



The Secure Ledger of Things

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Abstract

Atonomi provides a security protocol and infrastructure to enable billions of IoT devices to have trusted interoperability for data and commerce.

The key innovation of the Atonomi protocol is to root the identity and reputation of devices on a blockchain-based immutable ledger. Atonomi accomplishes this by building and facilitating an ecosystem of participants designed to maintain decentralized consensus for device identity and reputation on the Atonomi Network. Combining on-chain and off-chain resources, and built on Ethereum technology, Atonomi's architecture is extendible by developers across IoT verticals to help secure the vast realm of IoT devices ranging from healthcare and home automation systems, to smart-city infrastructure, to industrial sensors and controllers.

This is required because vertically focused IoT companies are building diverse new applications for both controlled and autonomous device-to-device interactions, but the attack surface represented by billions of IoT devices—most of which are now unprotected or poorly protected—could enable hackers to disrupt the services that are expected to control many aspects of our lives in the coming years.

The Atonomi Security Protocol provides the following fundamental contributions to enable interoperability and secure exchange of data and commerce at scale:

- a. Trusted immutable identity of devices through its device identity registration service
- b. Reputation protocol to incent and enable Atonomi and distributed third-party auditors to build systems to detect and remove bad device actors
- c. Tokenized economy for the registration and activation of devices, and facilitation of a reputation-scoring ecosystem among third-party auditors, and for transaction validation services
- d. Fully extensible architecture designed to be built on top of by vertical IoT applications for security

Atonomi leverages established technology of its parent company, Seattle-based CENTRI Technology. CENTRI is a leader in providing IoT data security solutions, with partnerships with Arm, Flex, and STMicro. CENTRI's security technology protects data for IoT devices and provides a solid foundation for Atonomi's security protocol.

The Atonomi Network is integral to securing the IoT and its world of applications. For example, homeowners could register smart home devices with the Atonomi Network to validate devices on the premises and help eliminate the risk of hackers accessing personal information. Within industrial IoT,

the Atonomi Network can help protect against hackers gaining control of the sensors, controllers, and other devices that regulate the operation of essential infrastructure, such as hydroelectric dams and utility grids. To unleash the power of IoT, cybersecurity is required.

Table of Contents

1.0	Introduction	6
1.1	The Need for Device Identity & Reputation	7
1.2	The Right Technology	7
1.3	How Atonomi Differs from Other Proposed Solutions	8
1.4	Building Upon Years of CENTRI's IoT Security Experience	8
2.0	Proposing a new IoT Ecosystem with Trust at the Core	9
2.1	Service to Establish Identity	9
2.2	Protocol and System to Manage Reputation	10
2.3	Token to Facilitate Services in the Atonomi Network	10
2.4	Extensible Architecture to be Built Upon	11
3.0	The Atonomi Network - Technical	12
3.1	Registration	12
3.1.1	Overview	12
3.1.2	Device Identity	12
3.1.3	Manufacturer Interface	13
3.1.4	Registration Smart Contract	14
3.2	Activation	14
3.2.1	Overview	14
3.2.2	Device SDK	14
3.2.3	Activation GUI	14
3.2.4	Activation Service	14
3.2.5	Activation Smart Contract	15
3.3	Validation	16
3.3.1	Overview	16
3.3.2	Device SDK	16
3.3.3	Validation Service	16
3.3.4	Reputation Database	16
3.3.5	Validation Database	16
3.4	Reputation	17
3.4.1	Overview	17
3.4.2	Device SDK	18

3.4.3 Reputation Report Database	18
3.4.4 Reputation Service	18
3.4.5 Reputation Smart Contract	18
3.4.6 Reputation Auditor	18
3.5 The Atonomi Token	20
3.6 Additional Elements	20
3.6.1 Attributes Registration Service	20
3.6.2 Transaction Service Creation and Maintenance Services	20
3.6.3 Device Ownership Transfer Service	20
3.6.4 Reputation Caching and Lookup Services	21
3.6.5 Transaction Validation and Facilitation Services	21
3.7 Scalability	21
4.0 Faster and More Secure Technology	22
4.1 Fast and Secure Authentication	22
4.2 Small Footprint	22
4.3 Device Agnostic	22
4.4 Secure Data	22
4.5 Intellectual Property and Patents	23
5.0 The Atonomi Secure IoT Ecosystem	23
6.0 Atonomi Use Cases	24
6.1 Early IoT adopters in Healthcare	25
6.2 Innovation in Industrial IoT, Smart Cities, and Home Devices	25
6.3 Supporting Diverse Use Cases	25
7.0 Atonomi Token	26
7.1 Tokenized Identity & Reputation	26
7.2 Commercial Transactions and Data Exchange	26
7.3 Processing Commercial Transactions	26
7.4 Ecosystem Partners and Innovation	27
8.0 Leadership	27

Table of Illustrations

Figure 1. Atonomi Token	11
Figure 2. Atonomi Registration	13
Figure 3. Atonomi Activation	15
Figure 4. Atonomi Validation	17
Figure 5. Atonomi Reputation	18
Figure 6. Transaction Flow	21
Figure 7. End-to-End Security Protocol	24

1.0 Introduction

“Secure interoperability is essential for the Internet of Things to reach its full potential. The Atonomi blockchain technology vision for a global service that enables secure transactions and commerce through device identity and reputation is something Arm is excited to see realized.”

- Ian Ferguson, VP Ecosystem Development, IoT Services Group, Arm

The Atonomi Network is designed to help secure the Internet of Things.

That is, there are billions of IoT devices already deployed today and billions more coming. Gartner, the U.S. research and advisory firm, estimates there are already some 8.4 billion IoT devices deployed in the world as of 2017, up 31 percent from 2016, and further projects the number of IoT devices to increase to 20.4 billion by 2020,¹ with 5 million new IoT devices deployed each *day* in 2016.² Billions of connected devices will propagate between a quadrillion and sextillion of transactions of data and/or commerce over time.

Adding to the scale of IoT is the emergence of autonomous device-to-device commercial transactions and microtransactions, which are expected to play a growing role in how our world functions. As IoT becomes more robust, so will the interactions between devices, creating the need for devices to securely and autonomously conduct transactions—such as devices in the field negotiating for and purchasing (using digital tokens) bandwidth, electric power, and other resources to most efficiently function.

As the growth in devices and their associated interactions become foundational to our lives, it will present increasing and substantial security threats. The global IoT represents a huge attack surface for criminals and other bad actors, and IoT devices often exist outside the protective barriers of corporate firewalls and lack the computing and storage resources to host traditional security software. The need for security further intensifies as more and more IoT devices are given the ability to autonomously engage in financial transactions, as hackers and other bad actors could be attracted to the idea of devices having access to wallets and look for ways to digitally steal funds.

These potential security threats are a concern for everyone from homeowners to businesses, to municipal, state, federal, and international government agencies. For instance, IoT devices have already been hacked and harnessed for denial-of-services attacks, including the 2010 Stuxnet attack on an Iranian nuclear facility, and the 2016 Mirai botnet attack that disrupted U.S. Internet traffic. IoT-based attacks have also targeted Netflix, Twitter, the BBC, and other organizations, including a university that suffered a DDOS attack launched through its vending machines, smart light bulbs, and other campus IoT devices.³

¹ <https://www.gartner.com/newsroom/id/3598917>

² <https://www.gartner.com/newsroom/id/3165317>

³ <https://www.csoononline.com/article/3168763/security/university-attacked-by-its-own-vending-machines-smart-light-bulbs-and-5-000-iot-devices.html>

Gartner placed security at the top of its list of the top 10 IoT technologies for 2017 and 2018: “The IoT introduces a wide range of new security risks and challenges to the IoT devices themselves, their platforms and operating systems, their communications, and even the systems to which they're connected. IoT security could be complicated by the fact that many ‘things’ use simple processors and operating systems that may not support sophisticated security approaches.”⁴

1.1 The Need for Device Identity & Reputation

The ability to establish IoT device identity and reputation is essential to enable the secure interoperability between devices without the need for human intervention. Such a service could prevent unintended consequences from hackers attempting to disrupt critical systems or benefit economically from actions that have become common in traditional computer networks.

Immutable device identity, much like our own fingerprints, can be obtained from the device through a function commonly referred to as root-of-trust, using either hardware or crypto certificates. Once the device identity is established, it can be written to the blockchain as a permanent record.

Device reputation would evolve over the lifetime of the device, much like personal credit scores. The device’s dynamic reputation can also be written on the blockchain for public review. This provides for both a method to establish risk rating for the device and, in the event the device is compromised by hackers, the reputation could be adjusted accordingly.

Validating device identity and managing reputation provides a foundation for securing the IoT as diverse application developers build on top of the Atonomi Security Protocol.

1.2 The Right Technology

Blockchain uniquely solves for fundamental vulnerabilities in data security, particularly focused on central authorities for data storage and access control rights, by bringing a decentralized architecture and consensus security protocol to the IoT space. As such, the Atonomi Network is able to establish an immutable digital identity for every device on its network using a decentralized architecture and consensus mechanism. In addition to a trusted device identity, blockchain also enables secure and immutable management of a device’s reputation throughout its life. Moreover, as more devices begin to use the Atonomi Network for secure, trusted interoperability, network effects attract additional devices enabling the machine-to-machine economy to flourish. Further, Atonomi envisions a world where blockchain technology allows humans to confidently govern autonomous devices and smart contracts secured through identity and reputation.

The ability of blockchain to scale to meet the transactional demands in the IoT space is an area in which Atonomi is keenly focused. Our architecture combines on-chain and off-chain resources to enable IoT to operate at scale. Further, as part of the Ethereum community, Atonomi intends to support, and to encourage other members of the peer-to-peer Atonomi Network to support and adopt, scaling solutions as they become necessary for the health of the Atonomi Network such as Plasma, Raiden, Sharding, and Swarm, as well as alternative solutions currently in development.

⁴ <https://www.gartner.com/newsroom/id/3221818>

1.3 How Atonomi Differs from Other Proposed Solutions

While the need for IoT security has triggered increased development efforts, other proposed IoT solutions are incomplete or based on poor security designs. For example, many proposed solutions ignore blockchain, thereby lacking immutability while representing a centralized single point of failure. While others using blockchain, have a limited and specific application-based focus, and lack interoperability, extensibility, and the need for establishing immutable identity and reputation tracking.

Atonomi's solution provides the following:

- **Low-level protocol for secure IoT.** Atonomi enables secure transactions between IoT devices through our blockchain-based Identity Registry, which establishes root-of-trust using encrypted whitelist data from participating OEMs/ODMs providing unique device identity and a cryptographic key for each device to be validated onto the Atonomi Network. Atonomi uses the Ethereum blockchain as part of our decentralized solution. Others generally don't address the critical element of security nor leverage the immutability of blockchain technology.
- **Trust and Reputation.** Trust and reputation are essential for autonomous devices to engage in transaction of data and value, and are part of the Atonomi Network design, including our Reputation Tracking service. Reputation tracking allows for automated detection of, and response to, rogue or compromised devices. Other proposed solutions lack the capability of identifying and responding to untrusted devices, something that the Atonomi Network design addresses. Also, others leave the critical elements of trust and reputation to be handled by third parties, or simply omit them in their solutions.
- **Existing IoT Security Market Leadership.** IoT devices typically have limited computing, storage, power, and bandwidth resources. Atonomi's parent company CENTRI has pioneered the precision coding and engineering required to provide security solutions—with a footprint measured in kilobytes, not megabytes—for deployment in even the most resource-constrained devices. This past experience is being integrated in the Atonomi Network, which accommodates the fact that autonomous devices, through multiple unique IoT stakeholders will need to negotiate new relationships, negotiate data structures, and interact. In contrast, some IoT solutions require participating devices to perform computationally complex peer-to-peer functions or simply require too large a footprint to be useful across any but the more powerful IoT devices.

1.4 Building Upon Years of CENTRI's IoT Security Experience

CENTRI Technology (www.centritechnology.com), the parent company of Atonomi, was formed as a technology transfer out of the University of Mississippi to address the growing cybersecurity need for data protection and optimization. CENTRI has been recognized as a leading provider of data

security for the Internet of Things by technology research firms Frost & Sullivan⁵, and Gartner Research.⁶

CENTRI's patented security technology is being integrated into the full Atonomi Embedded SDK to enable its solution to uniquely operate at the high speed required by IoT. As a result, the Atonomi product has a unique and competitive technical advantage over others that may offer an alternative IoT security platform. The technologies developed by CENTRI are protected by 10 issued patents and an extensive patent portfolio roadmap. Two of the technologies integrated into the Atonomi services layer are:

1. Secure Communication Services—a lightweight communications protocol able to create a secure session in 3 milliseconds on average
2. Multi-layer crypto key management—a scalable crypto key management methodology that enables decentralization of encrypted data without centralized key management

These technologies and others developed by CENTRI provide Atonomi with advanced data security capabilities to protect decentralized data and enable the scale and transaction speeds necessary for IoT.

CENTRI's data security products have been validated by leading technology companies, including: Arm, Flex, and STMicro. This track record demonstrates that CENTRI's data security technology, as incorporated in the Atonomi Network, could be a powerful and effective technology for protecting the data of many IoT devices.

2.0 Proposing a new IoT Ecosystem with Trust at the Core

“Connected devices that think, transact and exchange sensitive and confidential data are the next evolution of IoT. There are a few impediments that must be overcome prior to the full utilization of this hugely disruptive technology. Initiatives like Atonomi which are marrying essential concepts of trust, identity, autonomy and security show great promise, and I look forward to using their platform.”

- Gary Conktight, Chairman, CEO and Co-founder, physIQ

2.1 Service to Establish Identity

Trusted identity provides a level of protection necessary for IoT devices to exchange information, enable actions and buy and sell products and services. IoT device manufacturers and solution providers have a vested interest in securing the products they sell. The starting point for the root-of-trust begins with the device manufacturer. New manufacturers in the Atonomi Network are screened by existing members of the network and then provided with a unique manufacturer identifier used when registering devices submitted to the network. This screening process is used to assess their cybersecurity best practices and assign a default reputation score to the manufacturer and their devices. The process of qualifying manufacturers and assigning scores to their devices helps ensure

⁵ <https://ww2.frost.com/news/press-releases/centri-earns-frost-sullivans-entrepreneurial-company-year-recognition-its-internet-things-security-solutions/>

⁶ <https://www.prnewswire.com/news-releases/centri-technology-named-to-gartners-2013-list-for-cool-vendors-in-communications-service-provider-operational-and-business-infrastructure-207180691.html>

the integrity of the network. This is an essential step to preventing rogue and hacked devices from entering the network.

Trusted manufacturers submit their list of devices, including unique device ID and cryptographic public key, to the Atonomi whitelist which is written to the Ethereum blockchain, and referenced later during device activation. Identity Registration (covered in section 3.1) is the Atonomi consensus service that validates the integrity of the whitelist. Select manufacturers of the Atonomi Network will run an instance of a limited number of Identity Registry servers. As the Atonomi Network expands, the Identity Registry servers will publish to secondary Identity Registry servers. Once registered, the device is known and trusted by the Atonomi Network and now ready for the device owner to activate the device when placed in service.

2.2 Protocol and System to Manage Reputation

Once device identity is established, the reputation of devices must be managed in order for secure interoperability to exist. A device's reputation consists of its unique behavioral signature representing varying degrees of security, commercial, and service quality measurements as an example. The Atonomi Network enables registered devices to validate a device's reputation stored on the blockchain to establish trust before exchanging data or engaging in commerce.

Within a marketplace, there will be a provider and requester (of information/data and/or services). The device requesting services will be able to submit a request to the marketplace and the device providing the service will respond to the request. If the devices have a reputation score that verifies them as known trusted per the reputation auditors and the device manufacturers, the transaction can proceed. If the authorization for transaction has expired, then the devices can initiate another request for validation of the peer device from the Atonomi Network.

Atonomi's reputation protocol is a key enabler of a future consisting of trusted devices securely interacting in an autonomous manner. If a device begins to operate outside of predetermined parameters, auditors write low reputation scores to the device reputation data store and other devices can refuse interactions. Conversely, if an autonomous device has developed a positive reputation for effectively servicing others, the reputable device may attract more business as a service provider and might be able to increase its pricing for service. Reputation data will be collected, stored and managed by a distributed network of auditors. Auditors are paid through fees with Atonomi Tokens, to track device behavior on the Atonomi Network in order to score the reputation of each device, analogous to a FICO score but with the parameters for the machine economy. Scores are vectors with both magnitude and direction, similar to how FICO scores with a number (e.g., 740) and a direction (credit worthiness).

2.3 Token to Facilitate Services in the Atonomi Network

Atonomi is introducing the Atonomi Token for participants of the decentralized ecosystem to transact with each other. The Atonomi Token is used by the Atonomi Network for device registration, activation, reputation management and commerce transactions. Key participants such as OEM/device manufacturers, distributors, device owners and auditors are anticipated to seek Atonomi Tokens in exchange for their participation in the Atonomi Network.

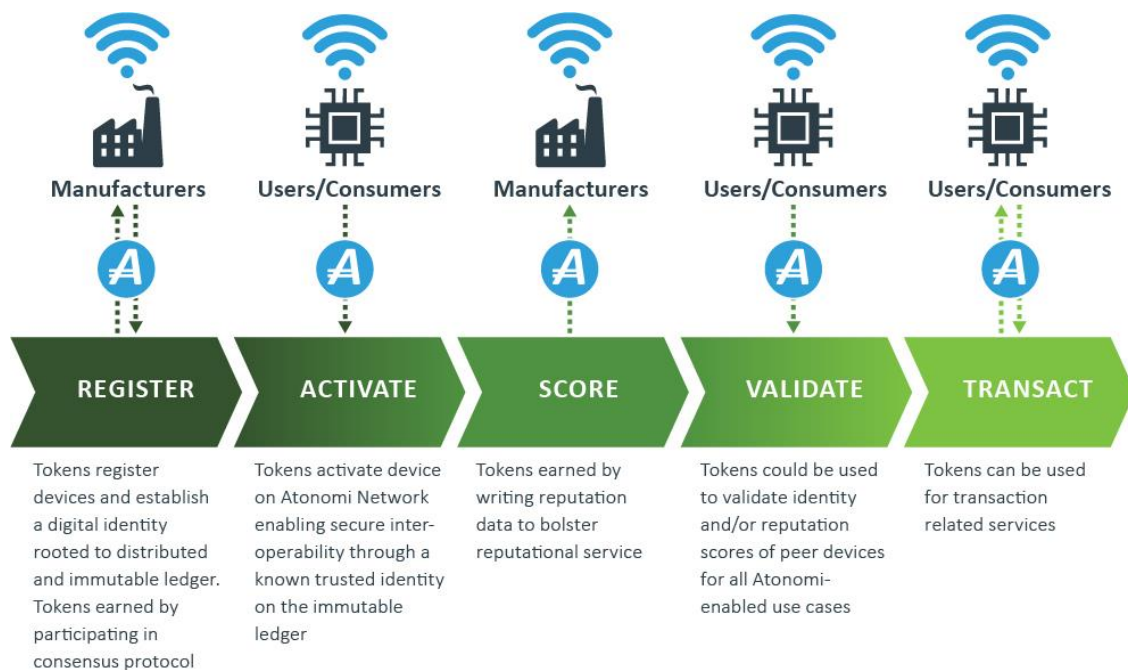


Figure 1. Atonomi Token.

The Atonomi Network relies on the Atonomi Token to facilitate registration, activation, reputation, validation and transaction related services, as described in the figure above.

2.4 Extensible Architecture to be Built Upon

The Atonomi Network has been designed for others to build upon and extend the services to meet the additional needs of new and existing market segments. The security protocol and infrastructure of the Atonomi Network provides the essential identity and reputation security to enable third-party services with device trust and reputation. The Identity Registry can be integrated into services such as healthcare, industrial IoT, and home automation to enable devices from different manufacturers to interoperate without the complexity of custom API development or the security risks associated with open communications between unknown devices.

A third-party service provider could extend their solution by using the Atonomi Network to validate the device identity and reputation before a transaction occurs. The devices in the transaction, once validated, could save specific transaction and metadata plus Atonomi identity and reputation data within their private database or submit the transaction to another third-party public blockchain. These transactions create an immutable record between trusted devices that provide a level of certainty not possible before. Getting security right has proven to be difficult for companies and experts focused on cybersecurity. Through the extensible architecture of Atonomi, non-security experts can build upon a network with the assurance of device identity and reputation.

3.0 The Atonomi Network - Technical

The Atonomi Network is designed to facilitate manufacturers in the registration of devices with immutable, blockchain-based identity; enable users to activate registered devices, provide a mechanism for one Atonomi-enabled device to validate the blockchain-based identity of another participating device, and to assign and track device reputation. At the heart of all of these functions is the compact security code of the Atonomi Embedded SDK.

The Atonomi Network's use of the public Ethereum blockchain, and our ability to incorporate side chain and other technology, is intended to ensure the permanence of Atonomi functionality, providing security for IoT devices into the foreseeable future. The Atonomi Network includes the Atonomi Token, which is a utility token used to activate devices onto the Atonomi Network and can also be used for secure device-to-device commercial transactions.

Basic elements of the Atonomi Network architecture include:

- Registration
- Activation
- Validation
- Reputation
- Atonomi Token

3.1 Registration

3.1.1 Overview

The Atonomi Identity Registration functionality provides Atonomi with the ability to add manufacturers to its trusted network and register them to the Ethereum blockchain. Through the Registration functionality those trusted manufacturers can then register their devices to the Atonomi device whitelist, again recorded via the Ethereum blockchain. The Registration functionality is driven by 4 main elements/components; Device Identity, Registration Service, Manufacturer Interface, Registration Smart Contract.

3.1.2 Device Identity

The device identity will be created during the device development or manufacturing process. This is critical as the device developer or manufacturer will register the device and its unique ID with the Atonomi whitelist, which will later be referenced when the user activates the device to the Atonomi Identity Registry Network. The IRN requires use of a unique ID for each device, combined with the public key of an Elliptic Curve public/private key pair.

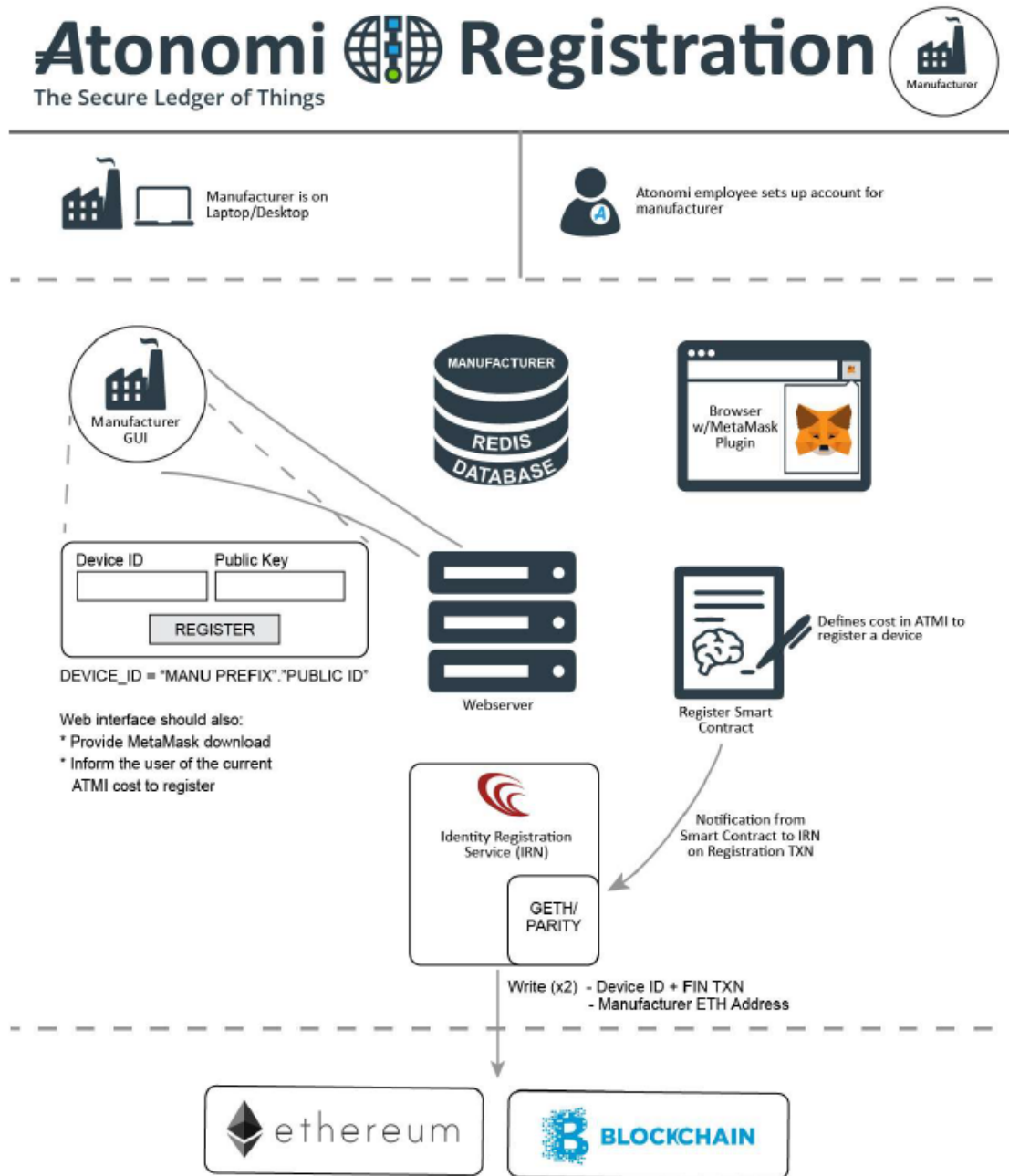


Figure 2. Atonomi Registration.

3.1.3 Manufacturer Interface

The device manufacturer interface is a graphical interface into the Identity Registration Service that device manufacturers use to register their devices with Atonomi before those devices enter the marketplace. This interface will be access controlled such that only manufacturers that have joined the Atonomi Network will have credentials. The manufacturer interface will have an Atonomi

administration component through which Atonomi administrators can set up accounts for new member manufacturers.

3.1.4 Registration Smart Contract

The Registration function of the Atonomi Smart Contract governs the writing of a new manufacturer member and its Ethereum address to the blockchain during manufacturer setup. It also governs the writing of new device IDs to the blockchain when the manufacturer adds new devices to the whitelist via the interface. It also facilitates the payment in ATMI for the registration of devices.

3.2 Activation

3.2.1 Overview

The Atonomi activation functionality (Activation) occurs after the Atonomi enabled device has been sold to an end user. The end user will receive activation instructions that send them to a web portal. They will enter a device identifier (provided in the instructions) and pay for the activation in ATMI via MetaMask. Devices that have been Atonomi enabled via the Atonomi Embedded SDK will contact the Activation Service upon first production boot. Devices will submit their signed device identifier. The manufacturer or developer of the device will have pre-registered that device's identity via the manufacturer GUI. Assuming the Registration Service of the IRN finds a match to the device's identity in its white-list, its signature is verified, and the activation payment cleared, the device will become activated within the Atonomi Network.

3.2.2 Device SDK

For the purposes of Activation the Atonomi Embedded SDK will have one device activation method. The intent will be that the device manufacturer 'hooks' into this method upon first boot up of the device. The method will then autonomously (without end user interaction) sign its device identifier with its own private key and the Atonomi Activation service public key and submit it to the Activation service for verification.

3.2.3 Activation GUI

The instructions the device owner receives will include a URL for a device activation portal and the public device ID for the device. The portal will be a simple web page, backed by the MetaMask plugin that will take in the device ID and when the Activate 'button' is pressed invoke MetaMask to handle the activation transaction.

3.2.4 Activation Service

The Atonomi Identity Activation Service (IAS) is a primary component, that when globally distributed, becomes part of the central hub of the Atonomi Identity Registry Network. The IAS is a cloud-based, globally accessible, highly available, high-volume service that provides the second step in the Atonomi process. The Activation service provides a couple of key functions to the overall Activation functionality; it provides a device interface that newly booted devices communicate with to finalize the Activation process and it includes a module (Parity) for writing the device activation to the blockchain.

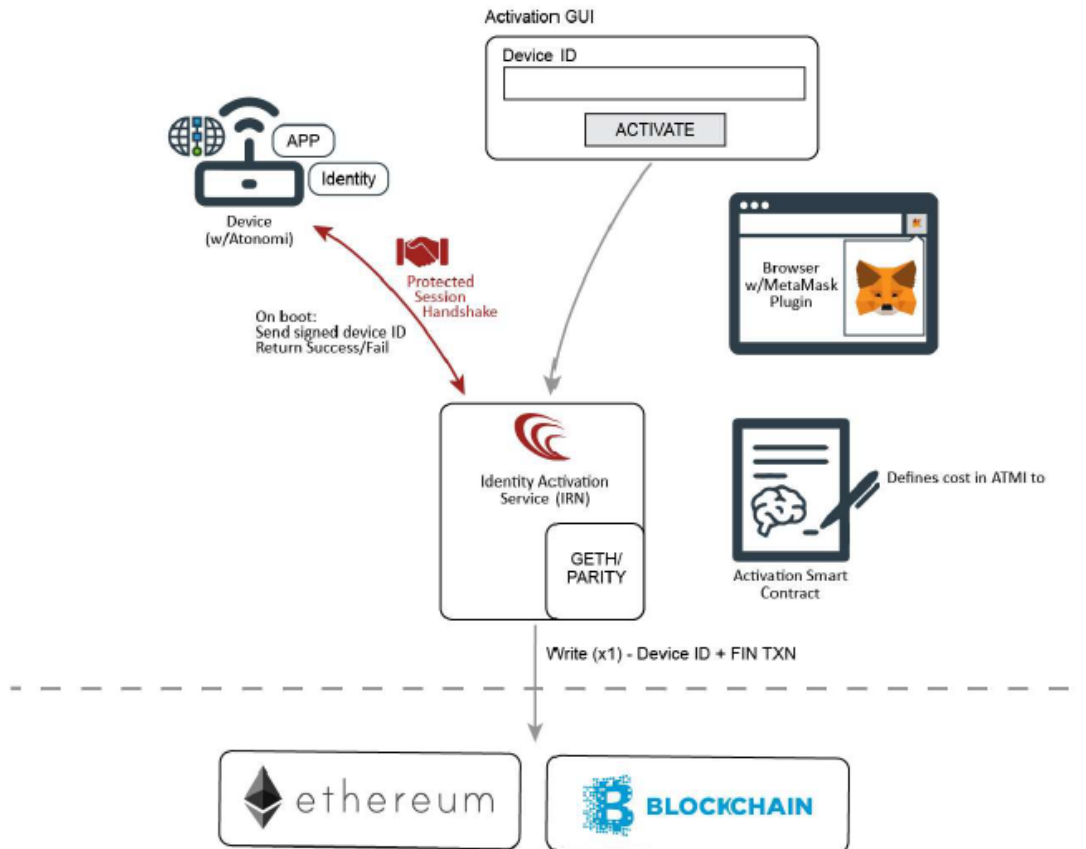


Figure 3. Atonomi Activation.

3.2.5 Activation Smart Contract

The Activation function of the Atonomi Smart Contract governs the writing of newly activated device IDs to the blockchain when the device owner boots the device and activates it via the interface. It also facilitates the payment in ATMI for the activation of devices.

3.3 Validation

3.3.1 Overview

Devices that have been Atonomi enabled via the Atonomi Embedded SDK and that have successfully registered and activated on the Atonomi network can begin to utilize the Atonomi validation functionality (Validation). Devices will exchange their signed device identifier with other devices that they want to transact with. Each device can then call the Atonomi Validation service, pass in its counterpart's signed device identifier and receive back an indicator of whether or not the device is an Atonomi network 'member' or not. In the event that the other device is a member of the Atonomi Network, the Atonomi Validation service will also send back the current reputation for that device.

3.3.2 Device SDK

For the purposes of Validation the Embedded SDK will have two additional methods for validating another device's identity. The first method will involve producing a CENTRI-protected sessions handshake package to be sent to another device for Validation. The second method will involve taking in a signed device identity (from another device via protected sessions handshake) and submitting it to the Validation service to be validated. The latter method will return a reputation score if the other device is valid.

3.3.3 Validation Service

The Atonomi Validation service is a primary component, that when globally distributed, becomes part of the central hub of the Atonomi Identity Registry Network (IRN). The Validation service is a cloud-based, highly available, high-volume service that essentially provides the third step in the Atonomi process. The Validation service provides a key function to the overall Validation functionality; it provides a device interface that devices communicate with to validate another device and it includes a module (Parity) for reading the device identity from the blockchain as validation that it has registered/activated on the Atonomi network.

3.3.4 Reputation Database

The reputation data for the Atonomi Network will be stored in a Redis database. For the purposes of device validation the Redis database will hold the following information per device: device identifier, device public key, reputation score.

3.3.5 Validation Database

A 'ledger' of validation transactions will be maintained for future reference during the reputation recording process. Each mutual validation (two devices validating each other) will result in two records in this database.

Atonomi Validation

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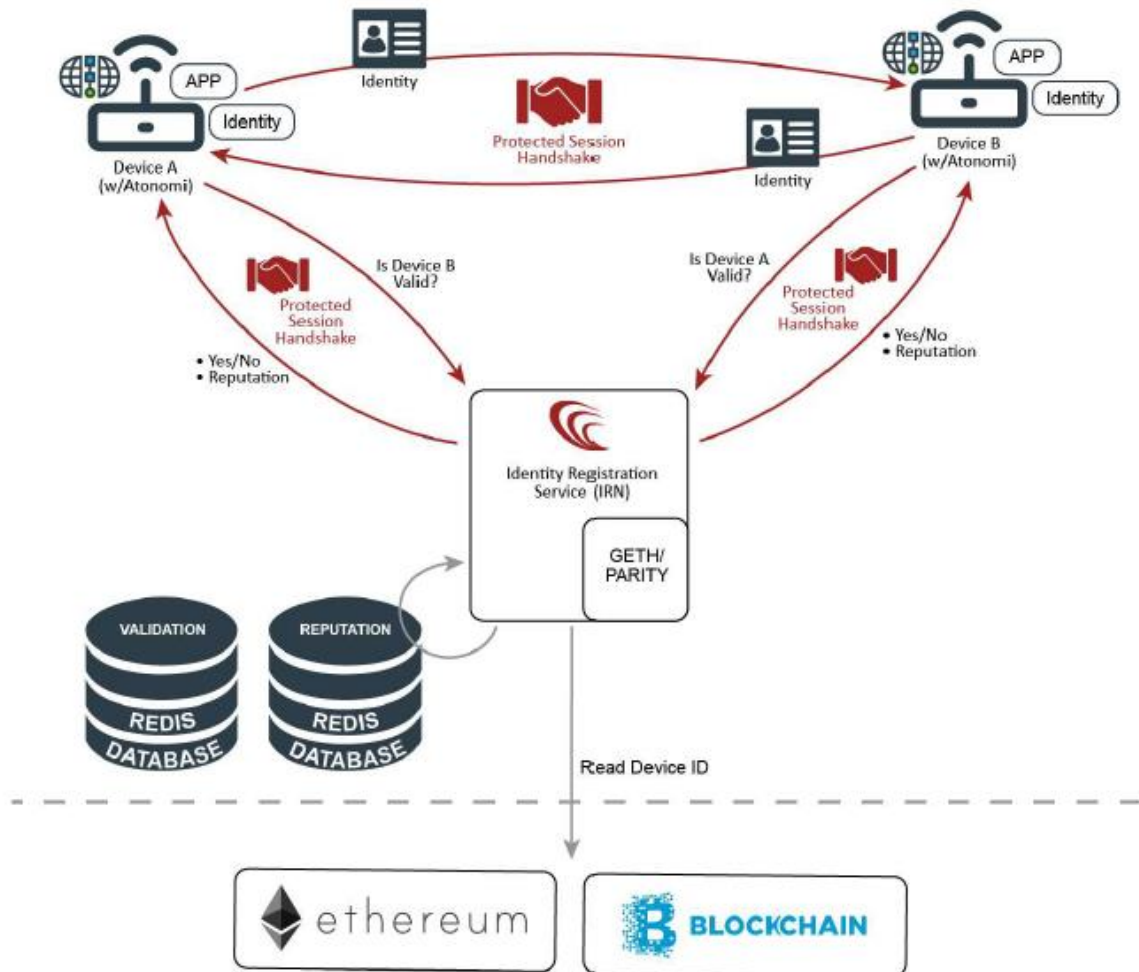


Figure 4. Atonomi Validation.

3.4 Reputation

3.4.1 Overview

The Atonomi reputation functionality (Reputation) is used after the Atonomi enabled device has been sold to an end user and begins to transact with other devices. Devices that have been Atonomi-enabled via the Atonomi Embedded SDK will be able to submit a reputation report concerning other devices it has transacted with. The Atonomi Embedded SDK will contain a method that produces the 'report' from input criteria. Once submitted the Reputation service will receive the report, validate it against the Validation database and log it into the Reputation database for 'future' processing.

3.4.2 Device SDK

For the purposes of Reputation the Embedded SDK will have one reputation report method. The intent will be that the device manufacturer ‘codes’ their application to generate the report based on criteria specified in the SDK documentation and then submits the report as input to the reputation report method.

3.4.3 Reputation Report Database

The reputation database will be initially implemented in Redis with the intent of moving it to a sidechain at some point in the near future. The reputation database will store the reputation reports that are submitted by devices. The reputation reports will periodically be audited by the reputation auditors to produce updated reputation scores for the devices involved.

3.4.4 Reputation Service

The Atonomi Reputation Service is a primary component, that when globally distributed, becomes part of the central hub of the Atonomi Identity Registration Network (IRN). The Reputation Service is a cloud-based, highly available, high-volume service that essentially provides the third step in the Atonomi process. The Reputation Service provides a key function to the overall Reputation functionality; it provides a device interface that devices communicate with to provide reputation feedback on another device.

3.4.5 Reputation Smart Contract

The Reputation function of the Atonomi Smart Contract governs the writing of updated device reputation scores to the blockchain after the reputation auditors have processed the reports. It also facilitates the payment in ATMI for the reputation score updates.

3.4.6 Reputation Auditor

The Reputation Auditor is a node/service that processes reputation reports using the Reputation Model and updates the reputation scores of effected devices. The updated reputation scores are then written to the Ethereum blockchain and to the Redis Reputation database. For purposes of the utility the initial reputation auditor node will be within the IRN. Eventually, post utility, this functionality will be broken out into a separate node so that it may be hosted in a Federated way by Atonomi Reputation partners.

Atonomi Reputation

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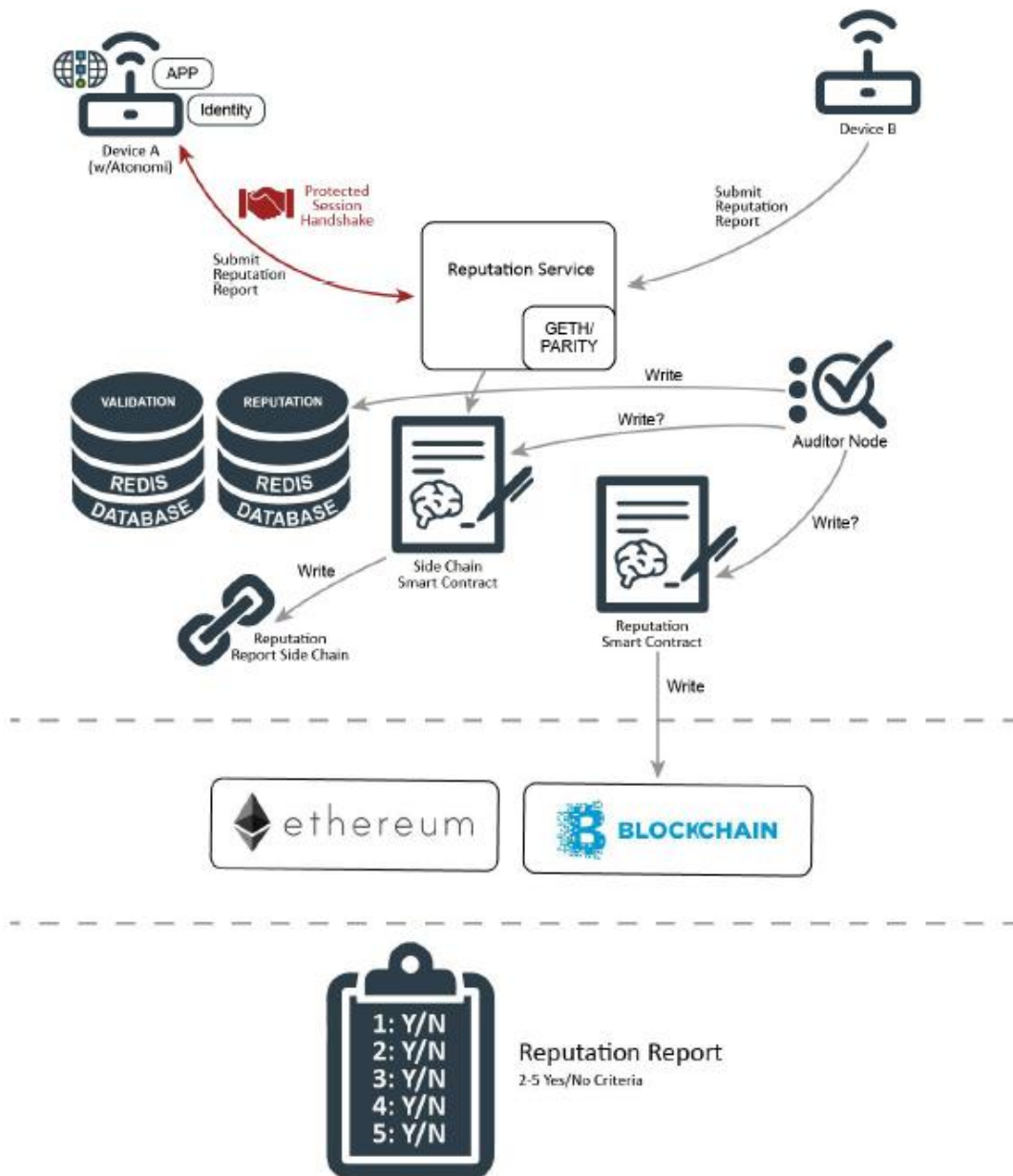


Figure 5. Atonomi Reputation.

3.5 The Atonomi Token

The Atonomi Token, which functions in compliance with ERC-20 standards, is a utility token used to register devices onto the Atonomi Network during the device registration process, to activate devices, and to reward Reputation auditors. The Atonomi Token can also be used to pay processing fees for secure device-to-device commerce between devices registered onto the Atonomi Network. Moreover, the token serves as a reward mechanism to facilitate ecosystem participants to the Atonomi Network.

3.6 Additional Elements

The extensible design of the Atonomi Network architecture was created to support deployment of future elements and services—from Atonomi, and third-parties.

3.6.1 Attributes Registration Service

The Atonomi Embedded SDK in a later release may provide APIs for integration with a manufacturer's existing device application stack where attributes and other user-defined metadata are assigned to devices. Attributes could include:

- Data exchange only with Identity Registry-validated devices
- Data exchange with any device
- Data exchange with any device within scope of geofencing
- Per-transaction spending limits
- Transactions per-minute (hours or days) spending limits
- Geographic limitations on transactions
- Counter-party reputation requirements

The above attributes aren't intended as a complete list, but as an example of the ways in which device owners can use the Atonomi Embedded SDK to ascribe attributes which will have meaningful use for their own vertical and specialized needs.

3.6.2 Transaction Service Creation and Maintenance Services

The Atonomi Embedded SDK supports use of existing—or creation of new—digital wallets or related transaction authorizations for devices that may need to support commercial transactions. Transaction authorizations or wallets can be created by device owners on either a device-by-device basis, or on a department-wide, company-wide, or other group basis. Atonomi Token-compatible wallets will be used to store Atonomi Tokens which will deduct a small percentage for some transactions taking place over the Atonomi Network.

3.6.3 Device Ownership Transfer Service

Atonomi plans to support ownership transfer of IoT devices—with or without wallet contents. Upon device transfer, a transaction log entry of the transfer will be broadcast to the Atonomi Reputation service which will update device reputation as needed.

3.6.4 Reputation Caching and Lookup Services

The Atonomi Network provides a cloud-based service giving devices the ability to perform a fast lookup of reputational data prior to engaging in peer-to-peer transactions—while also providing OEMs and ODMs the option of opting out of the service if not deemed necessary for anticipated device usage. Atonomi also maintains services to write to the Reputation Registry for whitelisted auditors.

3.6.5 Transaction Validation and Facilitation Services

The Atonomi Network maintains services to facilitate off-chain inter-device transactions. The data from these services are used for reputation analysis. The extensible nature of the Atonomi Embedded SDK means that different verticals can define which non-commercial transactions are stored off-chain. Atonomi Tokens may be used to pay network fees for inter-device commercial transactions, and eventually, they may be a useful default payment method for such inter-device commercial transactions. Though Ethereum network transaction processing might become cost- or speed-prohibitive, we believe the network is sufficient for immediate use. If and when necessary to maintain a healthy ecosystem, Atonomi and users of the Atonomi Network will evaluate migration or simultaneous use of alternative blockchain technologies for these transactions, such as Ethereum Raiden, Plasma, HashGraph, or others.

Successful Transaction Example Flow

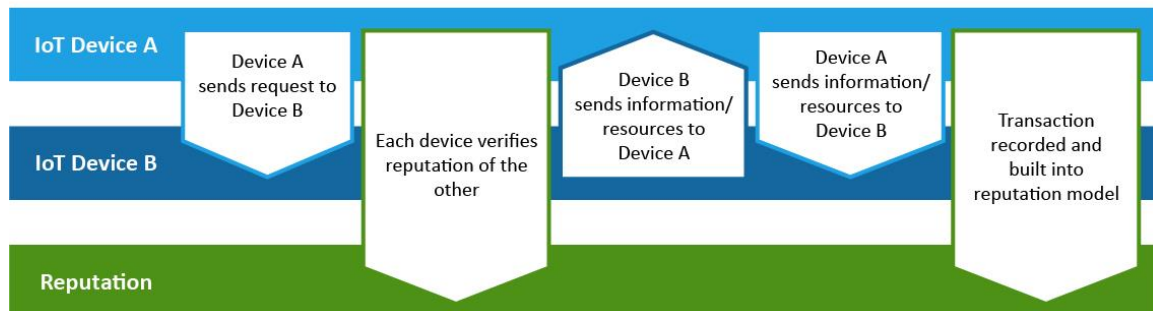


Figure 6. Transaction Validation Service.

3.7 Scalability

The proposed architecture leverages centralized cloud services scalable through traditional means as well as the Ethereum public blockchain. We recognize industry-wide concerns about the scalability of the Ethereum blockchain and will benchmark and forecast key performance metrics to ensure that our services and protocol can serve the necessary use cases. Note that many of the operations we support do not require high throughput writes to the blockchain. We will continue to monitor new developments in the space and prepare a migration path if and when scalability becomes a significant concern.

4.0 Faster and More Secure Technology

Integrated into the Atonomi Embedded SDK is CENTRI's advanced IoT security technology. As device performance and blockchain data security are essential elements to secure IoT, the Atonomi Embedded SDK includes advanced security technology developed by CENTRI. Atonomi has integrated the high speed communications technology described below to allow IoT devices to operate at real-time data speeds. CENTRI technology also gives Atonomi the option of encoding data stored on the blockchain.

4.1 Fast and Secure Authentication

CENTRI has a process for assigning secure device identifications upon registering a new device into an IoT environment. This allows for immediate, and encrypted, single-stage handshake communication between IoT devices using the CENTRI Secure Communications library, and the Cloud infrastructure side using the CENTRI Secure Communications Service. With CENTRI security technology, there's no need to exchange certificates or employ a third-party certificate authority solution, though manufacturers can elect to do so. We plan to use technology similar to our security-enhancing single-stage handshake within our Atonomi Embedded SDK for guiding initial contact between a newly activated device and our Identity Registry.

4.2 Small Footprint

The CENTRI solution has a minimal footprint, making it easy to embed the code into applications. CENTRI only requires about 50 kB of RAM for efficient performance on typical IoT devices. CENTRI developed "vault-less" technology—a patented process to embed key seed information within the data, to eliminate the need for hardware key storage systems. The seed data used to generate each one-time key is protected with asymmetric encryption. The result is unlimited key management, which is essential for IoT security to scale. Our experience in creating tight code and embedding key seed data will inform our creation of the small code footprint of our Atonomi Embedded SDK, which we see as essential for integration with IoT devices that can be resource-constrained.

4.3 Device Agnostic

Developers can use the C-based libraries and tools across a spectrum of operating systems, including Android, iOS, Windows, Linux, RTOS, and custom network stacks and other code that organizations might want to use in creating IoT solutions. Atonomi uses this same device agnostic approach in creating an open and extensible development platform that can be customized to the exacting needs of different verticals.

4.4 Secure Data

CENTRI security technology protects data during transport, in use, and at rest through standards-based, leading edge cryptography, including Elliptic Curve Diffie-Hellman Cryptography (ECDH) 25519, Salsa20 Symmetric key cipher data encryption, and SHA-512 cryptographic hash function for key derivation. Atonomi will be guided by this same approach to protecting data with leading-edge cryptography.

4.5 Intellectual Property and Patents

CENTRI's security technology is protected via multiple patents:

- Single-Pass Data Compression and Encryption, U.S. Patent [8,886,926](#) which compress and encrypt data in a single pass to reduce inefficiencies that occur from compression and encrypting data separately.
- Single-Pass Data Compression and Encryption (Broadening), U.S. Patent [9,503,434](#)
- Seeding of a Workspace to Optimize CODEC Operations, U.S. Patent [8,804,814](#) which improves codec performance by seeding the computation workspace that may be used by various codec processors.
- Seeding of a Workspace to Optimize CODEC Operations (Broadening), U.S. Patent [9,025,657](#)
- Secure Storage for Shared Documents, U.S. Patent [9,298,940](#) which improves management of data storage for secure storage of shared documents, using an encryption key based on instruction set and header information.
- Secure Storage for Shared Documents (Broadening), U.S. Patent [9,584,321](#)
- Transparent Denial of Service Protection, U.S. Patent [9,210,187](#) which uses instruction set information that references a seed file communicated to a client computer and a network packet key generated by the instruction set information encrypted and provided by a server.
- Transparent Denial of Service Protection (Broadening), U.S. Patent [9,503,262](#)
- Fast Indexing and Searching of Encoded Documents, U.S. Patent Application 15/453,853
- Big Data Markers for Stream Labeling, Identification and Decoding, U.S. Patent Application 15/402,122
- Process for Distributing Computing Datasets, U.S. Patent applied for.

5.0 The Atonomi Secure IoT Ecosystem

“The number of connected devices are growing exponentially driving up the value provided by IoT solutions. The Atonomi blockchain initiative offers intriguing possibilities to secure this world of automated device-to-device transactions and exchange of data.”

- Mrinalini Lakshminarayanan, Director of Products and Services, Gogo Inflight

An important part of securing IoT is building an ecosystem that is designed to maintain and expand IoT security and interoperability. Atonomi plans to accomplish this in multiple ways.

First, unlike other IoT security offerings, Atonomi begins at the source of the IoT value chain by placing code onto the chip with the Atonomi Embedded SDK. The chip-first solution is relevant to the Atonomi architecture because the small number of chip manufacturers create the foundation for an end-to-end security protocol that could be widely used by smart device manufacturers, and then built on by application developers.

End-to-End Security Protocol



Figure 7. Atonomi Network provides an end-to-end security protocol for the IoT value chain.

Next, the Atonomi ecosystem is designed to serve as a decentralized network of IoT stakeholders who act as key participants in Atonomi's identity and reputation service. For instance, participants such as utilities, smart cities, industrial IoT, and OEM and device manufacturers may elect to audit data and publish reputation data, provide service layers to interact with Atonomi's smart contracts, or validate and process transactions between devices on the Atonomi Network. As a low-level protocol for secure IoT, Atonomi will also enable a community of developers to build the next generation of IoT applications and platforms. By facilitating trusted interoperability between devices, Atonomi solves a fundamental problem of security in IoT and facilitates an innovation hub for the dApp developer community.

The Atonomi Network is engineered to support extensibility. We provide known and trusted device identity and reputation, and other companies and organizations will be able to extend the definition based on their own future needs. For example, builders of IoT devices for the HVAC industry may identify new transaction types, as could participants in IoT for industrial controllers, the power grid, agricultural devices, healthcare, retailing, shipping, and a world of other areas. Creating an extensible platform, open to all, will foster new—and secure—ways to derive benefit from the Internet of Things.

Audit partners are anticipated to seek fees in Atonomi Tokens to serve as validators on the Atonomi Network. For instance, a smart device such as an electric vehicle may enter into a service transaction with a charging station to recharge its battery. While Atonomi secures identity and reputation of these devices enabled by smart contracts, Audit partners (run by OEMs, Smart Cities, and other stakeholders could validate this transaction and, in return, receive a reward fee in Atonomi Tokens.

6.0 Atonomi Use Cases

According to Gartner, an estimated 5 million connected devices are being added per day to the IoT. The burgeoning IoT market can be viewed as a continuum, with early adopters that will over time drive future market opportunities. Atonomi seeks to be the standard low-level security protocol for the IoT industry.

Below are applications that are of immediate relevance to potential users of the Atonomi Network. The healthcare, industrial, smart city and home device markets are considered to be current movers in the IoT space.

6.1 Early IoT adopters in Healthcare

Given the aging baby boomer generation and the many use cases IoT can provide for healthcare, the healthcare industry can derive substantial benefits from Atonomi Network products. For example, consider the case of adding Atonomi security into an IoT solution, used for a proprietary health application platform, which is then built upon by application companies creating connected monitoring products, analytics tools, trackers, and other innovations.

At the application level, for instance:

- An inventory sensor inside a hospital emergency room blood-storage appliance could autonomously order re-stocks of specific blood types from regional suppliers based upon existing inventory, anonymized electronic health record reports of scheduled surgeries, and day-of-week historical ER needs. This system could be secured with the Atonomi Network.
- A diabetic patient wearing an insulin pump could allow the pump to share anonymized blood chemistry data with researchers to advance the science, or with healthcare monitoring systems that could intercede to prevent adverse events. This system could also be secured with the Atonomi Network.

6.2 Innovation in Industrial IoT, Smart Cities, and Home Devices

Industrial IoT requires a secure ecosystem within which a wide array of device types can seamlessly operate together to help manage the consistent execution and monitoring of workflow across multiple processes. Additionally, industrial IoT devices often need to extend autonomous interoperability to include resources beyond the domain of the manufacturing facility. The result is a need for trusted identity, reputation, and the ability to ledger user-defined key events.

Regarding smart cities, municipalities are finding ways to employ automation to seamlessly connect IoT devices and resources to lower power consumption, reduce traffic congestion, enhance air quality, increase safety, and improve overall livability. IoT will be at the core of many of these efforts, and providing security across this broad array of attack surfaces will be essential.

Further, the IoT is already playing an increasingly relevant role in home automation, smart appliances, and an array of other devices designed to make life easier and more convenient. A consumer, concerned about Internet security, can require all IoT devices within the home to be identity-validated and secure to help eliminate attack surfaces.

6.3 Supporting Diverse Use Cases

While particular industries might be early adopters, the Atonomi Network is architected so that diverse verticals are able to build using our protocol over time. Consider additional use cases to illustrate the ways security is required as a core building block of IoT applications, and the way the Atonomi protocol could be integrated into various third-part applications:

- An electric vehicle recharges its batteries from a charging station, autonomously conducting the payment transaction through the owner's electronic wallet. The vehicle securely

- negotiates for the lowest-cost power available, while the owner is spared the hassle of plugging in a credit card and paying a service charge.
- A home with solar panels and a wall of storage batteries could use an IoT device to securely sell excess power to a neighboring home with a smart meter looking for cheap power while running the clothes dryer.
 - Moisture sensors in an industrial greenhouse could detect low soil nitrogen and securely transact with irrigation devices to add nitrogen from automated feeders.
 - An office building with an IoT-equipped HVAC system could securely negotiate just-in-time electric power from local or regional providers based on availability, time of day, and lowest cost.
 - A remote sensor securely negotiates just-in-time wireless services from a low-cost provider to facilitate periodic data transmission.

7.0 Atonomi Token

The Atonomi Token (a standard ERC827 token, which is backwards compatible with ERC20) is central to the entire Atonomi Network. The use of a token is ideally suited to secure IoT devices, which typically have constrained memory and CPU resources, because the token can link the identity between the device and device owner through a crypto wallet. IoT devices can't be expected to carry a PCI stack for credit card purchases, nor are credit cards suitable for the kind of autonomous device-to-device micro-transactions required in many use cases which may involve purchases of less than \$1 and in some cases less than one cent.

7.1 Tokenized Identity & Reputation

Atonomi Tokens serve as a multi-use token for the internal mechanics of the Atonomi Network. Specifically, when new devices are registered and activated on the Atonomi Network, Atonomi Tokens can be used as fees for creating a device's digital identity through the use of smart contracts. Additionally, tokens are designed to be a key component of Atonomi's Reputation service by rewarding auditors for capturing, analyzing, and scoring reputation data. Atonomi Tokens also enable devices to validate other device identities that are stored on the blockchain encountered throughout its lifecycle.

7.2 Commercial Transactions and Data Exchange

Atonomi Tokens can be used as a digital token to enable device-to-device autonomous transactions. This token-based economy enables devices to securely engage in peer-to-peer autonomous transactions. While Atonomi doesn't charge for data exchanges, and the Atonomi Network is agnostic as to the particular token used for device-to-device transactions, Atonomi Tokens could be used in a future Atonomi release to enable devices to engage in commercial transactions with each other. For example, a smart meter on a home or building may autonomously negotiate with the power company or a micro grid to acquire electricity and pay for services using the Atonomi Token.

7.3 Processing Commercial Transactions

Atonomi plans to enable fees to be structured into the smart contract and blockchain-based transactions, including device registration and activation, with a future release facilitating commercial

transactions. For instance, Atonomi may elect to charge a minimal processing payment for handling commercial transactions between IoT devices. Nothing is charged for data exchange, as noted above. It is anticipated that these transaction fees would be shared between Reputation auditors in relation to the auditing services they perform, and Atonomi.

7.4 Ecosystem Partners and Innovation

Atonomi anticipates that ecosystem partners will seek to participate in key functions on the network, including device registration, activation, reputation management and commerce transactions. For instance, as explained above, device manufacturers may elect to serve as auditors to write reputation data to the Reputation service, and receive Atonomi Tokens as a reward for their service to the network. Additionally, Atonomi Tokens may be used to attract new chip/device manufacturers and end users to the network through customer acquisition programs.

Lastly, as a low-level security protocol, Atonomi aims to unlock many new use cases and future innovations such as a marketplace for IoT commerce. The developer community can build on the Atonomi protocol to innovate new projects and service offerings leveraging the Atonomi Token as fuel for their initiatives. For example, Swytch.io is a new blockchain-based project intending to disrupt the energy market by democratizing access to electricity through encouraging local, micro-grid production. In this case, Swytch may leverage the Atonomi security protocol (and the Atonomi Token) to secure the end points on Swytch's network and enable trusted interoperability.

8.0 Leadership

Leadership for the Atonomi Network includes:

- Vaughan Emery, Founder and CEO
- David Fragale, Co-Founder and Chief Product Officer
- Mike Mackey, CTO and VP of Engineering
- Dr. Luis Paris, Chief Scientist

Advisors to Atonomi include:

- Dr. Paul Clippinger, Senior Advisor; MIT Media Lab
- Andrii Zamovsky, Technical Development Partner
- Peter Kinnaird, Technical Development Partner; Ambisafe
- Dr. David Kravitz, Vice President, Crypto Systems Research at DarkMatter
- Dr. Ulf Lindqvist, Program Director at Stanford Research International (SRI)
- David Jevans, CEO, CipherTrace
- Rob May, CEO, Talla and Botchain

For brief biographies of our Leadership Team, please visit the Atonomi [website](#).