

Blockchain Micro Transactions

Field of the Invention

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The present invention relates to a system and method for recording transactions on a distributed ledger and in particular, for a device or object to generate such transactions securely.

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Background of the Invention

There is a common need for different entities to interact and transact with each other to exchange value and data. However, for this to be done in a safe and secure manner for each party to a transaction, a level of trust is required to exist between transacting entities. In the absence of such trust, other structures and procedures are necessary such as enforceable contracts and third party authorities or intermediaries.

Cryptocurrencies are digital currencies that are a form of alternative currency (or private currency). They are usually distinct from centrally controlled government-issued currencies (for example, fiat money) and offer a decentralised or distributed form of currency and/or medium of exchange. Digital currencies may be transacted or transferred from one owner or entity to another and may be used for any purpose, such as buying goods, purchasing services or even obtaining data. As such, digital currencies represent an alternative to traditional currencies.

One example of a cryptocurrency is bitcoin, although many other cryptocurrency systems have been devised. Bitcoin was developed by Satoshi Nakamoto and the original paper, 'Bitcoin: A Peer-to-Peer Electronic Cash System', outlining the fundamentals of bitcoin technology and principles may be found at <https://bitcoin.org/bitcoin.pdf>.

Technology underlying distributed cryptocurrencies, such as distributed ledgers, can also be used to record other types of transactions and can form a verifiable history of exchanges or other forms of data without requiring trust to exist between entities. Distributed ledgers, such as blockchains, enable transactions and exchanges of value to occur in the absence of such trust. However, this requires the use of public blockchains to form a consensus that is difficult to corrupt or control by any individual actor or entity. This

usually takes the form of a race to consensus based on a proof of work but this itself can consume very high levels of resources in the form of computing and electrical power.

An alternative approach uses private blockchains but this reintroduces the requirement for trust to be developed between parties and the owner and controller of the private blockchain itself.

Trust can be developed by determining and verifying the identity or other characteristics of the entities but this effort can introduce overheads and additional work leading to inefficiencies and extra load for a computer or telecommunications network. Furthermore, such verification or checks often depend on separate sources of information, each of which may also need to be verified and approved or trusted. This may require significant bandwidth and processing resources. Therefore, this approach may only be appropriate for certain entities transacting above a particular value, where the overheads do not become a significant burden. This also prevents new exchanges of value and data from developing between entities that are new to each other or transient exchanges of low value but at high volume. For small or numerous entities or devices, such as those forming the internet of things or other low computing power devices, the overheads can vastly overwhelm the small exchanges of value. Therefore, this limits the efficiency and scalability necessary for exchanging value or data packages, especially for autonomous or unsupervised devices.

Therefore, there is required a method and system that overcomes these problems.

Summary of the Invention

A method and system initiates a secure channel between a device and a server (e.g. a digital asset broker, DAB) using a UICC (e.g. a SIM). The server receives an instruction over this secure channel to execute a transaction. The server requests or sends an instruction for a distributed ledger (e.g. a blockchain) to execute the transaction and the distributed ledger signs the transaction in response to this request using a stored public and private key pair (e.g. within the distributed ledger and/or the UICC of the device). This enables a device to interact more securely with one or more distributed ledgers and also provides more convenient and safer management of wallet identifiers and keys. This system and method enable more efficient transaction processing, which may be used with a higher volume of lower-value transactions.

This digital asset broker (DAB) wallet can bundle and harmonise several wallet-like functionalities. This DAB Wallet provided by Public Key Infrastructure (PKI) on SIM (e.g. by GSMA IoT SAFE standard) can authenticate for and transact within different blockchains in a hybrid way. The SIM can provide identity and signing capabilities through the blockchain node directly. Additionally, it is also able to leverage a trusted connection to a DAB backend service or middleware (e.g. proxy server) through PKI on SIM or SIM Trust to authenticate and transact within blockchains, across blockchains and on traditional non-blockchain payments networks.

10 In accordance with a first aspect, there is provided a method for executing secure transactions, the method comprising the steps of:

- initiating a secure communication channel between a device having a UICC and a server, wherein the secure communication channel is secured using the UICC;
- receiving at the server from the device over the secure communication channel, an instruction to execute a transaction;
- in response to the received instruction, transmitting from the server to a distributed ledger a request to execute the transaction; and
- in response to the request, signing the transaction at the distributed ledger using a public and private key pair stored within the distributed ledger and/or the UICC (e.g. SIM) of the device. The transaction may originate at the device or may be initiated by a further device (e.g. with or without its own UICC or SIM).

Optionally, the secure communication between the UICC and the server may be initiated using a public and private key pair stored on the UICC. This further improves security as the UICC (e.g. SIM) may already have secure memory and storage for other purposes.

Preferably, the method may further comprise the step of generating the public and private key pair within the UICC. This may already be a function of the UICC and so an additional secure processor is not necessary.

Optionally, the secure communication between the UICC and the server may be initiated using a shared secret. For example, this may be a symmetric key, including but not limited to Twofish, Serpent, AES, Camellia, Salsa20, ChaCha20, Blowfish, CAST5, Kuznyechik, RC4, DES, etc.

Optionally, the secret may be shared between the UICC and the server by:
storing the shared secret within the UICC and within a telecommunications network
component when the UICC is manufactured; and
5 the telecommunications network component sending the shared secret to the
server.

Preferably, the telecommunications network component may be a home location
register, HLR (or another component within the core network).

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Advantageously, the shared secret may be generated using generic bootstrapping
architecture, GBA.

Preferably, the secret may be shared between the UICC and the server by:
15 generating the shared secret within the UICC and a bootstrapping server function,
BSF; and
the BSF sending the shared secret to the server. Other sharing or exchanging
mechanisms may be used.

20 Optionally, the transaction may be recorded on the distributed ledger with a wallet
identifier associated with the device.

Advantageously, the method may further comprise the step of generating the wallet
identifier associated with the device on the distributed ledger by verifying the device using a
25 different physical communication channel to the secure communication channel.

Optionally, the different physical channel may be SMS.

Preferably, the transaction may be a blockchain transaction.

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Optionally, the transaction may be a credit card or bank transaction. The
transaction may also be a token transaction or other value transaction on a blockchain.

In accordance with a second aspect, there is provided a system comprising:
35 a device having a UICC;

a distributed ledger storing a public and private key pair;
a server having one or more processors and memory storing instructions configured to cause the one more processors to:

5 provide a secure communication channel with the device using the UICC;
 receive from the device over the secure communication channel an
instruction to execute a transaction; and
 in response to the received instruction, transmit from the server to the
distributed ledger a request to execute the transaction,
 wherein the distributed ledger has one or more processors and memory storing
10 instructions configured to cause the one more processors of the distributed ledger to:
 sign the transaction using the stored public and private key pair, in response
to a request from the server.

Optionally, the memory of the distributed ledger may further comprise instructions
15 configured to cause the one more processors of the distributed ledger to:
 record on the distributed ledger a wallet identifier associated with the device,
 wherein the transaction is recorded on the distributed ledger with the wallet
 identifier associated with the device.

This provides a direct association between the device (or user of the device) and
20 the transaction. Indirect associations may be used, e.g. by using an external database,
mapping or lookup table between an identifier of the device (or of the UICC) and the
transaction identifier or wallet identifier.

Optionally, the memory of the distributed ledger may further comprise instructions
25 configured to cause the one more processors of the distributed ledger to:
 generate the wallet identifier associated with the device on the distributed ledger by
verifying the device using a different physical communication channel to the secure
communication channel.

30 Optionally, wherein the UICC of the device may further comprises memory storing a
secure applet comprising instructions to respond to verification requests.

Optionally, the transactions are associated with an identifier of the device. This
may be by direct or indirect associations.

The methods described above may be implemented as a computer program comprising program instructions to operate a computer. The computer program may be stored on a computer-readable medium.

5 The computer system may include a processor or processors (e.g. local, virtual or cloud-based) such as a Central Processing unit (CPU), and/or a single or a collection of Graphics Processing Units (GPUs). The processor may execute logic in the form of a software program. The computer system may include a memory including volatile and non-volatile storage medium. A computer-readable medium may be included to store the logic
10 or program instructions. The different parts of the system may be connected using a network (e.g. wireless networks and wired networks). The computer system may include one or more interfaces. The computer system may contain a suitable operating system such as Java, UNIX, Windows (RTM) or Linux, for example.

15 It should be noted that any feature described above may be used with any particular aspect or embodiment of the invention.

Brief description of the Figures

20 The present invention may be put into practice in a number of ways and embodiments will now be described by way of example only and with reference to the accompanying drawings, in which:

FIG. 1 shows a flowchart of a method for recording transactions on a distributed ledger;

25 FIG. 2 shows a schematic diagram of a system for recording transaction on a distributed ledger, including a device having a SIM;

FIG. 2a shows a schematic diagram of a system for distributing sensor data using a distributed ledger, including a first device and a second device both having SIMs;

30 FIG. 2b shows a sequence diagram of more detailed example steps of the method of figure 1;

FIG. 2c shows a sequence diagram of more detailed example steps of the method of figure 1;

FIG. 2d shows a schematic diagram indicating the flow of steps of the method of figure 2b;

FIG. 2e shows a schematic diagram indicating a further example of the flow of steps of the method of figure 2b;

FIG. 2f shows a schematic diagram indicating a further example of the flow of steps of the method of figure 2b;

5 FIG. 3 shows a schematic diagram indicating high-level functionality of the system of figure 2;

FIG. 4 shows a shows a schematic diagram of several architectural components of the system of figure 2;

10 FIG. 5 shows a schematic diagram of an example implementation of the system of figure 2, including a device and a SIM, proxy server and distributed ledger;

FIG. 6 shows a schematic diagram of a further example implementation of the system of figure 2;

FIG. 7 shows a schematic diagram of a system of devices operating according to the system of figure 5;

15 FIG. 8 shows a schematic diagram in more detail of the system of devices operating according to the system of figure 5;

FIG. 9 shows a schematic diagram of an example implementation of the system of figure 6;

20 FIG. 10 shows a schematic diagram of a further example implementation of the system of figure 2, including one or more nodes;

FIG. 11 shows a schematic drawing of a node of figure 10;

FIG. 12 shows a schematic diagram of the method steps carried out by the system of figure 10;

25 FIG. 13 shows a schematic diagram of an example implementation of the system of figure 2;

FIG. 14 shows a schematic diagram of an example implementation of the SIM of figure 5;

FIG. 15 shows a schematic diagram of an example implementation of the device of figure 5;

30 FIG. 16 shows a flowchart of a method for managing keys used in the method of figure 1;

FIG. 17 shows a schematic diagram of components used within the example implementation of figure 6;

35 FIG. 18 shows a schematic diagram of the interaction of components used within the example implementation of figure 6;

FIG. 19 shows a schematic diagram illustrating method steps used to generate keys within the example implementation of figure 6;

FIG. 20 shows a schematic diagram illustrating method steps used to exchange data within the example implementation of figure 6;

5 FIG. 21 shows a schematic diagram of device architecture within the system of figure 2;

FIG. 22 shows a schematic diagram of architecture middleware used to interact with a secure element within the SIM of figure 2;

10 FIG. 23 shows a sequence diagram of a procedure for signing transactions according to the method of figure 1;

FIG. 24 shows a schematic diagram of method steps within a procedure for signing transactions using the secure element of the SIM of figure 22;

FIG. 25 shows a schematic diagram of a TLS authentication process that uses PKI and using the SIM of figure 22;

15 FIG. 26 shows a schematic diagram of an example implementation of the distributed ledger of figure 2;

FIG. 27 shows an example use case that implements the method of figure 1;

FIG. 28 shows a sequence diagram of a portion of a method for matching offers within a data exchange;

20 FIG. 29 shows a sequence diagram of a portion of the method of figure 28;

FIG. 30 shows a schematic diagram of a messaging system used within the system of figure 2;

FIG. 31 shows a schematic diagram of an example implementation of the system of figure 2;

25 FIG. 32 shows a sequence diagram of method steps used within the messaging system of figure 30;

FIG. 33 shows a sequence diagram of further method steps used within the messaging system of figure 30;

30 FIG. 34 shows a sequence diagram of an example implementation of the method of figure 1;

FIG. 35 shows a schematic diagram illustrating method steps for provisioning a device for use with the method of figure 1;

FIG. 36 shows a schematic diagram illustrating method steps for setting up a device for use with the method of figure 1;

FIG. 37 shows a schematic diagram illustrating method steps for setting up a device for use with the method of figure 1;

FIG. 38 shows a schematic diagram illustrating method steps for authenticating a user for use with the device of figures 36 and 37;

5 FIG. 39 shows a schematic diagram illustrating method steps for authenticating a user for use with the device of figures 36 and 37;

FIG. 40 shows a schematic diagram illustrating method steps of an example implementation of the method of figure 1;

10 FIG. 41 shows a schematic diagram illustrating further method steps of an example implementation of the method of figure 1;

FIG. 42 shows a schematic diagram illustrating further method steps of an example implementation of the method of figure 1;

FIG. 43 shows a schematic diagram illustrating further method steps of an example implementation of the method of figure 1;

15 FIG. 44 shows a schematic diagram of an example implementation of the system of figure 2;

FIG. 45 shows a schematic diagram illustrating example architecture components of the system of figure 2;

20 FIG. 46 shows a schematic diagram illustrating an example implementation of a portion of the system of figure 2;

FIG. 47 shows a schematic diagram illustrating an example implementation of the device within the system of figure 2; and

FIG. 48 shows a schematic diagram illustrating an example implementation of an interface with the system of figure 2.

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It should be noted that the figures are illustrated for simplicity and are not necessarily drawn to scale. Like features are provided with the same reference numerals.

Detailed description of the preferred embodiments

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The 'Internet of Things' is growing and transitioning to an 'Economy of Things' (EoT). The number of IoT devices is growing and generating large volumes of data. IoT devices and smart services interact and interoperate across ownership domains and offers the potential to support data and smart service value transactions automatically in near real time. This can improve interoperability and functionality.

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The 'Economy of Things' requires the capability for devices/services to identify, trust each other, and where required automatically transact value directly or using peer-to-peer functionality. There are a range of technologies ranging from Distributed Ledger, Secure Elements, Cryptography and Device Wallets which support Digital ID, Federated Security and transaction applications and services needed for IoT, but they are fragmented, have high costs and not sufficiently scalable.

Figure 1 shows a flowchart of a method 10 for executing transactions. At step 20 a secure communication channel is initiated between a device having a UICC and a server (e.g. a digital asset broker, DAB). At step 30 the server receives from the device over the secure communication channel an instruction or message to carry out a transaction. At step 40 and in response to the received instruction, the server transmits to a distributed ledger (e.g. blockchain) a request to execute the transaction. This may be a payment transaction, a token transaction or a data transaction, for example. In response to this request from the server, at step 50 the transaction is digitally signed at the distributed ledger using a public key of a public and private key pair stored within the distributed (e.g. within the same or another block) or within a UICC or SIM.

Figure 2 shows a schematic diagram of an example system 100 used to implement the method described with reference to figure 1. The device 110, having a SIM (120), and the server 140 (DAB) communicating securely over a communications channel. The distributed ledger 150 receives the instruction to execute the transactions from the server 140.

Figure 2b shows a sequence diagram of an example method for generating or adding transactions to a distributed ledger 150. This method provides additional detail to the method 10 described with reference to figure 1. In this example implementation, two ways are shown to establish a secure channel between the SIM 120 (with device 110). One way is to generate a public and private key pair on the SIM 120, within its secure location 130. This key pair is used for a secure connection to the server 140, using GSMA IoT SAFE standard for example. Another way is to share a shared secret between the SIM (with device 110) and the server 140 (DAB backend). This is achieved by using a GBA server with SIM Trust protocol, for example.

Once this setup process has completed, the server 140 (DAB backend) receives transactions instructions from the device 110 and instructs the distributed ledger 150 (blockchain) to trigger the transaction. This may be implemented as a smart contract within

the blockchain, for example. The process shown in figure 2b results in a transaction recorded and completed solely on the blockchain. This may be described as a token transaction, where value may be realised within the blockchain itself. The token may be used in further blockchain transactions, for example.

5 Figure 2c shows a sequence diagram for a further example method for adding transactions to a distributed ledger 150. Whilst this method is similar to the method described with reference to figure 2b (and a similar initial or setup procedure is used to generate symmetric or asymmetric keys to setup secure communications), it also involves traditional payment rails, such as a banking transaction, or a credit or debit card transaction
10 in addition to the transaction recorded on the blockchain. The traditional (or monetary) transaction is carried out within usual banking and credit card infrastructure but this transaction is also logged or recorded on the blockchain. The public and private key pair stored within the blockchain is used to sign the traditional or monetary (i.e. external) transaction on behalf of the SIM or device. This may be described as a payment
15 settlement transaction.

Figure 2d shows a schematic diagram of an example implementation of a system using the method described with reference to figure 2b. In this example implementation, the device is a vehicle. A person delegates permission for the vehicle to pay an EV charger on their behalf using a primary account number, for example. For fleets or multiple
20 vehicles, an admin console may be used to setup an account enabling payment across the fleet. SIMs may be present in each vehicle as well as within each charging station. In this example, the payment is made within the distributed ledger 150 as tokenised transactions. Local wireless communication (e.g. vehicle to everything - V2X) may be initiated between each vehicle and any changing station in order to provide transaction details and
25 confirmation.

Figure 2e shows a schematic diagram of an example implementation of a system using the method described with reference to figures 2b or 2c. Again, a unique digital identifier and wallet is set up by a user to provide consent to pay for charging. When the vehicle arrives at an EV charging station, local communication (e.g. V2X) is used to identify
30 the vehicle and the particular EV charging point, which triggers a transaction. In this example implementation, a smart contract is used for this triggering step. Payment for the charge is initiated at the EV charging point and this includes a confirmation of the charged amount and validation of the car payment method.

The EV charger completes verification (of the vehicle, e.g. car), processes the
35 payment via a payment method indicated in the smart contract and completes a charge to

amount outlined in the smart contract. The EV Charger signs the transaction using a private key on its SIM. Payment processing and settlement takes place. Confirmations are made to accounts or parties to the transaction. This represents a tokenised transaction recorded on the distributed ledger 150. However, in an alternative embodiment, payment
5 rails may be used to initiate monetary transactions, with the distributed ledger recording these transactions.

Figure 2f shows a further example implementation of a system using the method described with reference to figures 2b or 2c. In this example implementation, the device is also a vehicle buy may be part of a fleet that is authorised to obtain and pay for charging
10 with the charging stations. Otherwise, this system operates in a similar way to that described with reference to figure 2e in both tokenised and payment rail (e.g. EMV payment) implementations.

The DAB Wallet operating as described above, may enable at least three wallet
15 functionalities (e.g. as a hybrid approach).

1) (not shown in the figures) Authentication and signing functionalities on the SIM/edge device through Public Key Infrastructure (PKI) on SIM (classical wallet):

a) DAB Wallet leverages the DAB PKI on SIM Technology (IoT SAFE Applet, elliptic curve) to authenticate into major blockchains (for example, Ethereum, Hyperledger,
20 R3, etc.) and initiate and sign peer to peer transactions within multiple blockchains (because multiple PKIs can be generated on the SIM Secure Element).

b) Like well-known hardware wallets it provides the functionality in a very secure way.

25 2) See figure 2b: Authentication against a trusted backend service that provides further functionality for transacting within blockchains and across blockchains

a) DAB Wallet may integrate with PKI on SIM for authenticating into DAB backend service and performs asymmetric key encryption of transaction data between SIM/device and the DAB backend service, which then orchestrates authentication and transactions into
30 the blockchains. This can also include usage of additional wallet-to-ledger protocols or smart contracts.

b) DAB Wallet integrates with SIM trust/GBA for authenticating into DAB backend service and performs symmetric key encryption of transaction data between SIM/device and the DAB backend service, which then orchestrates authentication and transactions into

the blockchains. This can also include usage of additional wallet-to-ledger protocols or smart contracts.

3) See figure 2c: Authentication against a trusted backend service that provides further functionality to access traditional non-blockchain payment networks.

a) DAB wallet leverages PKI on SIM as well as SIM Trust (as described under (2) above) to authenticate through DAB backend service into traditional payment rails. External Payment Service Providers are used by DAB to trigger traditional transactions (through APIs).

b) DAB wallet leverages PKI on SIM as well as SIM Trust (as described under (2)) to authenticate through DAB backend service into tokenized Primary Account Numbers (PANs) where credentials have been delegated to the device and trigger processing and settlement.

DAB Wallet can do a combination of (2) and (3), as mentioned above and interact with smart contracts and oracles across blockchains, including PAN compliant smart contracts and traditional transactions executing business logic on the DAB service to initiate flows. The DAB Wallet can therefore be seen as the “wallet of wallets” bundling up all of the mentioned functionalities in one solution.

Figure 3 illustrates schematically the high level functionalities of the systems described earlier.

UICC (SIM)

Role within the system: Provide secure entry point into a chain of trust (SIM as a customer’s asset). Throughout this disclosure, the terms SIM and UICC may be used interchangeably as are application and applet.

Variants:

- Secure Element on the SIM, preferably supporting the GSMA IoT SAFE Applet; or
- Vodafone SIM Trust based on 3GPP Generic Bootstrapping Architecture (GBA).

There are different implementations of the system. In one implementation, a SIM or UICC applet generates one or more cryptographic key pairs. In another implementation, the SIM or UICC may be provisioned with cryptographic material. For example, this may use 3GPP GBA. However, any of the examples or combinations of features and implementations described throughout may be used with either or both implementation.

Device

Role within the system: Provide integrator into higher layers (Digital Asset Broker, DAB, Management Core) and harmonize communication (also for SIMs from different telecommunications networks or non-SIM devices). The device may take various forms from simple IoT devices (e.g. a utility meter) to vehicles, for example.

Components:

- DAB Middleware for IoT SAFE Applet; or
- DAB Middleware for SIM Trust;
- Sensor Data Extraction for Monetizable Event Detection

DAB Management Core

Role within the ecosystem: Brokering of interactions within the DAB system to use on-chain and off-chain functionalities.

Components:

- Flow Orchestration Engine
- Common APIs

DAB Management Services

Role within the ecosystem: Simplifying flow for MVP (MasterCard, VISA, PayPal) and customizing DAB.

Components:

- Customized Off-chain Processing (off-chain)
- Customized APIs

DAB Blockchain Services

Role within the ecosystem: Providing connectors that translate DAB interactions into blockchain language.

Components:

- Ledger of Things
- DAB Exchange
- Blockchain Hub including Smart Contract Engine

Architectural Components

Figure 4 illustrates schematically various architectural components of the system and method.

While the IoT SAFE applet implementation provides convenient functionality, the use of GBA provisioning (e.g. Vodafone SIM Trust) enables the use within the system of legacy SIMs that may already be deployed. Therefore, the combination of both implementations (that may work simultaneously or separately within the system) allow as many participants as possible to use the system. Device firmware may be updated over the air for legacy devices and so the GBA implementation (e.g. SIM Trust) may be used without changing the UICC or SIM within a device.

Figures 5 and 6 illustrate at a high level, the use of both implementations with the system 100. The mechanisms are independent but interchangeable and may be suitable for different use cases. As well as providing flexibility for new and legacy SIMs, each implementation option has different advantages. For example, banks & utilities may prefer to interact with the GBA implementation (e.g. SIM Trust) shown in figure 6 because it supports symmetric keys. The SIM applet implementation (e.g. IoT SAFE) shown in figure 5 provides improved blockchain interaction because transactions can be signed directly by the UICC or SIM without requiring the need for an intermediate or proxy server 140. Therefore, both mechanisms contemplate each other and satisfy specific technical requirements.

On a high level the main difference between these two mechanisms lies in the cryptographic approach. The IoT SAFE Applet uses a secure element on the SIM to store and manage keys predominantly for asymmetric encryption (also known as PKI) with public and private key pairs being generated and stored. In the GBA (e.g. SIM Trust) approach mobile network capabilities are used to establish a symmetric encryption between SIM and an endpoint (e.g. a server such as a DAB server).

Asymmetric encryption or PKI is the technology that is used by many IT infrastructures to secure https and other connections between servers using public/private key pairs.

Figures 7 and 8 shows schematically how secure communication channels may be set up between IoT devices and servers using the IoT Safe Applet running with the SIM 120. Figure 8 shows in more detail how the device initiates the secure connection with the server.

The device is pre-provisioned with a client PKI certificate (e.g. within a UICC or SIM). In the example shown in figure 9, the device is a vehicle but may be any device,

mobile or otherwise. The client PKI certificate is preferably a public trust certificate that is procured and signed by a Certificate Authority. The server holds a similar server certificate. When a communication channel is initiated by the client to the server, there is an exchange where both parties authenticate each other using the certificate authority (CA) to confirm the validity of the other party.

The mechanism implemented using the CA makes use of pairs of keys used together, where one encrypts and the second decrypts. The keys can be used with either of them performing the first encryption function while the other key can be used to perform the decryption operation. Because of the asymmetric nature of two different keys performing these functions this is often referred to as "asymmetric" cryptography. One of these keys is public and the other is secret. In a public encryption system, anyone can encrypt a message using a receiver's public key but only the receiver will be able to decrypt the message using his secret key.

Apart from the cryptographic approach, the solution based on IoT SAFE delivers some additional features that facilitate further functionalities that may be used with distributed ledger (e.g. blockchain) related environments.

Symmetric encryption algorithms use the same cryptographic keys for both encryption and decryption. The keys, in practice, represent a shared secret between two or more parties that can be used to maintain a private information link. The requirement that both parties have access to the same secret key is one of the main drawbacks of symmetric key encryption, in comparison to asymmetric encryption. In the mobile communication space this solution is facilitated by the device containing a mobile SIM that has a connection to telecommunications network service. Mobile telephony originally had many of the requirements that are present in the IoT device space and uses standards based solutions to these problems. These have been developed and scrutinized for a period of more than 20 years and so can be trusted by many entities and organisations.

When a telephony appliance connects to a mobile cellular network, it performs at least two actions including:

- Authenticate with and to the mobile network; and
- Agree keys that can be used to encrypt communications with the mobile network.

This is typically achieved using the standards based Authentication and Key Agreement (AKA) protocol. The AKA protocol therefore creates trust between a mobile

appliance (roaming or otherwise) and a (possibly untrusted) cellular network, such that the two parties can communicate with confidentiality protection.

This alternative technique uses the same AKA protocol, which has been formalized as the Generic Bootstrapping Architecture (GBA), e.g. the Vodafone implementation of SIM Trust, but unlike the conventional cellular use case, the trust is created between the device
5 and an application platform under a user or customer's direct control.

Figure 13 illustrates this GBA implementation. While the UICC or SIM is creating a standard mobile connection to an application server, the AKA protocol is used to create a confidentiality protected communication between the device and a visited Mobile Network.
10 SIM Trust (using the GBA protocol) adds another layer of trust by repeating the AKA flow to create a symmetric encryption between the Device and the App Server. The result is a mutually authenticated secure channel for communications between the two endpoints.

Figure 10 shows an example network arrangement in which individual devices communicate with a node within a distributed ledger network. This network arrangement
15 may be independent of a particular cryptographic scheme (e.g. it may use symmetric or asymmetric encryption). Figure 11 shows schematically the form of these individual nodes. One or more nodes may be present in the network.

In more detail, figures 10 and 11 illustrate the following features. A secure applet (e.g. DLTapplet) on the SIM (within a device) or on the node generates and holds keys
20 securely. These keys may be representation of wallet(s), certificates and/or other modes of digital trust used for the secure exchange of value (using a blockchain). The secure applet may be logically an extension of a home subscriber server's (HSS) hardware secure module (an existing network element deep in the core network of a telecommunications company or operator). The HSS relationship with the secure applet on the SIM may be
25 managed by another existing network element (e.g. an over the air OTA server), which may be a machine used to create a secure communication channel directly with the SIM. The telco node plays the role of a distributed ledger technology (DLT) notary, acting in governance with a decentralised authority in each of the DAB nodes to create and manage certificates needed to manage a lifecycle of the secure application distribution, update,
30 permissions and decommissioning activities, for example.

The telco node also acts as the CA (certification authority) for services provided by the system (e.g. DLTsecure services). As the HSS's hardened security is extended to the SIM via the DLTsecure services, the DAB DLT uses the SIM and stored keys to create a new consensus protocol ("Proof of Secure SIM"), where the SIM is asked to prove its
35 validity on the system (DAB) upon each transaction, without the need for expensive, high

processing proof-of-work/stake type processing across the network. This makes each DAB node lightweight, as well as limits computation requirements for the SIM (as the PUB/PRV keys may be generated asynchronously then offered to the DAB DLT for validation at the point of transaction initiation).

5 Device owners or other entities may program or define smart contracts or other conditions so that heterogeneous devices from different systems can interact with each other using a common root of trust (i.e. the SIM and secure applet or GBA enabled device). This provides a mechanism and protocol allowing devices to interact and transact. This may be done at scale with multiple devices (and their SIMs) interacting with one or more
10 nodes. This protocol allows for devices to exchange tokens-to-tokens, as well and exchange token-for-data, a use case that has been traditionally resolved using APIs. Furthermore, devices enabled in this way (DAB devices) may autonomously exchange tokens in their one or more wallets for value, ranging from action (e.g. access control) to data streams (e.g. device location of the first or offering device), with secondary "parent"
15 nodes being able to recharge these wallets to manage and track service consumption, for example. This system provides a micropayment and micro billing system as well as a request/transfer/settlement of value exchange that may be coupled with the credit/debit of a decentralised ledger.

20 The following describes the steps taken when operating the example network arrangement of figure 10. Again, either encryption scheme (symmetric or asymmetric) may be used. The numbers below correspond with the numbers shown in figure 12 indicating method steps occurring between different components:

0. Background: A & B have been registered on the DAB NW and have been
25 permissioned to exchange value to each other.
1. Owners of A & B have agreed a smart contract (i.e. "if you give me data X, I will give you Y tokens")
2. B requests data from A based on pre-determined smart contract (C)
3. B's request is signed with DLTsecure B security, and validated by Dapp C
30 (Proof-of-secure-SIM)
4. "Buy" transaction is published on behalf of B on DAB DLT network
5. A downloads applicable requests for transaction determination
6. DLTsecure A verifies request (4)
7. Device A signals to DAB DLT that it wants to "Sell"
- 35 8. Device A receives & packages Data A from Sensor A

9. DLTsecure A signs package A
10. A acknowledges exchange on DLT calling upon Smart Contract C to be invoked
11. A sends package A to B (either on or off chain)
- 5 12. DLTsecure B updates DLT, DLT records and initiates settlement using Smart Contract C
13. Device B fulfils C
14. Device A confirms token receipt
15. DLT validates C closure
- 10 16. Device B analyses package A, makes determination to conduct Action A

The next two sections provide details on how the two implementations operate in more detail.

- 15 The UICC applet implementation uses a secure element within the UICC (e.g. SIM). The SIM acts as a hardware wallet protecting cryptographic keys and communications. This implementation enables a SIM to provide a Root of Trust for IoT devices for easy and efficient implementation of key security features. The SIM may securely store transaction signing keys and performing crypto asset transaction signing securely within a secure
- 20 environment.

- Figure 14 illustrates a schematic diagram of an architectural design of the SIM and an OTA server. SIMs may be provided with a GSMA IoT SAFE applet. In addition to holding the SIM Crypto Wallet for transaction signing, this enables mutually authenticated TLS connections that are bound to SIM Hardware Root of Trust as defined in GSMA
- 25 Specification <https://www.gsma.com/iot/wp-content/uploads/2019/12/IoT.05-v1-IoT-Security-Applet-Interface-Description.pdf>.

- GSMA IoT SAFE based solutions provide Chip-to-cloud security for IoT deployments. Using a hardware secure element, or 'Root of Trust', IoT SAFE based solutions provide end-to-end security. The usage of the GSMA standardized secure
- 30 element and IoT SAFE Applet additionally ensures interoperability across different enterprises and consistent use by IoT device manufacturers.

For communication between the IoT SAFE Applet, which is located on the SIM, and external parties (e.g. a proxy server, blockchains, etc.), Crypto Middleware libraries are also executed within the device but not necessarily within the SIM.

In this implementation, standard authentication mechanisms occur between the SIM and the device as well as between the SIM and an Over-the-Air (OTA) Server. These mechanisms may also involve a secure element on the SIM. This is joined by basic mechanisms to unlock an application and/or the SIM (e.g. by using PIN protection), SIM lock mechanisms, mutual authentication between SIM and device application, etc.

Blockchain transactions are validated by blockchain nodes using protocols that include digital signatures sent as part of the transaction.

Generic Smart SIM Wallet

By using the IoT SAFE Applet, the SIM provides access to one or more key containers or storage locations within the Secure Element of the SIM. These containers may be used for different use cases or even to providing multiple identities for the same use case or operation. Figure 15 illustrates schematically the storage of multiple identities within the SIM. Each identity may be used as a SIM Wallet that enables a user to authenticate and sign transactions against within different applications. This is not limited to blockchains but may also be used within off-chain mechanisms such as traditional payment rails (e.g. direct communications with other devices or enterprises). Over the air (OTA) update capability of the SIM enables the addition of new containers and key management functions for use in particular implementations.

SIMs can be personalized with additional key containers to sign keys for different blockchain networks. In a preferred implementation, there are three key containers available by default in the SIM. Two containers holding SECP256 K1 ECDSA key pairs and one holding SECP256 R1 ECDSA key pair. However, different key pair types may be used and in any combination.

Considering an end to end solution, a SIM crypto wallet in an IoT (or other) device and using SIM as hardware Root of Trust may provide any or all of the following features:

- Hardware wallet (signing payment/digital asset transfer transactions)
- Verifying signed transactions
- Secure communications
- Secure storage of sensitive data

The SIM itself thereby could provide any or all of the following capabilities

- Additional crypto capabilities
- IoT device ID metadata storage

- Secure Backup / Restore, Key Management
- Device initiated bootstrap

Using a cryptographic key vault within the SIM keeps the private keys and secrets
 5 tamper proof and secure. SIMs are generally tamper proof hardware with a dedicated
 crypto processor and a highly secured SIM OS, providing the level of assurance required to
 private keys safe. Keys stored on the SIM in this way, are generated on the SIM and
 preferably never leave the SIM.

10 Table 1 summarizes the list of preferable crypto algorithms that are used. Other
 algorithms may be used.

Blockchain / Crypto Network	Public & Private Key Crypto Transaction Signing Algorithms
Bitcoin	ECDSA SECP256k1
Bitcoin Cash	ECDSA SECP256k1
Ethereum	ECDSA SECP256k1
Ripple	ECDSA SECP256k1
R3 Corda	ECDSA SECP256k1 / R1, RSA (3072), EdDSA using the ed25519 and SPHINCS-256 (experimental, post
Hyperledger Fabric	ECDSA / RSA

Table 1

Blockchain and crypto currency networks typically rely on asymmetric cryptography
 15 because their transactions are peer-to-peer or within a group of participants. The list of
 participants amongst different transactions may be different. Given this peer-to-peer nature
 of blockchain transactions, the usage of Symmetric Cryptography may not be feasible.
 Additionally, using Asymmetric Cryptography, blockchain and DLT transactions are
 auditable by third parties. The use of PKI within the current system makes it is possible for
 20 an entity or person to verify a transaction without having access to the private keys.

EMV tokens

EMV is abbreviation for Eurocard (RTM), MasterCard (RTM), Visa (RTM) and
 stands for a defined specification for payment applications and implemented in most of
 25 today's banking card chips. It works with symmetric cryptography by accessing securely
 stored authentication information on a banking card chip. In the present environment, EMV

may be used to sign payment transactions and send them to existing payment rails to enable transactions. Therefore, the SIM Wallet will be used to hold (symmetric) key values for payment applications, which are then used by device middleware and facilitate EMV payment through the present system.

5 In this enhanced or optional feature (used with any of the described implementations), this provides an option for a user to select to pay using a blockchain or existing payment rails by EMV. From a security perspective, SIM cards are already able to pass banking card certifications.

Wallet of wallets

10 The SIM is used to provide keys relating to a desired payment method. The wallet itself that is used for payment does not need to be stored on the SIM (but may be). The wallets used to interact directly with the distributed ledger may be provided by a separate entity, server or proxy server, or broker (e.g. DAB) and selected based on payment method preferences dependent on the particular use case.

15 Third party documents may be deployed onto the SIM over-the-air (OTA). The wallet application on the device securely interacts with the SIM part of the application (applet) and establish a binding (also via OTA). This follows a Security and Certification process for the Security Domain as well as approval for integration with external applications.

20 Key Management

A well-defined mechanism to manage the lifecycle of keys used in transaction management may be implemented. Lifecycle management of cryptographic keys includes key backup, restore, key revocation and renewal and may implement security policies to handle lost, stolen and/or compromised devices. Private keys are the most sensitive asset,
25 and are not backed up in clear or unprotected environments. For backup and restore of transaction signing keys for blockchain, there are a number of different mechanisms that are used.

For example, Bitcoin defines deterministic key generation based on a human readable series of words to generate a seed and generate key pairs using the seed based
30 on the BIP39/BIP32 specification. BIP 39 implementation specifies deriving the keys from a mnemonic that may be remembered and re-entered in order to restore the keys. BIP32 defines hierarchical deterministic wallets, which derives keys based on a seed and an index value. Such mechanisms may be used in the present system and is illustrated schematically in figure 16.

In another example implementation, a SIM Backup Vault Service backs up components or parts of private keys on other SIMs in a transparent way so that no single SIM has the complete value. Restoring a key can be a collaborative effort involving the collection of components of backed-up values (k out of N) from a cluster of SIMs that were
5 used in the backup process.

In a further example implementation, a blockchain smart contract based solution reduces the complexity of the backup and restore process. For example, a smart contract account holds the digital asset similar to an escrow mechanism, until specified conditions are met. Accounts associated with IoT devices would only deal with micro payments and
10 would not hold any digital value or crypto currency on their own. Smart contract accounts can define the rules for resolving the scenarios in which some devices are faulty and how to transfer the account to some other device, for example.

Generic Bootstrapping Architecture (GBA)

15 The Vodafone SIM Trust architecture based on Technical Specification (3GPP TS 33 220) also known as the Generic Bootstrapping Architecture (GBA). As with certificates, GBA is used to establish trust between parties. Whereas certificates rely on asymmetric cryptography to create key pairs that are different and that can be used in conjunction with each other to support cryptographic functions. GBA uses a hardware based Trusted
20 Execution Environment (TEE) to store symmetric keys and to provide functions to use these symmetric keys to derive temporary keys that can be used to support at least three functions: Authentication, Confidentiality Protection and Integrity protection. More details on the GBA Standard can be found in ETSI Technical Specification TS 33.221 V14.0 (2017-05).

25 In the IoT environment the GBA TEE is provided by the SIM. The SIM is used to store credentials to support authentication key derivation and key agreement functions.

Symmetric encryption suffers from the disadvantage of requiring keys to be distributed and shared between all parties that need to communicate with each other. This is referred to as the Key Distribution Problem. The Telecommunications Industry relies on
30 Symmetric cryptography where the keys are distributed during the SIM manufacturing process and where symmetric keys are stored in two places:

1. Subscriber Identity Modules (SIM) which are hardware token devices that are stored on the User Equipment (UE) which might be a mobile phone or an IoT device; and

2. Centrally in the Operators core network on an Authentication Centre (AuC) and accessed via a Home Location Register (HLR).

5 The security of this distribution process relies on secure processes being followed by the SIM manufacturer and the Cellular Operator in the management of this key material.

However, a number of entities have been know to target the processes and the people involved in the distribution of this key material. Industries relying on SIMs to secure their assets have countered this Key distribution attack problem by using rigorous security processes and vendor selection. However, this can be costly.

10

Communication Flow

The SIM card is used as a root of trust to derive shared keys which can be used to achieve end to end authentication and encryption at the application layer at scale. In general, this process relies on the 3G AKA process (AKA = Authentication & Key Agreement). The AKA process is used when any mobile device attaches to a mobile network (>2G) and performs mutual authentication and key agreement. Figures 17 and 18 show at a high level, the communication flow used for the SIM Trust implementation of GBA.

20 The steps for establishing a secure channel between the device and a backend applications consist of two steps: Key generation and Exchange data through the secure channel using the key.

Key Generation Process

25 The key generation process is shown schematically in figure 19. The SIM interacts with a device API within the device, which obtains the symmetric key from the SIM Trust server in communication the core network. The device communicates with the SIM Trust server over http to derive the shared secret in the form of the symmetric key. This symmetric key is stored authenticated and stored within the SIM.

30 Exchange data through the secure channel using the key

Once the shared secret (symmetric key) has been derived, it may be used to secure a channel to communicate data. This is shown schematically in figure 20.

The Communication Flow through each network entity is described below:

- The Device Management (DM) Client queries the Generic Authentication Architecture (GAA) Server for a key.
GAA Server establishes identity of SIM (AT+CSIM).
Meanwhile, GAA Server tells the DM Client to wait.
- 5 The DM Client can handle other work whilst waiting.
The GAA Server asks the UbProxy for an Authentication Vector using the identity.
UbProxy validates the request and routes it to the correct Bootstrapping Server Function (BSF).
BSF request the AV from the HLR.
- 10 HLR returns an AV to the BSF.
BSF stores credentials and returns a version of vector to the UbProxy with 401 code.
UbProxy returns same message and error code to GAA Server.
Which requests an authentication from the SIM.
A valid response (DB at the start) allows a valid response to be extracted and sent to the
- 15 UbProxy.
Which then sends it to the BSF.
Which validates the response included in the message against that received from the HLR earlier and sends a 200 response.
UbProxy returns the 200 response to GAA Server.
- 20 GAA Server calculates the key and returns it to DM Client.
DM Client now uses the key as required and passes the Id to its server.
When DM Server needs the key it queries the UbProxy via the NAF using the Id.
The UbProxy sends the key request to the appropriate BSF.
Which calculates the key and returns it.
- 25 UbProxy returns key to DM Server.
DM Server uses key as necessary.

Starting from the SIM Trust (e.g. from Vodafone), middleware on the device side enables the device to message between the SIM and SIM Trust platform (bootstrapping server function, BSF) in the network. The device supports SIM Trust Device Libraries and have integrated software libraries (DDK). On the backend side an application retrieves the shared key from the SIM Trust platform using an application processing interface (API) call via an API Hub.

A particular global data service platform (GSDP) may enable GBA (e.g. SIM Trust)

35 for particular SIM cards or IMSI ranges.

Device

Generic architecture

For using the device as an integrator layer between SIM and DAB, four interlinked components can exemplarily be provided:

5 SIM Centric: a SIM card (including a secure element and a hardware component that stores cryptographic keys and that can authenticate and sign transactions and data).

 Libraries provided by the SIM manufacturer: a set of libraries exposing the SIM's functionalities for use by connected applications (e.g. Crypto Middleware mentioned).

 Middleware: Middleware component that exposes the SIM applet infrastructure
10 capabilities for applications that are unable to directly embed the SIM manufacturer's libraries, or for applications and devices running outside the device (e.g. a data gathering network).

 Events Detection: application(s) / algorithm(s) that detect and transact events either with the rest of the DAB Service, or directly with blockchains and marketplaces and/or
15 exchanges.

 These components are shown schematically in figure 21.

 Together with the Services, and the use of existing capabilities like GDSP (Vodafone's Global Data Service Platform for managed IoT Connectivity), SIM Trust or IoT
20 SAFE, devices can be seen as edge integration points, fulfilling the functions of blockchain wallet and trusted authenticator. They also open up the ability to provide secure autonomous events, or to be used as simple Hardware Secure Modules (HSM).

 The Middleware enables devices to smoothly participate in a transaction ecosystem, enabling applications to embed manufacturer libraries and consume SIM
25 capabilities for key provisioning and transaction signing. Applications running outside the connected device can also access the Middleware through its APIs, making use of these capabilities.

 Devices process or gather data ranging from direct readings to computed analytics (e.g. cargo occupancy assessments) , that (in the PKI on SIM case), once encrypted and signed with the SIM Cards' private keys, can be tokenized into any blockchain or stored
30 elsewhere within the platform for cross-vertical usage.

Middleware for Secure Element on SIM

 Typical IoT deployments such as those shown in figure 22 may benefit directly from GSMA IoT SAFE providing secure transfer of sensitive data and device authentication.

Nevertheless, it requires the mentioned middleware on the device to facilitate communication between the SIM Applet and the application side.

Architecture

5 The Middleware for Secure Element on SIM abstracts dissimilar types of applet management through a modular application, enabling the integration of devices and a digital asset broker (DAB) Service platform. It provides a unified single RESTful API (the SIM Service API) for applet management, regardless of manufacturer.

10 In order to expose SIM capabilities to devices, a Crypto Middleware library provides and interface with an applet execution platform. The libraries may include OS-level C libraries and/or framework-ready modules for Java, Android or Swift, and provide methods for managing the applets themselves (deployment, deletion, updating, etc.), as well as the operations made available by each. The DAB Middleware components are outlined in figure 22.

15 The SIM Service API is a set of base endpoints that expose the unified operations described previously and for each received request, the Encryption Core is responsible for orchestrating the necessary steps for interacting with third-party vendor integration options, be they external or embedded Java libraries, for example. Since each of those come with their own logic flows for applet management and utilization, individual adapter components
20 may be interfaced by a DAB Middleware Provider Commons layer. This enables operations provided by different manufacturers to be available.

Implementation

25 In an example implementation, two device configurations aligned with the IoT SAFE applet running inside Secure Element of the SIM cards are provided:

1. DAB App running on a mobile phone directly accesses its SIM card through an embedded Android library for signing and validating datasets as instructed by the DAB Service; and
2. A 4G-connected automotive M2M router (in a test, simulated using a
30 RaspberryPi and a Vodafone USB Connect 4G v2 dongle but other suitable hardware may be used) contains the SIM but exposes its cryptographic capabilities to other applications through the DAB Middleware.

35 The implemented DAB Middleware use the following example technologies:
Spring Boot;

OpenAPI;

Java Native Interface (JNI); and

iot-safe-middleware. Other technologies may be used.

In one example implementation Java Spring Boot covers a large number of possible
5 integration scenarios with manufacturer libraries. This also opens the possibility to include it
in several kinds of devices, including smart devices or IoT Gateways, as long as they can
run JVMs. For low end devices where CPU and Memory may be constrained, using a JVM
is not the most efficient implementation but it does abstract away hardware differences.

This may be split into configurable modules that can be extended for each supplied
10 library, an approach taken for providing easier integration of integrations methods, either by
directly importing code modules, or by interacting with OS-level libraries (when e.g. C
libraries provided by the SIM manufacturer need to be interfaced by way of a JNI foreign
function interface). This may be instantiated as a standalone application running on the
same device connected to a communications unit or it may be embedded on the event
15 detection software (if Java-based, for example).

Four example SIM Service operations may be defined, which are concerned with
the cryptographic capabilities made available by the IoT SAFE applet installed in the SIM.
These operations mirror very similar signatures of the API methods made available by the
Thales Crypto Middleware C++ library (see also [https://github.com/ThalesGroup/iot-safe-](https://github.com/ThalesGroup/iot-safe-middleware)
20 [middleware](https://github.com/ThalesGroup/iot-safe-middleware)). The Crypto Middleware library provided by Thales can in itself be used in two
ways or compilations: the Java Android library for direct applet communication from inside
a regular Android app, or the C++ build, suited for the middleware approach described
above.

DAB Middleware APIs

25 In an example implementation, the SIM Service operations concerning
cryptographic capabilities made available by the IoT SAFE applet installed in the SIM are
called by applications according to their need to get a public key or sign a message. They
all follow the "container"-based approach ("containers" are secure memory spaces holding
each a client certificate and a key pair), and each deployed DAB use case may be aware of
30 which key type or digital signature algorithm it requires. Therefore, it may also be aware of
which parameters/containers to use when calling the DAB Middleware.

In an example, the API may be briefly summarized as such:

/containers: for listing information about a SIM's containers;

/certificate: for retrieving the client certificate of a particular container;

35 /pubkey: for read the public key of a particular client certificate/container; and

/sign: to sign a message using a particular client certificate/container.

This business logic is shown in figure 23.

Applications

5 Transaction Signing using SIM Wallet

Blockchain, Crypto currency networks and other micro payment solutions rely on ability of nodes to sign transactions. Due to this peer to peer nature of these transactions, it is important to be able to prove that node participated in the transaction to ensure non-repudiation. Keeping the private key associated with a Blockchain address in a safe
10 location (ideally, tamper proof crypto module) is therefore critical.

A transaction prepared by DAB Middleware is signed using private key securely stored on the SIM. An example of this is shown schematically in figure 24.

TLS authentication

Client Keys and Server Root Certificates securely stored on the SIM (e.g. an IoT
15 SAFE SIM) can be used not only to support DAB blockchain applications but also to perform mutually authenticated TLS session between the device and a service running in cloud. This is shown schematically in figure 25.

The DAB Middleware may also deliver control over key generation, wallet administration, and the management (installing, deletion, etc.) of applets installed on the
20 SIM. This may entail, e.g., exposing control over the IoT SAFE applet to generate new key pairs or modify digital signature algorithms.

Due to the diversity of SIM and Devices manufacturers, the DAB Middleware is available as a software development kit (SDK) for multiple languages and operating systems, making it possible for OEMs to smoothly embed it into their own devices. Given
25 its Java-based nature, another option includes porting it into the Java Card technology delivering a single application that may be preinstalled in all SIMs for out-of-the-box DAB accessibility.

The SIM Service API is available at the DAB API Inventory for direct device management by application accelerators or third-party applications connected to the DAB
30 platform (if authorized to do so). Preferably, this may be consumed by each DAB Service instance for controlling the devices transacting in its own use cases.

Sensor Data Extraction for Event Detection

In an example implementation, IoT deployments may use devices as end nodes, which can
35 have various functions. These can include:

Directly forwarding sensor data to upper layers (cloud or server); or

Communicate with a gateway that performs the same function.

The sensor data may originate within the device, for example.

5 Smart devices and secure elements are increasingly prevalent, the ability to extract knowledge or generate actions upon the resulting data is becoming a key to IoT autonomy. The ability to authenticate datasets, applications running detection algorithms may directly embed compatible libraries for accessing the SIM cryptographic applet or use the DAB
10 Middleware to sign the information with a selectable private key, leading to an unalterable dataset.

The DAB device may also act as a control point for the deployment of device-side capabilities that can come into play on DAB-powered use cases (such as detection algorithms deployment, wallet management, etc.). DAB-powered devices may be accessible for the DAB Service to manage their detection software and SIM applets.

15

DAB Framework

In an example implementation, the DAB Service is the instantiated component for a DAB stack and acts as the transaction and authentication platform for a DAB ecosystem. It provides capabilities for IoT devices to transact value for services/data and handles
20 connectivity between mobile IoT devices, multiple types of blockchain technologies, and any third-party external systems. For this, the DAB Service may offer REST-based APIs for the setup of use case orchestrations, for transaction committal, digital identity management and third-party service access.

Preferably, the system use the Java Spring Boot framework. This enables
25 modularity capable of running in most on-premises or cloud-based machines. This is also a flexible environment for interconnection with different kinds of software and hardware applications, be they libraries, drivers and communication stacks. However, other frameworks may be used.

In an example implementation, the DAB Service may use the following
30 technologies:

Spring Boot, Web3J, OpenAPI, Firebase Java SDK, Spring Quartz, Liquibase, Failsafe SDK, JWT lib, Paho MQTT, PostgreSQL 10, and/or Spring Reactor.

35

Role inside the ecosystem

DAB Service is the engine of the ecosystem, managing devices, use cases, flows and entities. In addition to all capabilities exposed through the APIs, the DAB service integrates external systems from third party marketplaces, other telecommunications components or additional blockchains networks.

Beside the connection to networks, devices are managed and accessed, with the DAB Service the connecting, managing, authenticating and certifying devices. If an external entity (e.g. company) wants to join the ecosystem, then it may use the DAB Service – “as a service”. If another entity wants to have more control around the devices, an instance of DAB service can be deployed for specific use with their own devices and control their own pieces of the ecosystem.

IoT devices may act as sensors or low-energy devices with a low computational power. Furthermore, devices do not need to be connected every time and it is not necessary to connect to a distributed ledger (e.g. blockchain) or other type of network all of the time. To reduce the computational burden of devices, the DAB service may acts as a proxy (or proxy server) to connect devices with any kind of network. This reduces the weight of processing data from devices, allowing the less powerful devices to be part of the ecosystem.

DAB Management Core

A DAB Management Core acts as a main communication layer between all the parties, consisting of a flow orchestration engine and an API component. The flow orchestration engine consists of three components. Each component is accessible through APIs.

Flow Orchestration Engine

A Provisioning Engine is responsible for handling both the setup and management of the use cases instantiated in each DAB Service instance, abstracting the linking up of use cases with particular implementations or technologies. Additionally, the provisioning engine handles the configuration of these technologies and third-party services. It delivers an access layer for the management of devices participating in the DAB stack for deploying algorithms and key management (via SIM Service API). Following functionality is handled in this component:

Business Rules: A set of rules that define the interactions that each device can have with a certain network or marketplace / exchange.

Use Cases Management: Management (creation, edition and deleting) of available use cases for each DAB instance. It is also responsible for provisioning on devices the usable use cases that they can trigger.

Connectivity: Integration with other platforms like GDSP for SIM management,
5 location services, etc.

Algorithms: Governing, cataloguing and deploying of algorithms into DAB-powered devices leveraging the SIM Service API. This capability provides a high level of customization and possibilities on the devices preferably upgraded over the air so that they can discover new events based on their own data, without the data leaving the device.

10

Authentication Engine

An Authentication Engine is responsible for handling all digital identity logic for connected devices and created smart services. Entities ranging from devices, to Partners or Services have a Digital Identity that can be used to pair and connect businesses
15 (managing what is accessible to each other at a given time). Therefore, this engine offers the ability to create IoT devices entities within a network of external back ends and authenticate against the respective registry. Therefore, the authentication engine univocally asserts identities across the DAB ecosystem, preferably by way of a unique identifier. Devices holding provisioned keys and as such, providing context on identity and
20 transaction authenticity, can be authorized to plugin and provide data with proven and provable provenance.

Transaction Engine

Depending on the use case, different functionalities can be activated, and this
25 customisation is an additional benefit of the DAB platform. Authenticating devices in this way assures that received transactions are encrypted and signed from a trusted device i.e., through the SIM card's private keys, making sure of provenance and identity. Therefore, transactions can immediately be performed on multiple marketplaces/exchanges (normally, each focused on specific domains).

30 As such, the Transaction Engine may be responsible for handling logic tending to the processing of received device transactions and API calls. This requires redirecting information across DAB Service layers and making inter-component requests. For example, this can include accessing databases, external systems, or the blockchain integration. On receiving a candidate event, the DAB Service may decide which use case

to apply depending on more than the contained data and may check for algorithms chosen at the device or insights produced over those data.

In cases where transactions require “long” processes or a marketplace-type offer/demand matching procedure, the Transaction Engine provides interfaces to the DAB Management Services off-chain processing component that provides services to run
5 special algorithms in secure CPU enclaves. This may include services controlled by the DAB Service or by a third party.

The Transactions Engine provides ingress endpoints where datasets enter the DAB stack. These may be delivered by synchronous HTTP POSTs to DAB (or other
10 communication protocols) which parses and routes them to an applicable use case, initiating the (configured) orchestrated flow associated with it.

A typical value transaction process may follow three steps. These may be applicable to most use cases and show how a use case implementation is approached:

A received message triggers the start of a value transaction process. For example,
15 this may be a transaction sent by a DAB-powered device (see Transactions Engine), or a specific message received on a Custom API deployed by the DAB Service for third-party consumption.

The producer’s identity is validated, and the activated use case identified. A resulting action is produced, such as deploying a transaction in a blockchain or delivering a
20 message or signal to an external system or DAB device.

Applications may cover several sorts of use cases that go beyond simple token transference, such as the concepts of session recording and dataset matching that arise as viable practical applications for commercial use. In order to generalize the many types of data that may be transacted, the Transactions Engine may enforce an API message format
25 that is outlined to be as much generic as possible so as to contain all information needed to indicate which use case flow to activate.

In an example implementation, example JSON code is shown below. The message properties may indicate:

transactionId – a UUID generated by devices and unique for each message;
30 usecaseType – should univocally identify both the blockchain technology to be used, plus the operational mode of the use case (e.g. Ethereum, session-based, etc.);
transactionType – used by all use cases but limited to the keywords needed to describe each step of the that operational mode (e.g. Start session, open session, Pay);
fromDevice – the SSID - a globally unique identification code for each SIM – used
35 for device identification;

creationDate – timestamp generated by the device;

transactionObject – contains the data to be inserted into a blockchain

(blockchainObject), along with a "locationObject" property that carries GPS data sent by the device indicating its present location;

5 dataType – used to indicate the type of data to be inserted to the blockchain (the data contained inside the "blockchainObject"). This could be used to discriminate its JSON format.

```

{
10   "transactionId": "{{v4uuid}}",
    "transactionType": "newdata",
    "fromDevice": "8981300999090900006F",
    "creationDate": "2020-04-27T17:32:47.020154Z",
    "useCaseType": "service",
15   "dataType": "generaldata",
    "transactionObject": {
        "blockchainObject": "{\"borrower\": \"Daimler\", ...}",
        "locationObject": "{\"location_data\": {\"lat\": 51...}}"    }
    }
20

```

Supportive Functions, e.g. Data Persistence Service

A Data Persistence Service deals with all the database connectivity the DAB Service needs for storing information describing use cases orchestrations, device configurations, device-service association data, and dataset hashes. It may be used especially when timing becomes critical.

25 The functionalities of DAB Management Core may also be supported by a Platform GUI. This may be implemented through INVENT but may use other technologies.

Common APIs

30 The Flow Orchestration Engine may requires a set of Common APIs of core functionalities to provide endpoints suitable for building and managing use cases, authentications and transactions.

35

DAB Management Services

The DAB Management Services functionality serves as the place where customized data processing related to a certain industry vertical or use case may be implemented. It may be independent of the DAB Management Core and have its own APIs that can be defined and developed any time a need arises to integrate third-party services for DAB interaction. To improve scalability, core elements may be independent of customized elements.

Customized Off-Chain Processing

In cases where transactions require matching processing (e.g. Truck Capacity) or in case of micro-payments aggregation (e.g. Tolling Services), algorithms may be run in Python and in a software guard extensions (SGX) enclave.

Customized APIs

When a specific integration is required for a use case to be triggered by an external system, the endpoints exposed by the DAB Service may be organized in this component. These use cases generally depend on data already present in the DAB stack, such as querying the DAB for a digital device identity, requesting a signature, or triggering a blockchain transaction, for example. These bespoke control points can go beyond REST and be made available in any other technology supported by Java, such as SOAP, MQTT, etc..

DAB Blockchain Services

Ledger of Things

The Ledger of Things provides the ability to create, maintain and use digital IDs based on a Corda network, for example (other distributed ledger technology may be used). This will be then consumed by DAB Management Core for authentication and transaction signing. Bulk provisioning of Devices on the Ledger of Things allows enterprises to easily and simultaneously create the digital twin of a large number of their devices. A DAB Exchange includes event detection will be a key differentiator to map devices and use cases to each other automatically.

Blockchain Hub and Smart Contract Engine

Blockchain Hub

A Blockchain Hub governs the different integration mechanisms chosen by blockchain implementations, providing the DAB Core services with interconnection
5 capability. These mechanisms may range from the use of embedded Java libraries, to system level interactions with external applications running alongside the DAB Service itself. Therefore, a layer provides different classes that segregate by technology or partner all logic needed for their use. When building a use case (via the Provisioning Engine), a programmer expects to easily select one of these connectors, configure it to use a
10 particular node, server, or credentials, and be provided with simple methods for transaction management.

Different types of distributed ledgers may be used. For example the following three different blockchain may be used:

In Corda networks, transactions are made via RESTful API with several nodes of
15 the DLT network. It would be also possible to use RPC connectors, but RESTful API offer a low friction and easy integration.

In iExec networks, successive operating system processes are run, where a set of ordered commands (as described in the partner's documentation), are issued to a NodeJS client (iExec SDK), installed side-by-side with a DAB instance, that synchronously executes
20 and returns textual JSON outputs that need to be processed and interpreted by the DAB.

EWf built a system that uses an Ethereum blockchain as a data marketplace, but having in view device participation being limited to "dumb" devices that only receive MQTT messages. Therefore, for integrating their EWf into the DAB Service, a MQTT client /
connector manages all EWf flows for all devices that the DAB Service authorizes.

25 Given the complexity of existing blockchain implementations it is possible to integrate further connectors based on libraries such as Geth and Web3 to enhance fine-grained connectivity options.

Example Use Cases

30 Use Case: "Services Payments"

This use case demonstrates how token exchanges can be used to use and pay for services like Parking or Tolls (automotive). R3 Corda technology implements a token SDK framework to create a one-time token/payment transaction. Five nodes within a network include one notary acting as an authority node, two nodes for services and two nodes for
35 consumers. Each node on the R3 Corda blockchain represents major entities, like service

companies (e.g. parking, tolls companies or EV-Charging providers), and consumer companies, like automotive companies. Each device can trigger a transaction but its identity is not necessarily mirrored on the blockchain itself but may be represented on a smart contract that is triggering. This is shown schematically in figure 26.

5 In terms of smart contracts (flows on Corda), beside all the flows to manage the network, (including viewing all transactions, gathering information or performing calculations) a main flow to create and records transactions made by each device of each entity. A `CoinTokenTypeContract` represents a `CreateEvolvableTokenFlow` object. When triggering that flow, there's some mandatory fields like the identity of the device that is
10 starting the flow, which entity represents that device, who is the consumer of the service. APIs manage and trigger transactions on the network and integrate them with external portals and applications.

The network may be deployed on AWS (or other) environments, segregated by entities with a defined structure based on access and network available ports and APIs.
15 Each node has its own webserver capable of offering their own APIs and operate independently of the rest of the available network.

Integration of functionality has been made within a smartphone or other device (e.g. Android phone). The platform is capable of monitoring the network and manually triggering actions. The solution uses REST and SSH to interface with the R3 Corda instance, directly
20 on nodes and provides managed capabilities like monitoring network transactions, triggering new transactions and controlling nodes through a Node-CLI. The next images show that capabilities in detail.

Within the automotive scenario paying for services may be achieved automatically by using R3 Corda blockchain capabilities.

25 Interfaces/Dependencies

Various interfaces enable the control and triggering of transactions on the nodes through RESTful (or other) APIs. Other interfaces may be used, including RPC and SSH (see figure 26).

30 The following provides a list of example APIs that may be used, together with a description of their functionality. These APIs may be used internally or accessed by external entities.

Name	Description
getMe	Get information about who the node is.
35 getPeers	Get information about the other nodes on the network.

	getNetworkMap	Get a network map of connections.
	getNetworkFeed	Get a network feed of transactions.
	getNetworkParameters	Get network implementation parameters.
	getRegisteredFlows	Get a list of possible runnable flows for that node.
5	getTransactionsID	Get a list of transactions IDs where the node has been involved.
	getTransactionsInfoByID	Get information of a transaction by the ID.
	getNumberOfTransactions	Get the number of transactions in the network.
	getTransactionsInvolved	Get a list of transactions information where the node
10		has been involved.
	getNumberOfTransactionsInvolved	Get the number of transactions where the node has been involved.
	getNodeInfo	Get information about the node itself.
	getNodeTime	Get node current time.
15	getTransactions	Get a list of all transaction's information.
	getVodacoins	Get the number of "Vodacoins" in balance.
	postCreateTx	Create a transaction on the network. Described in the Business Logic Section.

20 For each node inside the distributed ledger (e.g. blockchain network) the API's are replicable and capable of running the same type of flows to interact with the rest of the network.

Business Logic

25 Since interactions with the DLT (e.g. Corda) are made through a set of established REST endpoints and SSH connections, a DAB Blockchain Service connector coordinates the call flows needed for inserting and retrieving data from the ledger. For triggering these scenarios, a collection of user layouts in the DAB App build transactions following a message format described in an Exposure layer.

30 For this functionality, the service payment scenario (useCaseType "service"), requires only a "newdata" transaction type. It is possible to manually trigger several use cases and scenarios using an application (DAB app), for example.

To pay for services like the Congestion Charges, one-time parking, or any other service, the user selects on the DAB App the menu entry "New Monetizable Data", tab
35 "Services", and fills out the fields:

Borrower - To who he wants to transfer tokens/value (service provider);

Value – Tokens quantity.

Type:

MIN - Duration amount (e.g. minutes).

5 CC - Congestion charge amount in monetary value.

PAY - Any other payments in monetary value.

Sub value – a numeric amount corresponding to the selected payment type (e.g.: 3 minutes, 3 euros, 3 Vodacoins)

VIN – Vehicle Vin

10 Slot ID – Optional field that can be used, for example, to specify a parking slot or toll port.

Location – Optional field that can be used, for example, to specify a congestion area entry point or a parking location.

ICCID – SIM Card ICCID or UICC.

15

This may be translated to a JSON object.

Automatically triggering and integration (e.g. automotive integration) provides improved direct interactions with the blockchain. Furthermore, settlement between network parties may be facilitated. The blockchain may register all the transaction made by consumers or between parties and so services are able to transact in the same network with settlements occurring between them. A smart contract/flow may determine a particular debt and automatically transfer funds from one party to another. Alternatively, external billing systems may aggregate all unitary transactions present on the network.

25

Use case: “Event Driven Fleet”

This use case directly may be used to generate data and provide a blockchain-based marketplace / exchange. This may be implemented in different situations and scenarios. In an example implementation, logistic companies may not make full use of freight cargo capacity. Sensor-generated data may be processed using edge confidential computing units to build “offer” datasets that, once shared in a marketplace or exchange, may be searched and bid on or bought by other parties or entities. In this example, the iExec platform was used to match jobs that are queued by the DAB Service and run by custom off-chain algorithms scripted by using iExec executed using Intel SGX enclaves.

35 This is shown schematically in figure 27.

Whenever a seller wants to sell a route, it manually or automatically fills out an UI in the DAB App that will request the DAB Service to insert it on the iExec marketplace other exchange. Another entity may uses a similar process or layout within an application to describe their needs. Compatible offers (both past and future) may be searched for and
5 matched. The DAB Service receives these queries and deploy matching jobs, notifying both parties if a match is found.

Automated deployment of datasets generated by detection algorithms may be employed.

10 Interfaces/Dependencies

In a test system, a set of user interfaces has been created in the DAB App (Android or iOS based) to build offer and demand transactions and send them to Transactions Engine of the DAB Service.

In order to use the marketplace / exchange, the DAB Service interacts with an iExec
15 SDK. This application is a command line NodeJS tool that wraps proprietary Ethereum transaction logic and another Blockchain Integration Layer connector for coordinating data insertion and retrieval. These operations each entail several OS calls to be run, where a set of ordered commands are issued to the SDK, which synchronously executes and returns textual JSON outputs that is processed and interpreted by the DAB Service. Since all iExec
20 off-chain algorithms are run on secure enclaves, the datasets they use are not directly inserted into their blockchain. Instead these are deployed into a public IPFS network (or other file system), once encrypted with a secret generated by the SDK. This secret, along with dataset's IPFS hash, are each pushed to iExec during the insertion flow: the secret is sent to the Secret Management Service, and the hash is sent to the blockchain. For IPFS
25 pinning services Piñata may be used. This implementation also use APIs.

The iExec SDK v4.0.3 was installed alongside the DAB Service instance in the same machine and required a configuration of NodeJS 8.10.0 and Docker 19.03.6.

The DAB App is used to create a set of user interfaces that build transactions that are sent to the DAB Service. This simulates capacity for offers and demand. However,
30 such processes are automated in production systems with offers and acceptances being generated by different entities and process. A similar message format is used with two different types of transactions:

if "transactionType" equals "newdata", then an offer dataset is contained, triggering the DAB Service to deploy it to the blockchain/marketplace/exchange;

if it equals "lookingfordata", then it carries a demand dataset, containing the desired trip parameters.

Since the matching algorithm prepared by iExec deals with a strict dataset format similar for both offer and demand, a JSON structure that typifies a test scenario where a
5 shipping company sells available truck space for hire at a certain price, date and route, both datasets inside the property "transactionObject".

Trading Information

To manually create a dataset describing a space offering for a truck trip, the user
10 selects on the DAB App the menu entry "New Monetizable Data", tab "Truck Capacity", and fills out the fields. In the production system, the dataset is created by individual trucks having sensors that can indicate capacity. The dataset includes:

Service Provider - Name of the service provider;
Offered Space – Quantity of available cargo units;
15 From – Trip origin;
To - Trip destination;
Date - Trip date;
Price – Asking price;

20 To manually create a dataset describing a request for a truck trip, the user selects on the DAB App the menu entry "Looking for Data", and fills out the fields:

Service Provider - Name of the entity looking for cargo space;
Required Space - Required cargo units;
From - Trip origin;
25 To - Trip destination;
Date - Trip date;
Price - Bid price.

Again, in the production system, the bids for cargo space may be automatically generated for entities requiring such services.

30

Upon reception of a "newdata" or "lookingfordata", the DAB Service begins a series of system level interactions with the iExec SDK. What is inserted into the iExec blockchain, is not the offer datasets themselves, but instead their IPFS hashes (along with other relevant iExec data).

If a “newdata” transaction identifies a dataset to be inserted into the marketplace/exchange, in turn, a “lookingfordata” triggers a DAB-side flow that requires looping through the previously inserted “newdata” datasets to sequentially deploy and poll off-chain matching tasks (to be run at an Intel SGX enclave worker pools managed by iExec). This process is shown schematically in figure 28.

A matching process entails the DAB Service selecting unmatched offer and demand dataset hashes and inserting them into a “task” into the iExec worker pools. These tasks are picked up and run by the iExec worker pool, and then repeatedly polled by the DAB Service until a result is calculated. The DAB Service keeps an updated list containing all dataset hashes in its database. This process is shown schematically in figure 29.

Since these off-chain tasks are unable to execute multiple comparisons at the same time, the DAB Service is responsible for issuing executions on a dataset-by-dataset basis. If a match is found between an offer and a demand, their dataset hashes are registered at the DAB Service database, and the buyer’s device notified.

In order to communicate matches to the devices that inserted both offer and demand datasets, Firebase Cloud Messaging platform may be used as it is a cross-platform cloud solution for messages and push notifications for Android applications, in particular. A component processes Firebase messaging for DAB-powered devices and all devices are made to register their Firebase connection token upon startup (sent along the device registration message POSTed to the DAB Service). Therefore, they are ready from boot. Again, in the production system, messages may be handled differently.

Automated feeding of data into the marketplace/exchange may be achieved using different mechanisms. For example, AI and sensor networks may be set up with automated market negotiations. Ready-made matching algorithms may also be deployed to secure worker pools.

In alternative implementations:

substituting IPFS with faster distributed storage solutions;

deploying matching algorithms capable of dealing with multiple datasets at the same time;

setting up specialized worker pools where the DAB Service unloads demand datasets and offer dataset hashes for continuous analysis providing asynchronous notification when a match is found.

Use Case: "Energy Identity & Payment"

This use enables "DAB-ready devices" (with secure element on SIM and respective middleware) to be integrated into the Energy Web Foundation smart energy platform and become active participants.

5 Connected devices exclusively read and digitally sign messages (all encoded in JWT strings) from Flexhub MQTT brokers. Asset owners' have programmed offer assignments (for buying or selling electrical power) and are managed and processed by the FlexHub platform. The DAB platform adds domain interconnection. This requires the DAB Service to be aware of transacted data and manipulates these data. Therefore, an
10 integration architecture uses the DAB Service broker for devices and processes messaging with FlexHub nodes on their behalf. EWF device-side code (originally written in Python) is ported into a Spring Boot component running on the DAB Core that now serves multiple devices, without impacting in any way on FlexHub functionalities. A schematic overview of this system is shown in figure 30.

15 The relevant user/actor/roles defined by EWF include:

 A TSO (transmission system operator) that submits requests for flexibility, defines constraints and limits and activates confirmed assets.

 Asset Owners define offer parameters so that each of their personal assets can submit offers consistent with those parameters.

20 Installers approve the registration of Asset Owners' assets.

 A Governing Body approves the registrations of other actor roles participating in the market.

 TSOs submit their energy flexibility requests and constraints into the system, Asset owners submit their offers (either themselves or via third-party providers of intelligence),
25 and the Flex system determines the lowest-cost way to meet the requests.

 Other enhancements may include:

 Registration, Provisioning, Offer creation automations.

 Devices beyond those using Android or Java.

30 Devices are requested to sign transactions and notified of offer activations. These are triggered by the DAB Service. This avoids devices from each device polling their respective FlexHub MQTT queues for instructions. The DAB App provides functionality including:

Devices receive messages containing EWF transactions for signing, which are then POSTed to a custom endpoint on the DAB Core Service API, triggering the DAB Core to complete a respective EWF business flow;

Whenever activation messages are received, the DAB App displays a user notification, which may be substituted by a useful and real action (e.g. turning on/off a device reachable from the mobile application). This is shown schematically in figure 31.

Business Logic

Flows are initiated from inputs made by the various EWF actors in the Flex WebApp. Since the DAB Service is the sole component that implements EWF business logic (and any sort of flow state observability), it asks devices to sign the various JWTs required by the FlexHub.

After signing the requested messages, devices return them to the DAB Service with enough information for it to determine which flow was running for the device sending the signed message. Devices may need to sign other JWTs apart from those pertaining to the use case at hand (one of the DAB stack objectives). Therefore, the Firebase Data Message format allow a fast adaptation for other scenarios. The property "useCase" specifies the DAB use case asking for a signature and, in order to identify the action to trigger on the DAB Service upon submittal, we felt appropriate to include an additional "useCaseAction" property to allow the server to distinguish between additional courses of actions within that particular use case. Figures 32 and 33 show a sequence diagram of this process.

For this integration the property "useCase" is tagged as "ewf", and the "useCaseAction" field was used to denote the specific EWF business flow that originally needed the device's signature.

In order to check the activation chart for a given offer as is fulfilled by a particular asset, Flex WebApp can also be used by Asset Owner and, through the dashboard a user can have access to the list of offers made, and select "data sheet" icon for the offer you wish to have charted.

Devices become part of the EWF network and this may be extended to further practical actions, such as turning on/off a generator, a battery, etc. The same is applicable to other marketplaces beyond flex grid, including Electric Vehicle Charging (EVC) or simple smart meter data monetization.

Use Case: "Business & Consumer Parking"

This use case uses digital identities (for people, services, and things) to create a full end-to-end experience where automobiles may be paired with services regardless of whether the payment:

- 5 1. is made either by the driver (a consumer B2C scenario - using the driver's digital identification and an associated private account within a banking platform);
2. charged to the car itself, whose use is kept on a DLT for later processing (an enterprise B2B scenario – where the car belongs to a third party, e.g., a rental company);

 The DAB Service manages and orchestrates flows (and hosting a Corda DLT for
10 use for B2B payments). The vehicle may contains an internal router that runs the DAB Middleware application and a customized version of the DAB App (e.g. a Tablet App). This may be installed at embedded (e.g. iOS or Android-based) dashboard computer.

Interfaces/Dependencies

15 A SPOT parking system may be installed at a same location as well as a Corda ledger similar to the "Service Payments" use case.

Secured by SIM

 For signing the transactions, the previously discussed Secured by SIM Approach may be used, consuming the PKI on SIM. The SIMs are added to a USB dongle which was
20 plugged into a processor or other device (e.g. a vehicle). DAB Middleware executes on the device, exposing the DAB Middleware API for signing as previously described.

 The SPOT parking system installed at parking infrastructure detects vehicles crossing its gates and operates with the DAB Service by calling an endpoint at a Custom API set (see above). This customization is used by SPOT to POST the license plate and
25 gate information to the DAB Service and in turn expect a return code to indicate if:

- On entry: a validated payment was setup and, therefore, the barrier can be opened;
- On exit: payment was completed, and the car can exit the park.

FINN

30 For managing the B2C scenario FINN (RTM) was used. This specialises in monetizing IoT solutions that are built on a commercial-ready platform including toolkits that add IoT payments to smart devices. In summary:

 A "product" provides a service and defines various actions for interacting with it, assigning for each a utilization price;

Devices register to use a “product”, whose actions are charged to a payment method setup by the device owner, such as a credit card;

Whenever a device triggers a “product” action, a micropayment is registered at the FINN ecosystem.

5 For FINN, a “product” can be any real system actuating on the real world (which integrate with a FINN IOT SDK for connecting “product” actions with any automated activity) or an abstract entity that stands for an offline service. All usage logic is within SPOT is controlled by a DAB Service component. Configured actions for this “product” include gate ingresses and egresses, respectively charged zero and a parking fee based
10 on the stay duration.

A sequence diagram for a parking session is shown in figure 34.

For triggering these scenarios, a collection of user layouts in the DAB App build transactions following the message format described in the DAB Management Core. For the car parking scenario (useCaseType “parking”), a session start and end are
15 distinguished by the value of their “transactionType” (“newdata” and “endcordasession”), and the content of “transactionObject”. This last field carries both purchaser (a car) and supplier (a car park) information to be committed to the DLT. Along with geographical information the DAB Service acts as a proxy server for each device (and used to verify device location when needed).

20 To begin a simulated parking session, the user selects on the DAB App the menu entry “New Monetizable Data, : tab “Parking, : and fills out the fields:

Initiator - Device starting the parking session (automatically filled with the device’s SIM ID);

Target - Corda node where the vehicle is register;

25 Target UUID - Corda identifier (UUID) of the initiator vehicle;

Source UUID - Corda identifier (UUID) of the parking slot chosen for parking the vehicle;

GPS Option:

30 MOCK_HAPPY_PATH - Starts a parking session using a GPS location: always results in a successful action;

REAL_GPS - Starts a parking session using the real GPS location, as read from the Android OS. If using this option to start a successful parking session, the initiator device and the parking slot should be at a maximum of 6m of each other;

35 To end a parking session, the user selects an open session in the “Transactions” menu entry, and fills out the fields:

Minutes/Value units that will be charged on the blockchain;

GPS Option:

MOCK_HAPPY_PATH - Stops the parking session using a GPS location; this results in a successful action;

- 5 REAL_GPS - Ends the parking session using the real GPS location of the device;
MOCK_END_SESSION_CAR_STILL_PARKED - a test flag that instructs the Corda DApp to act as if the car has not left the parking spot.

Business Logic

- 10 For this use case, the device using the “product” is the vehicle. However, its “actions” may be activated in B2C scenarios. Therefore, the concept of “Smart Services” has been used and is an association between users’ digital identities and services provided by a DAB stack.

- 15 DAB associates the device (car) with the SIM: Since this is a FINN-based Smart Service, the DAB Service needs to know all FINN data associated with the SPOT Parking “product” in order to pass it along to devices wanting to use it. This is done whenever the vehicle Tablet App (or other processor within the vehicle or device) starts up: installed alongside it is a FINN-provided app (embedding a FINN IOT SDK) that contains code to automatically set up that vehicle to be registered at the FINN Core backend and be ready to use the SPOT Parking “product” whenever required). This provisioning flow is shown in figure 35 and includes:
- 20

Step	Description	Trigger
25 1	Manufacturer adds a new car to the SCB-DAB system	Manufacturer
2	DAB will deploy a new smart contract for that car identity in the DDI blockchain network	DAB
3	The DDI blockchain network will respond with the corresponding did	DDI Blockchain
30 4	DAB will associate that did with the car license plate	DAB
5	DAB will send the car’s did to the corresponding car	DAB
6	The car will store its did in its database	Car

- Smart Service Onboarding: Whenever a user wishes to conduct a “Smart Service”
35 onboarding, he does it using a specially developed Android application (henceforth known

as “Smart Services App”). The app cooperates with a DID application for selecting a digital identity and associate with it a Smart Service chosen from its UI. This is shown schematically in figure 36.

5 At this point, if a user onboarded for using the “SPOT Parking Smart Service”, the DAB Service will have responded with enough data (the data sent at start by the Tablet app) for configuring user-side FINN payment methods, and, for this, the Smart Services app automatically communicates via intents with another FINN-supplied application (embedding the FINN Mobile SDK) that first asks the user for a valid paying credit card and
10 then registers it as a consumer of the SPOT Parking product. This is shown schematically in figure 37. The following steps may be taken in this example implementation.

B2C Service Onboarding (figure 37)

Step	Description	Trigger
15 1	Smart Services app triggers the DAB to create a new service for user	Smart Services App
2	DAB checks profile type (this case if Personal) and stores user data	DAB
20 3	DAB responds with data needed for User side initialization: user profile data + service data	DAB
4	Smart Service app triggers the Finn Mobile App to create a new service (via intents)	Smart Services App
5	Finn Mobile app forwards request to FINN Core	FINN Mobile Application
25 6	The FINN Core responds with a success or error message	FINN Core
7	Finn Mobile app responds with a success or error message (via intent return)	FINN Mobile Application
30 9	Smart Services app POSTs Finn onboarding confirmation to /services/confirmation	Smart Services App

Identify the device (e.g. car): In order to determine which car a user will be driving (and understand vehicle will trigger the FINN SPOT Parking “product” actions), a login
35 mechanism is established at the DAB platform that leverages on Digital Identity capabilities

to create sessions between users and things: in this way, whenever a car crosses an ingress gate, the DAB Service will know who is driving it. This flow is triggered when a driver inputs the car's license plate on the DAB App (pre-installed on the car's onboard tablet) and its subsequent activities can be divided in two phases:

- 5 QR Code generation: the DAB App generates a QR Code on the tablet for the driver to scan in order to proceed with the authentication process; and
- Driver authentication: the driver scans the QR Code triggering the DDI App to open. From there a driver authorises (or not) which personal information they want to share with the vehicle. While some of this data is compulsory, others are optional - this is a design
- 10 decision configured in the DAB (which acts as a proxy for all vehicles). All authorized information shared by the user may be stored in the DAB. This is shown schematically in figure 38.

Driver-Car Login through QR Code (figure 38)

15	Step	Description	Trigger
	1	Driver inputs license plate in the car tablet app	Tablet App
	2	Tablet App sends a login request to the DAB	Tablet App
	3	DAB generates a random topic UUID that identifies that login "session"	DAB
20	4	DAB request a nonce + authorization ID to the GCL	DAB
	5	GCL response: nonce + authID	GCL
	6	DAB associates the topic with nonce + authID + step 2 data	DAB
	7	DAB sends to the Tablet App data it needs to generate QR code	DAB
	8	Tablet App generates QR Code for authentication	Tablet App

25

Driver-Car Login through Decentralized Digital ID (DDI) (figure 39)

	Step	Description	Trigger
	1	The driver reads the QR Code with his phone (contains topic + car DID identity)	Driver
30	2	The DDI App will open and the driver will select and/or authorize the data he wants to share about himself	DDI App
	3	The DDI App shares that information with the	GCL
	4	The GCL will ask the blockchain for the DAB returnUrl stored in the provided car identity	GCL
35	5	The GCL POSTs that endpoint, checking for topic existence.	

	If topic exists, then DAB stores the indicated userDid pertaining to the user attempting to login.	GCL
6	DAB sends an Ok or error response to the GCL	DAB
7	GCL sends the login result to the DDI APP	GCL
5	8 Once the login result is successful, the DDI App POSTs the user profile + profile type to the DAB	DDI App
9	The DAB stores the user profile + profile type for this user/car session	DAB
10	The DAB sends the login result to the Tablet App	DAB
10	11 The Tablet App displays a success message	Tablet App

DAB service: The DAB Service is triggered every time SPOT POSTs information on detected vehicle license plates to a custom REST endpoint at the Custom API (implemented in accordance with specifications of the pre-existing SPOT infrastructure).

- 15 The ensuing logic required an additional component to be integrated within the DAB Core to manage the SPOT business flow, which can be summarised:

when a vehicle enters the car park:

- 20 if the Smart Service was onboarded with a B2B profile, the DAB Service uses the Corda connector at the Blockchain Integration Layer to open a session for that vehicle on the Corda DLT (mirroring the "Parking & Tolls" use case);
- if the Smart Service was onboarded with a B2C profile, a Firebase message is pushed to the vehicle's Tablet App to trigger a product activation on the Finn backend for the SPOT product identifier.

25

when a vehicle leaves the car park:

- if the Smart Service was onboarded with a B2B profile, the DAB Service closes the previously opened DLT session for that vehicle;
- if the Smart Service was onboarded with a B2C profile, a Firebase message is pushed to the vehicle's Tablet App to trigger a product deactivation on the Finn backend for the SPOT product identifier.

	B2B Start Parking flow detail (figure 40).	
	Step	Description
35	1	A camera at an entry gate scans a license plate
		Trigger
		Parking Gate

2	The parking gate request the DAB to start a new parking session for that license plate	Parking Gate
3	DAB checks user's DID profile type used for onboarding the parking service (this case if Business)	DAB
5	4 DAB triggers a new parking session in the Corda parking blockchain	DAB
5	5 Response from the blockchain to the DAB - success or error	Parking Blockchain
10	6 DAB sends a Firebase notification to the Tablet App notifying about a new parking session and returns step 2 with appropriate message, in turn triggering the gate to open	DAB
7	7 Tablet App show information on the screen regarding the new parking session	Tablet App
15	B2C Start Parking flow detail (figure 41)	
	Step Description	Trigger
	1 A camera in the parking gate scans a license plate	Parking Gate
20	2 The parking gate request the DAB to start a parking session for that license plate	Parking Gate
	3 DAB checks user's DID profile type used for onboarding the parking service (this case if Personal)	DAB
	4 DAB sends a Firebase notification to the Tablet App, triggering a Finn action (park entry)	DAB
25	5 Tablet App triggers to the FINN IoT SDK parking entry action, via intent	Tablet App
	6 FINN IoT SDK uses DAB Middleware to sign the transaction with the corresponding key pair	FINN IoT SDK
	7 FINN IoT SDK triggers a parking entry action in FINN Core	FINN IoT SDK
30	8 Response from the FINN Core to FINN IoT SDK - success or error	FINN Core
	9 FINN IoT SDK signals operation result via intent return and Tablet App displays notification popup	FINN IoT SDK
35	10 DAB returns from the POST made at step 2, triggering the gate to open	Tablet App

B2B End Parking flow detail (figure 42).

	Step	Description	Trigger
	1	A camera at an exit gate scans a license plate	Parking Gate
5	2	Gate requests the DAB to end a parking session for that license plate	Parking Gate
	3	DAB checks user's DID profile type used for onboarding the parking service (this case if Business)	DAB
10	4	DAB triggers a parking session close in the Corda parking blockchain	DAB
	5	Response from the blockchain to the DAB - success or error	Parking Blockchain
	6	DAB sends a Firebase notification to the Tablet App containing the parking session price and duration, and returns step 2 with appropriate message, in turn triggering the gate to open	DAB
15	7	Tablet App show information on the screen regarding the new parking session	Tablet App
20	B2B End Parking flow detail (figure 43)		
	Step	Description	Trigger
	1	A camera at an exit gate scans a license plate	Parking Gate
	2	Gate requests the DAB to end a parking session for that license plate	Parking Gate
25	3	DAB checks user's DID profile type used for onboarding the parking service (this case if Personal)	DAB
	4	DAB sends a Firebase notification to the Tablet App containing the parking session price and duration triggering a Finn action (park exit)	DAB
30	5	Tablet App triggers to the FINN IoT SDK parking exit action, via intent	Tablet App
	6	FINN IoT SDK uses DAB Middleware to sign the transaction with the corresponding key pair	FINN IoT SDK
	7	FINN IoT SDK triggers a parking exit action in FINN Core	FINN IoT SDK
35	8	Response from the FINN Core to FINN IoT SDK	

	- success or error	FINN Core
9	FINN IoT SDK signals operation result via intent return and Tablet App displays notification popup	FINN IoT SDK
10	DAB returns from the POST made at step 2,	
5	triggering the gate to open	Tablet App

A similar solution can be applied to different Parking solutions, and also to different domains in Smart Cities for example, where EV Charging and Tolls could follow the same flows. In terms of Consumer Digital ID and Payments, improvements on the end-to-end experience have been made

DAB User Interfaces

In the test environment there are two main User Interfaces (UI):

DAB APP: android (or other) mobile application

15 DAB AEP: Thingworx extension to connect DAB Corda Blockchain

UIs are important to enable customers to make use of all capabilities but also to allow operations and maintenance teams to manage the ecosystem and solution as well as monitoring and extracting information.

20 Figures 44 to 48 show example platform environments. Other server types and services may be used.

Although this describes a test scenario, a real parking session may be processed in a similar way but does not require the app. All messages may be initiated from sensors
25 within or around the vehicle (or parking location) and detected events.

As will be appreciated by the skilled person, details of the above embodiment may be varied without departing from the scope of the present invention, as defined by the appended claims.

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For example, different distributed ledgers or ledger technology may be used. The UICC may be an embedded SIM, for example. Many different types of devices may be used including mobile, movable, fixed, supervised, unsupervised, domestic, commercial or industrial devices, for example.

35

Many combinations, modifications, or alterations to the features of the above embodiments will be readily apparent to the skilled person and are intended to form part of the invention. Any of the features described specifically relating to one embodiment or example may be used in any other embodiment by making the appropriate changes.

CLAIMS:

1. A method for executing secure transactions, the method comprising the steps of:
initiating a secure communication channel between a device having a UICC and a
5 server, wherein the secure communication channel is secured using the UICC;
receiving at the server from the device over the secure communication channel, an
instruction to execute a transaction;
in response to the received instruction, transmitting from the server to a distributed
ledger a request to execute the transaction; and
10 in response to the request, signing the transaction at the distributed ledger using a
public and private key pair stored within the distributed ledger.
2. The method of claim 1, wherein the secure communication between the UICC and
the server is initiated using a public and private key pair stored on the UICC.
15
3. The method of claim 2 further comprising the step of generating the public and
private key pair within the UICC.
4. The method according to claim 1, wherein the secure communication between the
20 UICC and the server is initiated using a shared secret.
5. The method of claim 4, wherein the secret is shared between the UICC and the
server by:
storing the shared secret within the UICC and within a telecommunications network
25 component when the UICC is manufactured; and
the telecommunications network component sending the shared secret to the
server.
6. The method of claim 5, wherein the telecommunications network component is a
30 home location register, HLR.
7. The method of claim 4, wherein the shared secret is generated using generic
bootstrapping architecture, GBA.

8. The method of claim 7, wherein the secret is shared between the UICC and the server by:
generating the shared secret within the UICC and a bootstrapping server function, BSF; and
5 the BSF sending the shared secret to the server.
9. The method according to any previous claim, wherein the transaction is recorded on the distributed ledger with a wallet identifier associated with the device.
- 10 10. The method of claim 9 further comprising the step of generating the wallet identifier associated with the device on the distributed ledger by verifying the device using a different physical communication channel to the secure communication channel.
11. The method of claim 10, wherein the different physical channel is SMS.
15
12. The method according to any previous claim, wherein the transaction is a blockchain transaction.
13. The method according to any of claims 1 to 11, wherein the transaction is a credit
20 card or bank transaction.
14. A system comprising:
a device having a UICC;
a distributed ledger storing a public and private key pair;
25 a server having one or more processors and memory storing instructions configured to cause the one more processors to:
provide a secure communication channel with the device using the UICC;
receive from the device over the secure communication channel an
instruction to execute a transaction; and
30 in response to the received instruction, transmit from the server to the distributed ledger a request to execute the transaction,
wherein the distributed ledger has one or more processors and memory storing instructions configured to cause the one more processors of the distributed ledger to:
sign the transaction using the stored public and private key pair, in response
35 to a request from the server.

15. The system of claim 14, wherein the memory of the distributed ledger further comprises instructions configured to cause the one more processors of the distributed ledger to:

5 record on the distributed ledger a wallet identifier associated with the device,
 wherein the transaction is recorded on the distributed ledger with the wallet
 identifier associated with the device.

16. The system of claim 15, wherein the memory of the distributed ledger further comprises instructions configured to cause the one more processors of the distributed
10 ledger to:

 generate the wallet identifier associated with the device on the distributed
ledger by verifying the device using a different physical communication channel to the
secure communication channel.

15 17. The system according to any of claims 14 to 16, wherein the UICC of the device further comprises memory storing a secure applet comprising instructions to respond to verification requests.

20 18. The system according to any of claim 14 to 17, wherein the transactions are associated with an identifier of the device.