **Presence Claim**.

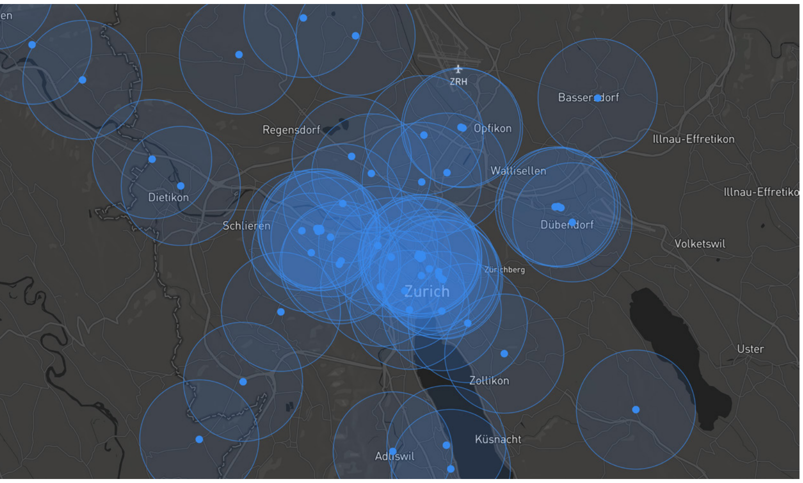
As discussed above, one use of the FOAM Token would be as the form of deposit to participate in the protocol correctly and contribute the necessary work, security and computation that enables time synchronization.

The staking of the token is needed on the Ethereum blockchain for the Zone operators to be granted access to the shared state machine of any given Zone, meaning each Zone is its own 'child' blockchain.

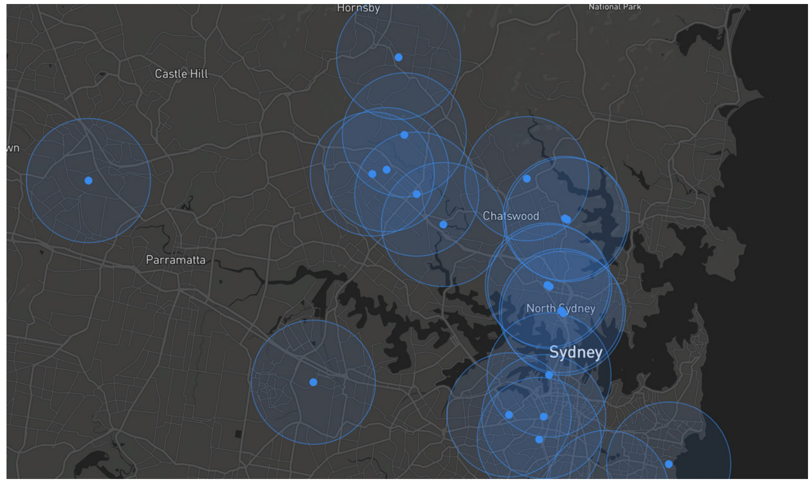
The FOAM Token further provides the framework and incentive for Zone operators to set up specialized hardware beacons to broadcast coverage, further participate in the protocol and develop an overlaying peer-to-peer network of radio beacons called **Zone Anchors**. Zone Anchors can arrive at consensus on whether something is located at a certain point in time and space based on these radio beacons. Anchors that are part of a Zone will share a state machine on the history of the time data logs of the Zone and vote on additions to the log with a blockchain consensus. A Zone operates as its own blockchain where the validators are the Zone Anchors, which need to stake tokens to be given the authority to participate. In addition to providing Zone operators with the ability to participate within a Zone, the token could also permit operators who choose to purchase the requisite hardware to offer location services via Zone Anchors, which would be similarly verified through the network-based consensus rules. Although any such upgrade would be dependent on the technological points discussed in the paragraphs below, from a network standpoint such upgrade could be achieved at a future date by voting/consensus mechanism within a particular FOAM TCR community that it would require such Zone verification from a certain point in time.

There are a number of radio technologies and techniques for localization/positioning systems that might be suitable for this task. While the Proof of Location protocol is hardware agnostic, the most promising is likely to be a form of radio technology called Low Power Wide Area Networks (**LPWAN**). LPWAN has potentially low throughput, but can offer the low power and longer battery life of bluetooth with the range of cellular while operating on the unlicensed radio spectrum, meaning no license would ordinarily be required. LoRa is a type of LPWAN particularly suited for a secure and decentralized network due to properties that make it difficult to detect and jam. It is permissionless, meaning anyone can install and maintain a node. Communities have emerged in major cities around LoRa open libraries and what is called The Things Network, creating a fruitful ground for future self-organized communities for Proof of Location.

Existing LoRa gateway operators can serve as the first FOAM Zone operators to offer location services and bootstrap the existing coverage though user participation.



The Things Network Zurich



The Things Network Sydney

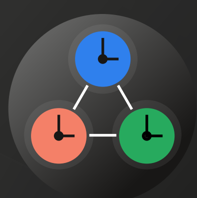
While this radio hardware and technology is available today, the FOAM token provides users with a fundamental economic incentive to purchase, install and maintain a beacon enabling them to better participate in, and provide work to, the network. With blockchain-based utility tokens, infrastructure can grow from the bottom up, without the need for central planning. Currently, there is no reliable way to calibrate the Dynamic Proof of Location without an initial commitment of Zone operators, and it is hoped that this potential spread of initial Zone operators can provide important calibration and improvements prior to the upgrade of the Proof of Location functionality. Bitcoin introduced the Proof of Work consensus mechanism which incentivizes an infrastructure of miners to use their computational power to make the network secure. With tokenized block rewards, Bitcoin demonstrated how to build decentralized infrastructure, offering people returns for joining and participating in the network. In other words, just as the growth of Bitcoin, Ethereum, and many other blockchains were assisted by crypto-economic incentives, so too is the FOAM protocol assisted by incentives to build out the hardware to provide a decentralized alternative to GPS. Similar to other blockchain mining, Zone operators on the FOAM protocol are in essence providing comparable work to Bitcoin miners.

Moreover, safety deposits held in smart contracts increase network resilience. With Ethereum's potential move to Proof of Stake consensus, the protocol can reward network participation and penalize malicious actors. In Proof of Stake blockchain protocols, participants commit a staked deposit of tokens to operate as a validator and obtain voting power. Stakers accrue a larger reward by participating correctly in the consensus protocol. A required security deposit is at the core of these incentive systems. If faulty behavior is detected by a node, the deposited tokens are destroyed and forfeited ('slashed'). FOAM uses crypto-economic incentives to grow a decentralized network of location-based services providers, employing staking and slashing to ensure location claims can be trusted. More specifically, Proof of Location utilizes token staking incentives to grow network coverage and utilize a verifier set for fraud proofs, and enforce protocol rules. Staked deposits allow for attributable byzantine behavior in the form of slashing conditions. The required staked deposit and risk of loss for faulty behavior is at the core of the incentive systems. If faulty behavior is detected, the staked tokens are destroyed and forfeited by the protocol.

Further, with smart contracts, participating Zone operators can enter into Service Level Agreements (**SLAs**) with particular projects, businesses or locations that require greater coverage and support. Zone operators can encourage commitment to these agreements with token deposits locked into a smart contract. An SLA might therefore enable autonomous service providers to maintain hardware nodes and extend coverage to offer services to particular projects, businesses or locations. Such potential SLAs are related to the Zones discussed above, and are not currently envisaged with respect to the existing utility of the FOAM TCR Proof of Location.

In order to ensure appropriate adoption, diffusion and growth of the FOAM network, all FOAM Token purchasers must prove their use of the FOAM Token upon receipt of their FOAM Tokens. Token holders can do this through either of the two initial utilities: (i) staking to a TCR, or (i) staking to the Signal smart contract on the Spatial Index. This requirement is intended to ensure that purchasers both understand and intend to contribute efforts as Cartographers in building out the FOAM Network. If purchasers fail to become Cartographers by proving their use, their FOAM Tokens will be incapable of transfer until such use is proven in accordance with this process.

Proof of Location Functionality



1. Trustless:

Byzantine fault tolerant clock synchronization.

2. Independent:

Does not rely on a centralized service such as GPS.

3. Open:

Anyone can utilize the network or offer utility services.

4. Accountable:

The economics are structured to ensure honest behavior and verified with fraud proofs.

5. Incentivized:

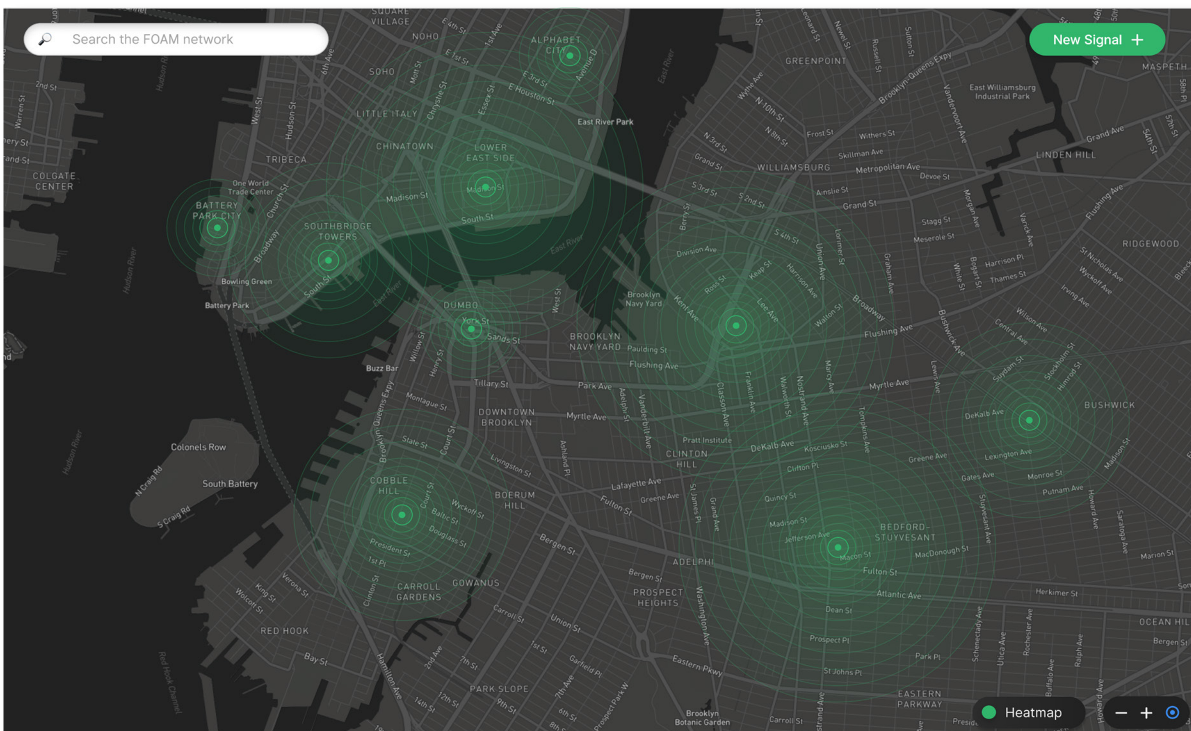
Service providers may be remunerated for extending localization and verification zones.

Crypto-economic incentives may further provide a means of developing decentralized infrastructure that is even more secure and encourages further network participation as further described above. Such hardware development is not guaranteed, may not develop and is not available at launch.

Block Rewards

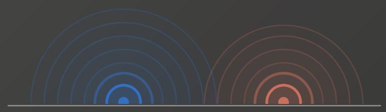
Zone Anchors and Zone Authorities are rewarded FOAM Token block rewards for setting up and maintaining Zones. This provides Zone Anchors and Zone Authorities with revenue in addition to any transaction fees they might be paid for validating location claims. Block rewards and the increase of a physical infrastructure will hopefully contribute to extending the geographical coverage of Proof of Location and its network effects. As discussed above, staking FOAM tokens allows a Zone operator to receive a share of transaction fees proportional to their stake. However, FOAM establishes a mechanism to incentivize the staking of tokens in a geographically diverse manner. This Signaling occurs on the Spatial Index, where users place indicators in areas where they need decentralized location-based services, which are then recognized within the token reward structure of the block rewards. FOAM uses general staking, proposing a spatial weighting for nodes that provide the security of the blockchain. Additionally, tokens in block rewards are spatially weighted by the signal. This further incentivizes the growth and dissipation of the network across a variety of users and locations.

Prior to the initiation of mining, participants will signal where location services are needed, and in doing so increase the eventual block reward of that location. This incentive mechanism is to coordinate contributors, in a grass roots fashion, to operating the protocol.



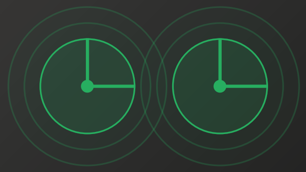
The Spatial Index Visualizer displaying Signals.

Dynamic Proof of Location anticipated to verify location claims in 7 steps:



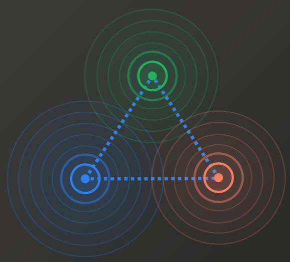
1. Zone Anchors and Zone Authorities

Radio beacons (Zone Anchors) and Radio gateways (Zone Authorities) are established and form a network to synchronize their internal clocks without the need for a trusted third party. With an encrypted and self-stabilizing time signal established, the network can determine spatial arrangements.



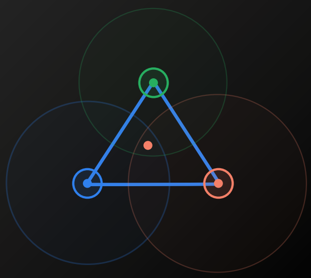
2. Clock Synchronization

Zone Anchors and Zone Authorities send messages until a consensus can be formed on the precise time. The timed difference of messages sent and received allows for location to be calculated and the geometry of the network to be determined.



3. Zone Formation

Once synchronized, Zone Authorities establish Zones and pledge to offer location services that are enforced by smart contract safety deposits.

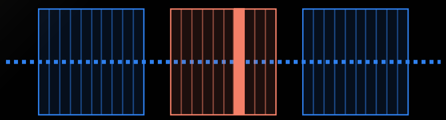


4. Triangulation

Zones can provide presence claims for customers in a competitive market for a transaction fee. This is done while Zones are resynchronizing clocks and publishing their time logs to a data store.

5. Verification

Agents that contribute computational power, called Verifiers, check the time logs of Zones for fraud.



6. Proof of Location

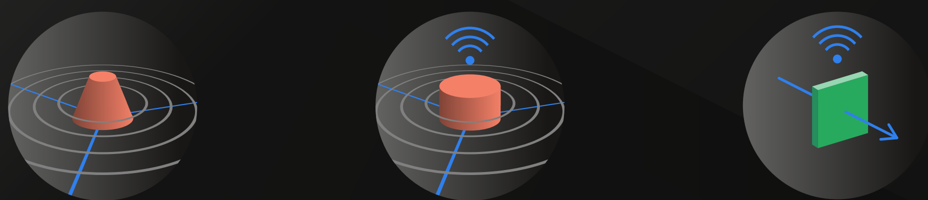
Verifiers send Fraud Proofs to the root chain (Ethereum Blockchain) and the Proof of Location certificates are getting created.

Note: these features *will not* be available at the time of sale, and are displayed for information purposes only. The availability of these features in the future will depend on the circumstances described in the Dynamic Proof of Location section of this document.

Participating in the FOAM Network as a Cartographer — A Summary:

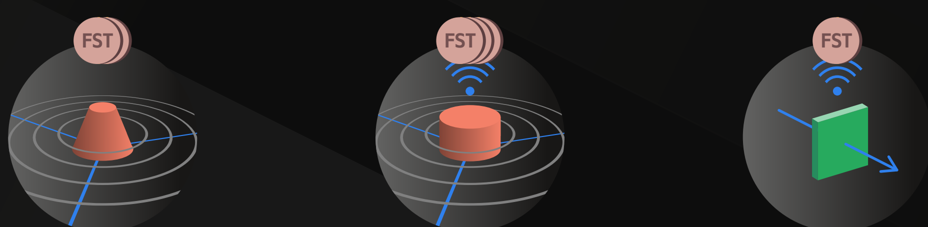
At launch, FOAM token holders can become Cartographers and can contribute to their locality and interests by curating, mapping and verifying the locations of static objects. As the FOAM network grows and Cartographers begin to fully explore and map the world, once the necessary technical upgrades are made, FOAM token holders may decide to contribute to the network as one of the entities below. In order to prepare their area for these upgrades, the Cartographers can also stake tokens in the Signaling process, to incentivize dynamic Proof of Location services to be offered in their area.

The FOAM protocol provides the technology, framework and incentives for service operators to set up hardware Zone Anchors, broadcast coverage, and earn block rewards. In the Proof of Location protocol there are three classes of nodes: Zone Authorities are full nodes, Zone Anchors are partial nodes, and Verifiers 'mine' triangulations, computing locations from time stamped data.



Zone Anchor Zone Authority Verifier

The FOAM Token is the native software utility token of the FOAM network. To begin offering location-based services as a Zone Anchor or Zone Authority, or to offer computing power as a Verifier, tokens must be staked and will be held as safety deposit over a limited time. This staking ensures that fraudulent behavior which violates protocol rules can be penalized.



Zone Anchor Zone Authority Verifier

Potential Applications of Dynamic Proof of Location

Proof of Location is intended to ultimately play a key role in our decentralized future, opening new marketplaces enabled by privacy-preserving location data. FOAM hopes to foster an ecosystem of applications in an array of verticals. Supply chain management, autonomous vehicle and ride sharing, gaming, and the Internet of Things (IoT) all stand to potentially benefit immensely from secure verified location data that can be used to prevent fraud. However, as noted above, these potential efficiencies are dependent on the significant contingencies outlined in this document and should not be read as a reflection of current FOAM Token utility.

Technical Whitepaper

View our white paper for an in-depth technical explanation of proof of location. Please note that information contained in the whitepaper or blog may have been superseded and/or altered since the time of publication. Such information is provided for informational purposes only, may not reflect the utility or functionality of the FOAM token at launch, and should not be relied upon as purchasing or any other form of advice under any circumstances.

https://github.com/f-o-a-m/public-research

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