US 20190097806A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2019/0097806 A1**

Vann et al. (43) **Pub. Date: Mar. 28, 2019**

(54) **SYSTEM AND METHODS FOR RESOLVING DATA DISCREPANCIES IN A DISTRIBUTED SYSTEM WITH BLOCKCHAIN CONTROLS**

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(21) Appl. No.: **16/142,726**

(22) Filed: **Sep. 26, 2018**

Related U.S. Application Data

(60) Provisional application No. 62/563,996, filed on Sep. 27, 2017.

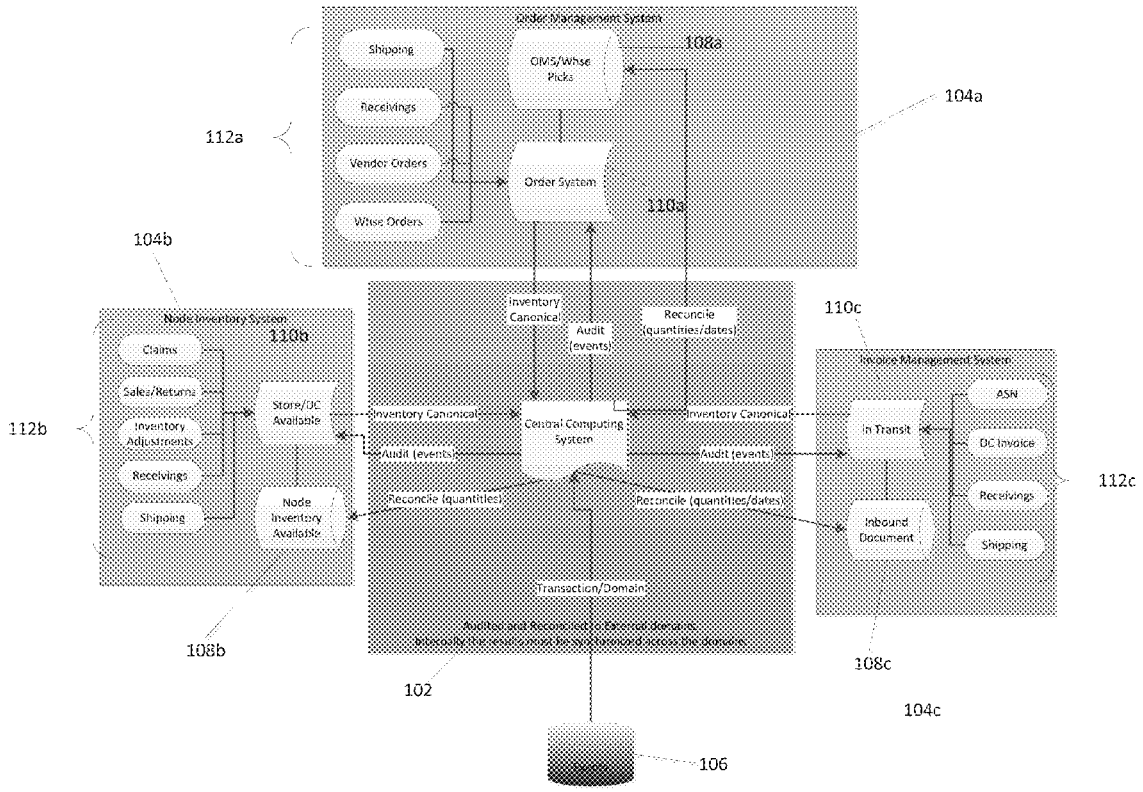
Publication Classification

(51) **Int. Cl.**
H04L 9/32 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 9/3236*** (2013.01); *G06Q 10/083* (2013.01); *H04L 2209/38* (2013.01)

(57) **ABSTRACT**

Described in detail herein is a system for resolving data discrepancies. A central computing system can generate a master cryptographically verifiable ledger. The central computing system can be in communication with independently operated domains. The central computing system can receive an event associated with at least one physical object. In response to receiving the event, the central computing system can generate an additional block containing one or more new transaction records in the master cryptographically verifiable ledger. The central computing system, can transmit an alert the independently operated domain affected by the one or more new transaction records. The independently operated domain can generate an additional sub-block in a sub cryptographically verifiable ledger associated with the first independently operated domain.



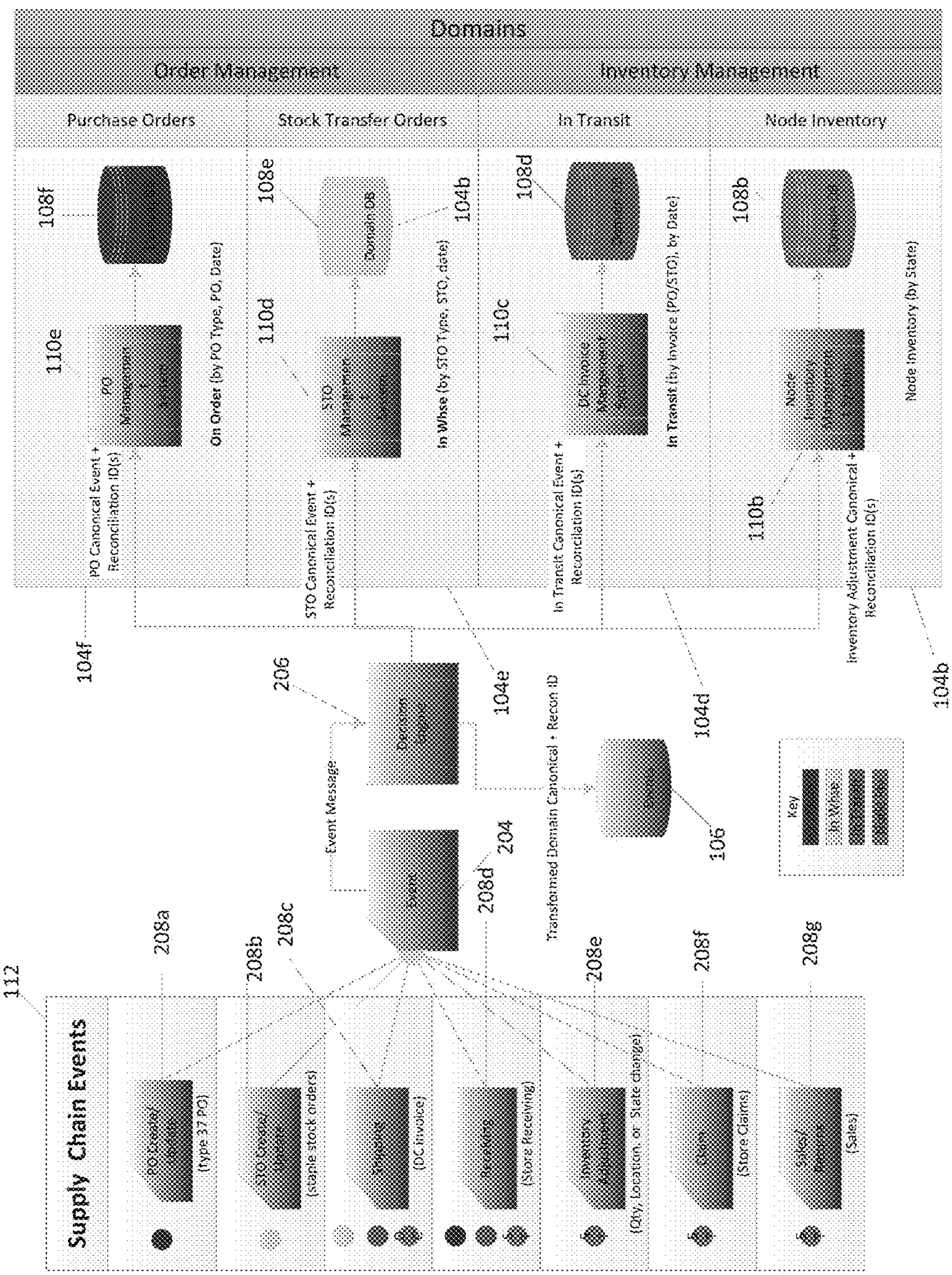

Domains
Order Management
Inventory Management
Purchase Orders
Stock Transfer Orders
In Transit
Node Inventory
108f
108e
108d
108b
104b
110e
110d
110c
110b
On Order (by PO Type, PO, Date)
In Whse (by STO Type, STO, date)
In Transit (by Invoice (PO/STO), by Date)
Node Inventory (by State)
PO Canonical Event + Reconciliation ID(s)
STO Canonical Event + Reconciliation ID(s)
In Transit Canonical Event + Reconciliation ID(s)
Inventory Adjustment Canonical + Reconciliation ID(s)
104f
104e
104d
104b
206
204
106
Event Message
Transformed Domain Canonical + Recon ID
Key
Supply Chain Events
112
208a
208b
208c
208d
208e
208f
208g
(type 37 PO)
(staple stock orders)
(DC Invoice)
(Store Receiving)
(Qty, Location, or State change)
(Store Claims)
(Sales)

FIG. 1

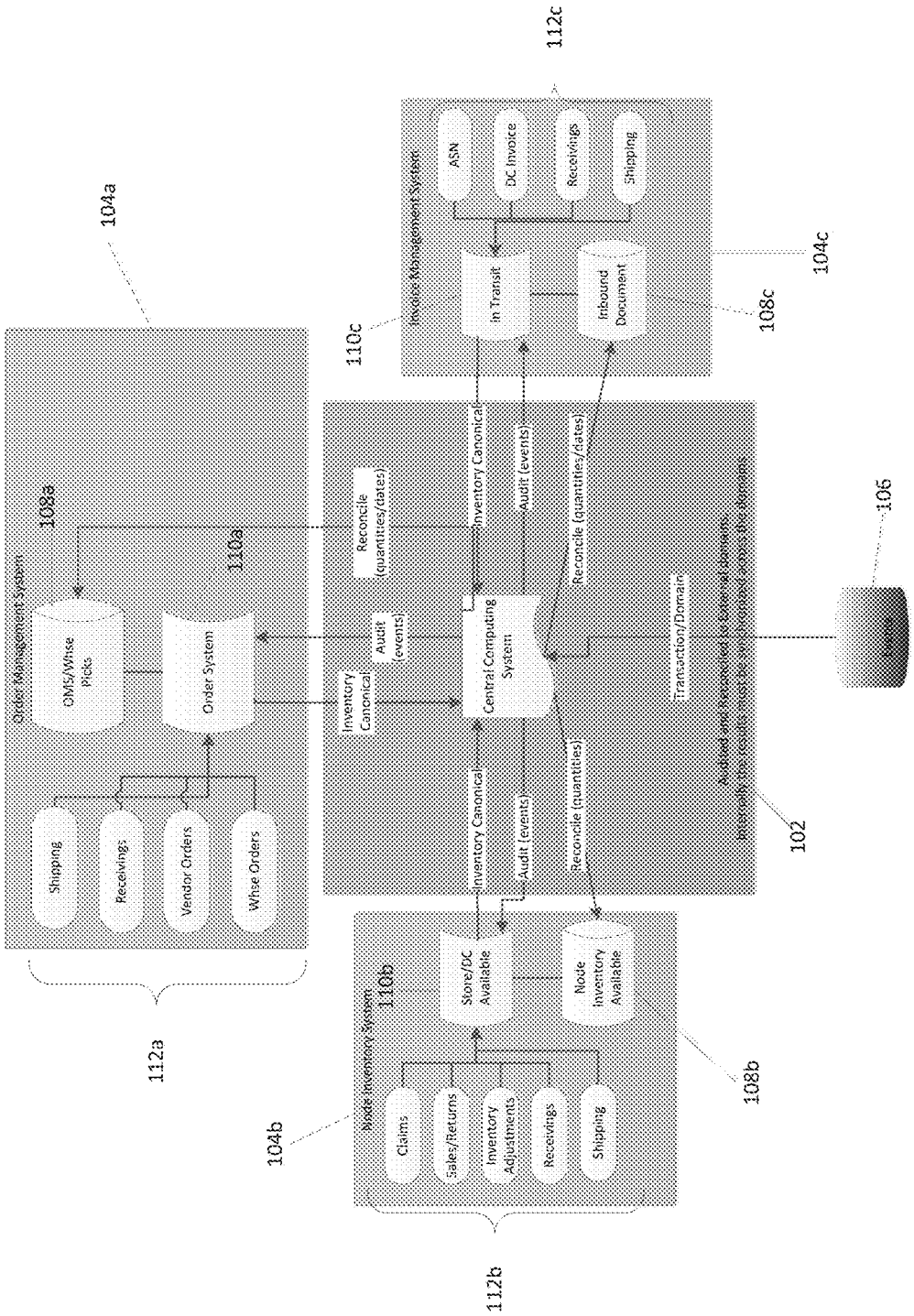

104a
Order Management System
108a
110a
OMS/Whse Picks
Order System
Shipping
Receivings
Vendor Orders
Whse Orders
112a
104b
Node Inventory System
110b
Claims
Sales/Returns
Inventory Adjustments
Receivings
Shipping
Store/DC Available
Node Inventory Available
108b
112b
Invoice Management System
110c
ASN
DC Invoice
Receivings
Shipping
In Transit
Inbound Document
108c
104c
112c
Reconcile (quantities/dates)
Inventory Canonical
Audit (events)
Central Computing System
Reconcile (quantities)
Transaction/Domain
102
106

FIG. 2

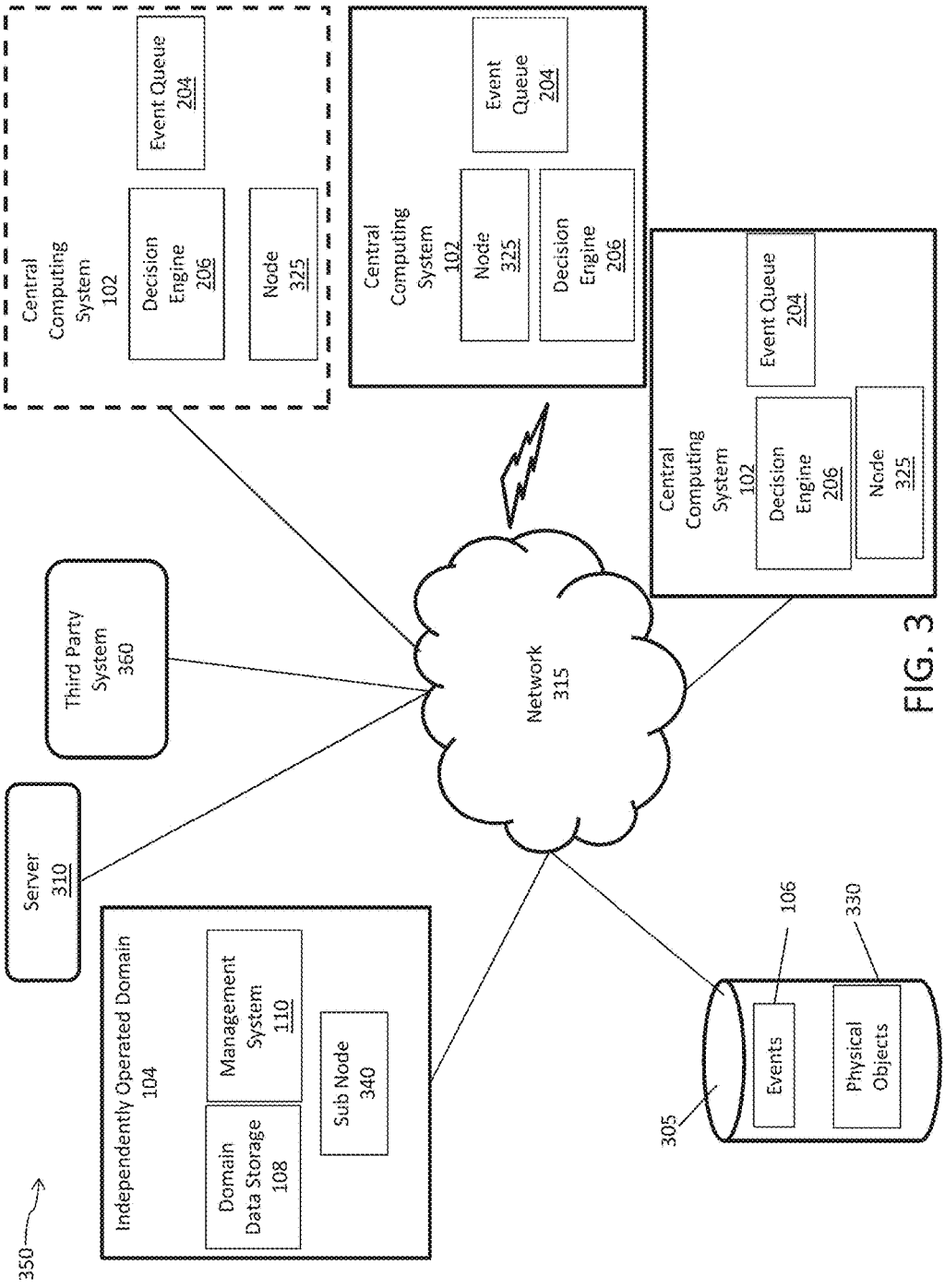

350
Independently Operated Domain
104
Domain Data Storage 108
Management System 110
Sub Node 340
Server 310
Third Party System 360
Network 315
Central Computing System 102
Decision Engine 206
Node 325
Event Queue 204
Central Computing System 102
Node 325
Decision Engine 206
Event Queue 204
Central Computing System 102
Decision Engine 206
Node 325
Event Queue 204
305
Events
106
Physical Objects
330

FIG. 3

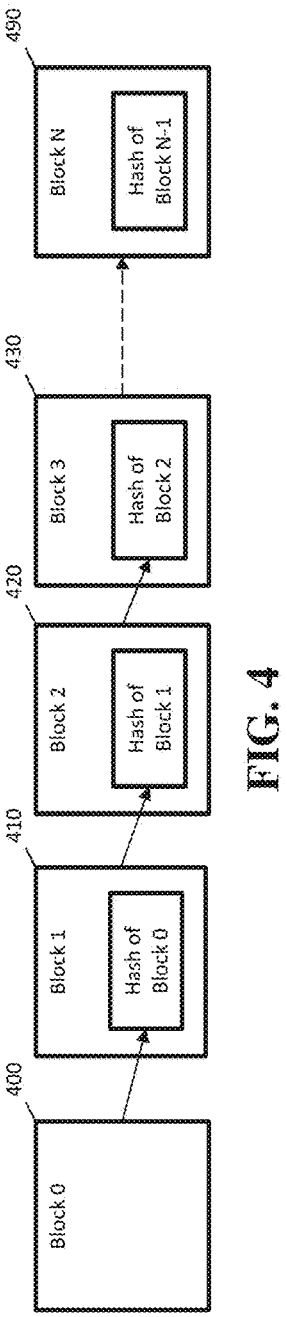

400
Block 0
410
Block 1
Hash of Block 0
420
Block 2
Hash of Block 1
430
Block 3
Hash of Block 2
490
Block N
Hash of Block N-1

FIG. 4

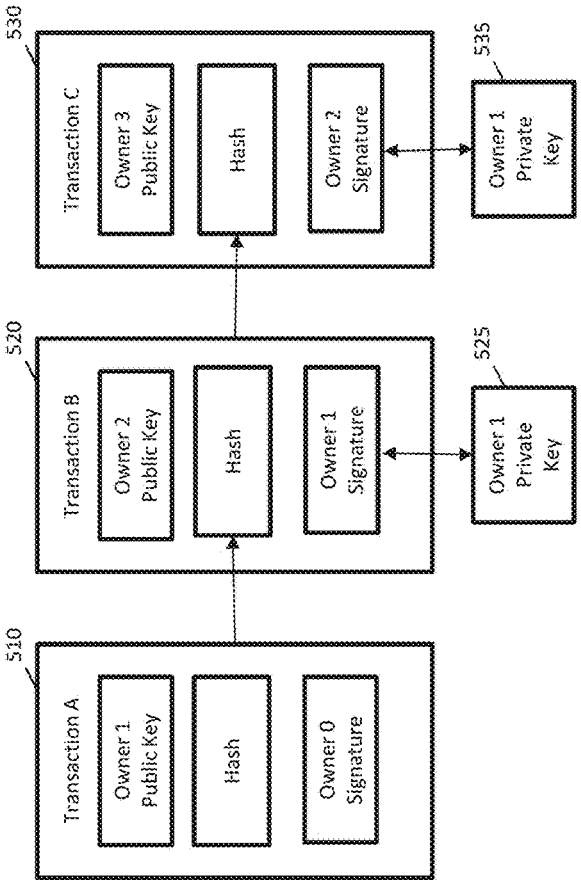

510
Transaction A
Owner 1 Public Key
Hash
Owner 0 Signature
520
Transaction B
Owner 2 Public Key
Hash
Owner 1 Signature
525
Owner 1 Private Key
530
Transaction C
Owner 3 Public Key
Hash
Owner 2 Signature
535
Owner 1 Private Key

FIG. 5

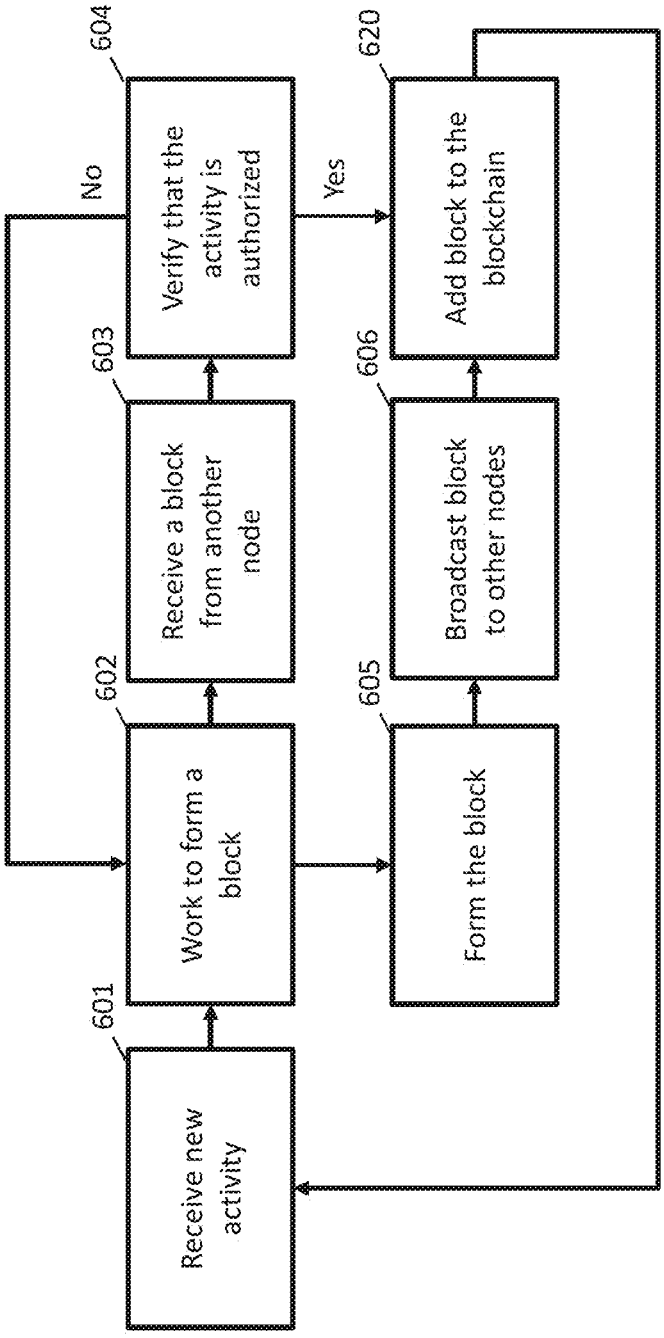

601
Receive new activity
602
Work to form a block
603
Receive a block from another node
604
Verify that the activity is authorized
No
Yes
605
Form the block
606
Broadcast block to other nodes
620
Add block to the blockchain

FIG. 6

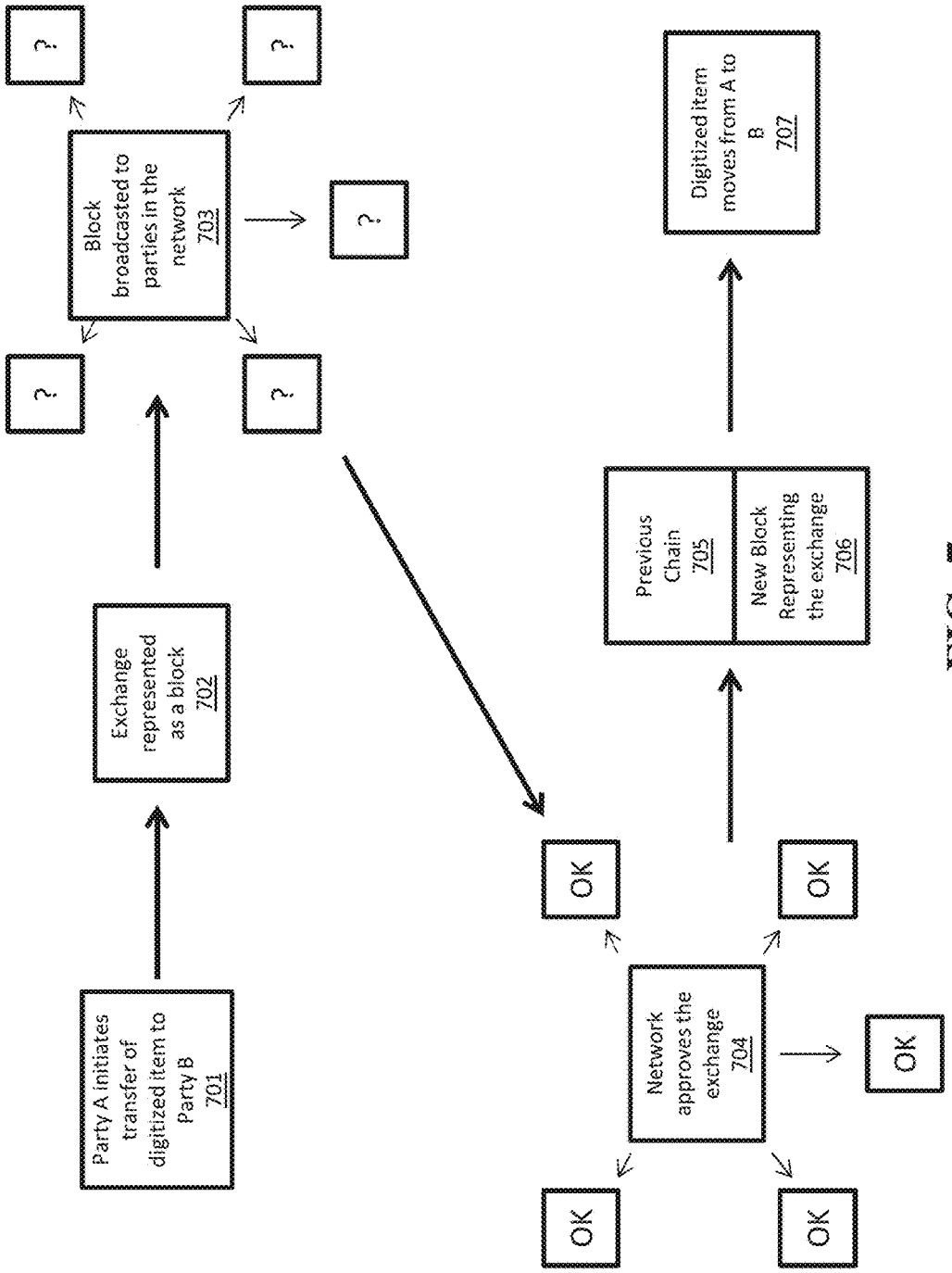

Party A initiates transfer of digitized item to Party B 701
Exchange represented as a block 702
Block broadcasted to parties in the network 703
?
?
?
?
?
Network approves the exchange 704
OK
OK
OK
OK
OK
Previous Chain 705
New Block Representing the exchange 706
Digitized item moves from A to B 707

FIG. 7

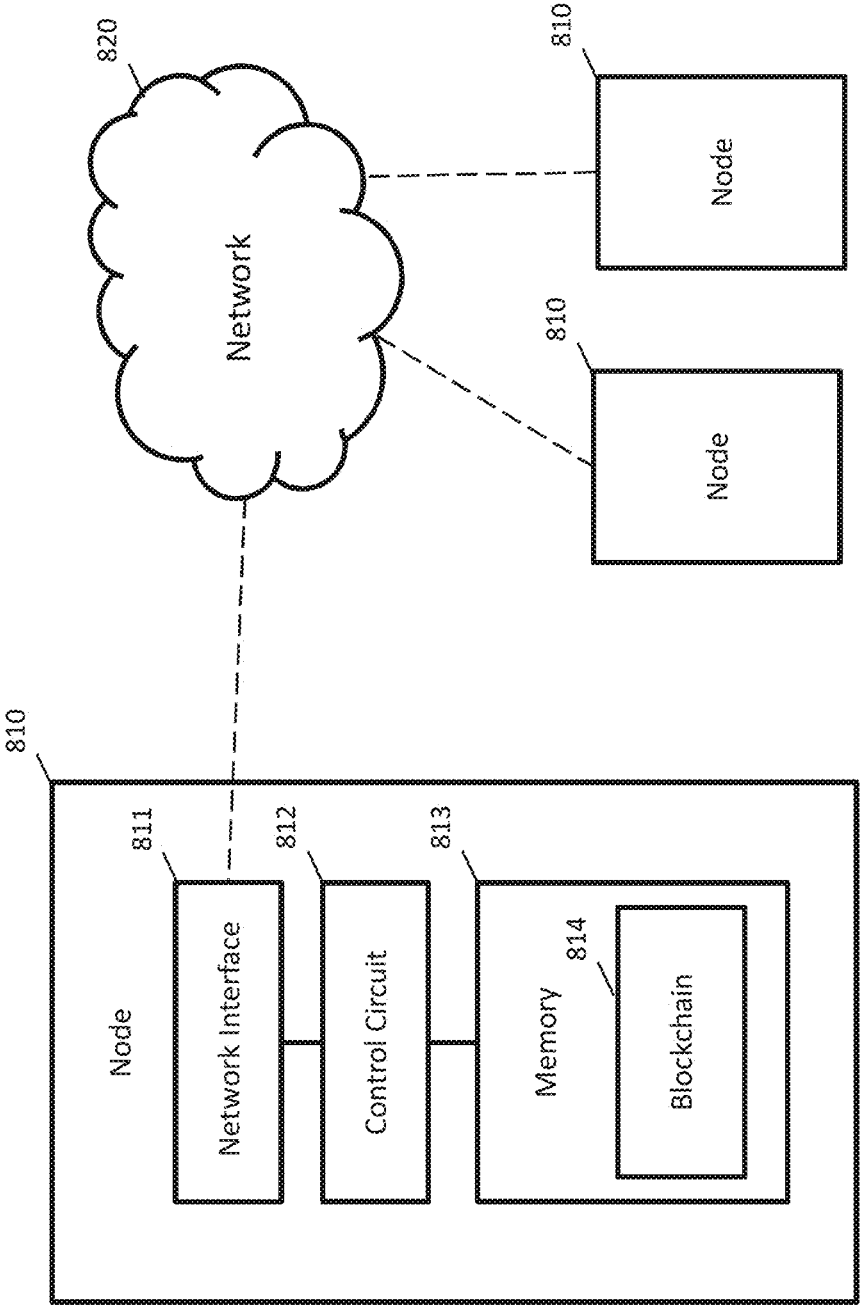

820
Network
810
Node
810
Node
810
Node
811
Network Interface
812
Control Circuit
813
Memory
814
Blockchain

FIG. 8

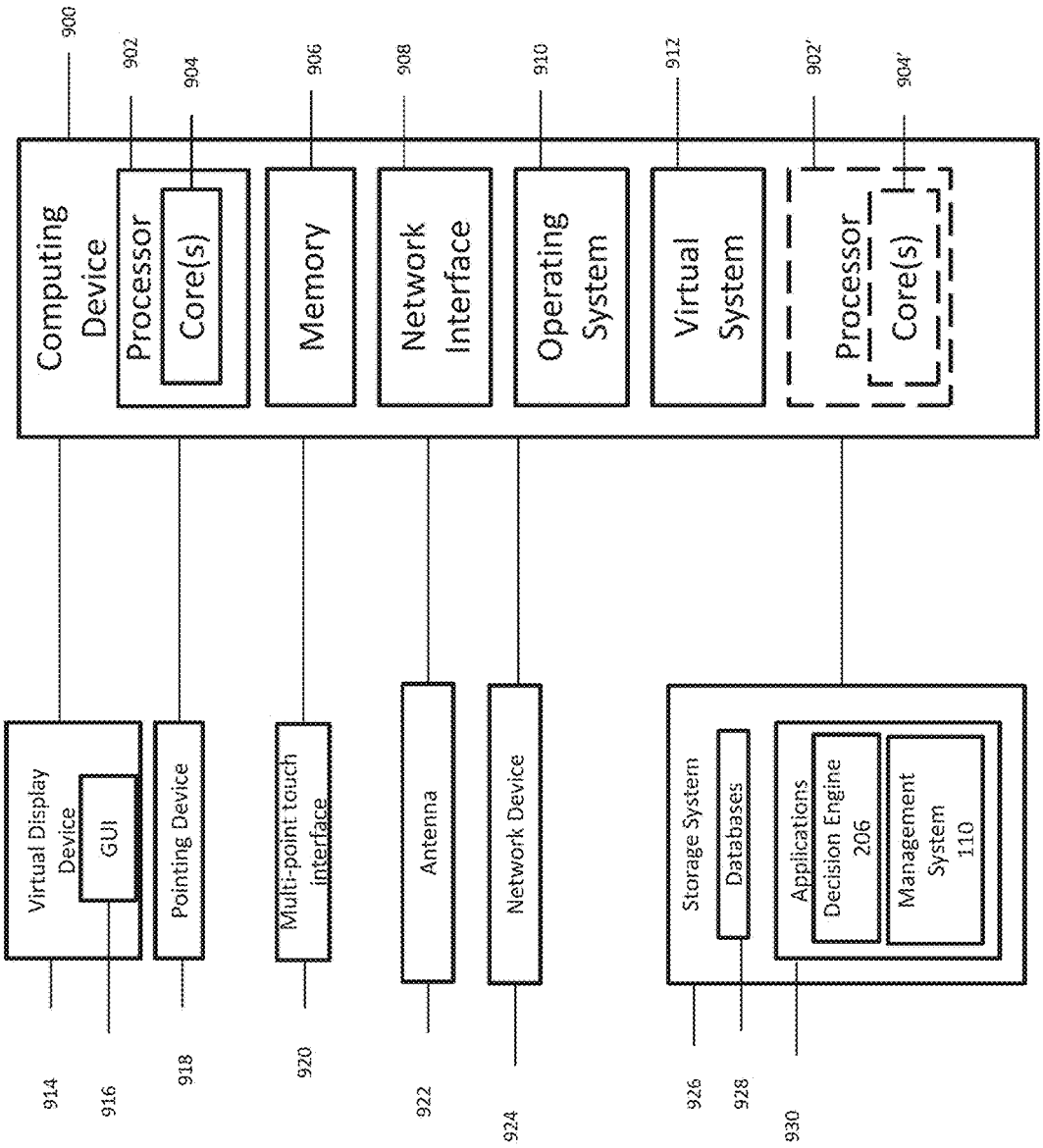

900
902
904
906
908
910
912
902'
904'
Computing Device
Processor
Core(s)
Memory
Network Interface
Operating System
Virtual System
Processor
Core(s)
Virtual Display Device
GUI
Pointing Device
Multi-point touch interface
Antenna
Network Device
Storage System
Databases
Applications
Decision Engine 206
Management System 110
914
916
918
920
922
924
926
928
930

FIG. 9

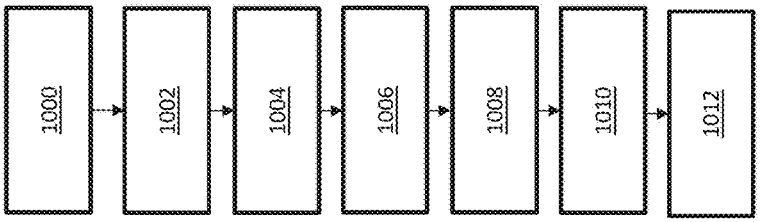


FIG. 10

SYSTEM AND METHODS FOR RESOLVING DATA DISCREPANCIES IN A DISTRIBUTED SYSTEM WITH BLOCKCHAIN CONTROLS

CROSS-REFERENCE TO RELATED PATENT APPLICATION

[0001] This application claims priority to U.S. Provisional Application 62/563,996 filed on Sep. 27, 2017, the content of which is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] Large distributed systems can encounter multiple errors and discrepancies when receiving updates to data.

BRIEF DESCRIPTION OF THE FIGURES

[0003] Illustrative embodiments are shown by way of example in the accompanying figures and should not be considered as a limitation of the present disclosure. The accompanying figures, which are incorporated in and constitute a part of this specification, illustrate one or more embodiments of the invention and, together with the description, help to explain the invention. In the figures:

[0004] FIG. **1** is a block diagram illustrating components of a system for resolving data discrepancies in accordance with an exemplary embodiment;

[0005] FIG. **2** is a block diagram illustrating components of the system for resolving data discrepancies in accordance with an exemplary embodiment;

[0006] FIG. **3** illustrates an exemplary network diagram of the system for resolving data discrepancies **100** in accordance with an exemplary embodiment;

[0007] FIG. **4** depicts an illustration of blocks as configured in accordance with an exemplary embodiment;

[0008] FIG. **5** depicts an illustration of transactions configured in accordance with an exemplary embodiment;

[0009] FIG. **6** depicts a flow diagram in accordance with an exemplary embodiment;

[0010] FIG. **7** depicts a process diagram as configured in accordance with an exemplary embodiment;

[0011] FIG. **8** depicts a system diagram configured in accordance with an exemplary embodiment;

[0012] FIG. **9** depicts a block diagram an exemplary computing device in accordance with an exemplary embodiment; and

[0013] FIG. **10** is a flowchart illustrating the process of a system for resolving data discrepancies using blockchain controls.

DETAILED DESCRIPTION

[0014] Described in detail herein is a system for resolving data discrepancies. A central computing system can generate a master cryptographically verifiable ledger represented by a sequence of blocks. Each block in the master cryptographically verifiable ledger can contain one or more transactions records. Each subsequent block can contain a hash value associated with the previous block. The central computing system can be in communication with independently operated systems/domains. The central computing system can receive an event associated with at least one physical object. In response to receiving the event, the central computing system can generate an additional block in the master cryptographically verifiable ledger. The additional block can contain one or more new transaction records associated with the event.

[0015] The central computing system can determine which of the independently operated domains are affected by the event captured in the one or more transaction records included in the one additional block. The central computing system can transmit an alert to the independently operated domain(s) affected by the one or more new transaction records to notify at least one independently operated domain of the generation of the at least one additional block in the master cryptographically verifiable ledger. The independently operated domains each maintain a separate and distinct sub cryptographically verifiable ledger represented by a sequence of sub-blocks specific to the respective independently operated domain. For example, an independently operated domain can receive the alert and verify the event. The independently operated domain can generate an additional sub-block in a sub cryptographically verifiable ledger associated with the independently operated domain. The sub-block can contain the one or more transaction records associated with the event and a hash value associated with the additional block in the master cryptographically verifiable ledger as well as a hash value to the previous block in the sub cryptographically verifiable ledger associated with the independently operated domain. Embodiments of the system facilitates asynchronously communicating and reconciling event data from various disparate sources in real time, so that embodiments of the system can provide an accurate view of the system state and data at any particular point in time despite delays in propagation of data through the system. The system is configured to resolve data discrepancies within the central computing system and independently operated domains. Additionally, the system is configured to automatically verify changes/updates to data and audit the independently operated domains to assure the independently operated domains are reflecting the most current and accurate data.

[0016] The independently operated domain is further configured to transmit another alert to the central computing system and to one or more of the other independently operated domains. In response to receiving the alert, the central computing system can verify the one or more transactions in at least one additional sub-block that is generated by the independently operated domain in the sub cryptographically verifiable ledger.

[0017] In one embodiment, an independently operated domain can receive the other alert, verify the event, and generate an additional sub-block in a sub cryptographically verifiable ledger associated with the independently operated domain. The additional sub-block generated in the sub cryptographically verifiable ledger can contain the one or more transaction records associated with the event. In response to the independently operated domain generating the additional sub-block, the central computing system can determine another independently operated domain failed to generate an expected sub-block based on the alert, and triggers the independently operated domain that failed to generate the expected sub-block to generate the expected sub-block in the third sub cryptographically verifiable ledger associated with the independently operated domain.

[0018] FIGS. **1-2** depict block diagrams illustrating components of a system **100** for resolving data discrepancies in accordance with an exemplary embodiment. Referring to

FIGS. **1** and **2**, the system **100** can include a central computing system **102**, multiple independently operated domains **104**, and an events database **106**. As a non-limiting example, the independently operated domains **104** can include but are not limited to a computing system for an order data management system **104***a*, a computing system for a node inventory data management system **104***b*, and a computing system for an invoice data management system **104***c*.

[0019] Each of the independently operated domains **104** can include a domain data storage device **108** and a data management system **110**. Each of the independently operated domains **104** can also generate various events **112**. The events **112** can be associated with transaction records of physical objects. Continuing with the non-limiting example described above, the order data management system **104***a* can generate events **112***a* associated with shipping, receiving, vendor orders, and warehouse orders. The node inventory system **104***b* can generate events **112***b* associated with claims, sales/returns, inventory adjustment, receiving, and shipping. The invoice data management system **112** can generate events associated with Advance Ship Notice (ASN), Distribution Center, aka Warehouse (DC) invoice, receiving, and shipping.

[0020] Events **112** generated at the independently operated domains **104**, can be transmitted to the central computing system **102**, via the data management systems **110**. The independently operated domains can update data in the domain databases **110** in response to the events **112**. The central computing system **102** can store the events in the event database **106**. The central computing system **102** can identify independently operated domains **104** affected by the received events and instruct the independently operated domains **104** to update the respective domain databases **110**. For example, the data in the domain database of one of the independently operated domains may need to be updated based on an event that is generated by another one of the independently operated domains to maintain data consistency across the system **100**. The central computing system **102** can recognize that the event affects the independently operated domains and can instruct the independently operated domain to update the data in the domain database **108** associated with the independently operated domain. In response, to updating the data in the domain database, the independently operated domain may generate its own event, which may propagate through the system **100** resulting in additional updates to data in the various domain databases **110** in the system.

[0021] The central computing system **102** can include an event queue **204** and a decision engine **206**. The decision engine **206** can be an executable configured to implement system **100**. As a non-limiting example, the central computing system **102** can receive events **112** such as a purchase order event **208***a*, STO Create/Update event **208***b*, shipping event **208***c*, receiving event **208***d*, inventory adjustment **208***e*, claims event **208***f* and sales return event **208***g*. The independently operated domains **104** can include a node inventory domain **104***b*, in-transit domain **104***d*, stock transfer order domain **104***e* and a purchase order domain **104***f*. Each of the domains **104***a-f* can be formed by one or more computing devices executing one or more applications to facilitate event generation and one or more database operations.

[0022] An event **112** such as a shipping event **208***c* from the node inventory domain **104***b* can be transmitted to the event queue **204**. The decision engine **206** can pull a shipping event **208***c* from the event queue **204** and store the event in the event database **106**. The decision engine **206** can determine the data in the shipping event **208***c* affects data in the purchase order domain **104***f* and the in-transit domain **104***d*. The decision engine **206** can instruct the purchase order domain **104***f* and in-transit domain **104***d* to update the data in the respective domain databases **108***f* and **108***d*, respectively.

[0023] The event database **106** can be embodied as a master cryptographically verifiable ledger and the domain databases **108** can be embodied as separately maintained sub cryptographically verifiable ledgers. The master and sub cryptographically verifiable ledgers are described in further detail herein with reference to FIG. **3**.

[0024] FIG. **3** illustrates an exemplary network diagram of an embodiment of the system **100** for resolving data discrepancies in accordance with an exemplary embodiment. In the present example embodiment, the system **100** can include one or more data storage devices **305**, one or more central computing systems **102**, and one or more independently operated domains **104**. The central computing system **102** can be in communication with the data storage devices **305** and with the independently operated domains **104**, via a communications network **315**. The central computing system **102** can execute at least one instance of a decision engine **206**. The central computing system **102** can include one or more nodes **325**. Each of the one or more nodes **325** can store a copy of a master blockchain record and/or a shared ledger associated with events. The one or more nodes **325** can be configured to update the blocks in the master blockchain record based on the operation of transfer of one or more physical objects.

[0025] The independently operated domains **104** can include domain data storage **108**, a data management system **110** and a sub node **340**. The domain database **108** can be embodied as a blockchain storage system that is configured to store a blockchain record or a shared ledger based on events of data associated with the independently operated domain. The node **340** can store a copy of a sub blockchain record and/or a shared ledger, stored in the domain database **108**, and associated events of data associated with the independently operated domain **104**.

[0026] In an example embodiment, one or more portions of the communications network **315** can be an ad hoc network, an intranet, an extranet, a virtual private network (VPN), a local area network (LAN), a wireless LAN (WLAN), a wide area network (WAN), a wireless wide area network (WWAN), a metropolitan area network (MAN), a portion of the Internet, a portion of the Public Switched Telephone Network (PSTN), a cellular telephone network, a wireless network, a WiFi network, a WiMax network, another type of network, or a combination of two or more such networks.

[0027] The central computing system **102** includes one or more computers or processors configured to communicate with the data storage devices **305**, and the independently operated domains **104**. The data storage devices **305** can store information/data, as described herein. For example, the data storage devices **305** can include an events database **106** and a physical objects database **330**. The events database **106** can be embodied as a blockchain storage system that is

configured to store a blockchain record or a shared ledger based on data affected by received events associated with physical objects. The events database **106** can be a master blockchain. As a non-limiting example, the event database **106** can store transaction records associated with physical objects such as invoices, purchase orders, inventory records, sales/returns records, vendor orders, claims, shipping orders, and/or receiving orders. The central computing system **102** can use the blocks of the blockchain to store transaction records associated with the events and to resolve data discrepancies between the independently operated domains **104**, as described herein. The data storage devices **305** and the central computing system **102** can be located at one or more geographically distributed locations from each other. Alternatively, the data storage devices **305** can be included within the central computing system **102**.

[0028] In an exemplary embodiment, the central computing system **102** can receive an event associated with one or more physical objects, from an independently operated domain **104** and/or a third party system **360**. The event can indicate data affected based on the occurrence of the event. For example, the event can include transaction records associated with the one or more physical objects. The information can include identifiers associated with the physical objects and the location of the event. The central computing system **104** can execute the control engine **320** in response to receiving the event.

[0029] The node **325** can generate a new block in the events database **106**. The block can store transaction records associated with the one or more physical objects based on the received event. The control engine **320** can query the physical objects database **330** to identify independently operated domains **104** for which data would be affected by the transaction records of the event. If the central computing system **102** receives the event from an independently operated domain **104**. The identified independently operated domains **104** can be different than the independently operated domain which transmitted the event. The control engine **320** can transmit an alert of the creation of the new block in the events database **106**. The alert can include the public and/or private key of the new block.

[0030] The identified independently operated domains **104** can receive the alert. The data management system **110** of an independently operated domain **104** which has received the alert, can access the transaction records in the new block stored in the events database **106**. The data management system **110** can verify the occurrence of the event based on the transaction records. For example, the data management system **110** can query the physical objects database **330** and the domain database **108** to confirm whether the data in the transaction records corresponds with the data stored in the physical objects database **330** and the domain database **108**. In response to verification of the event, the data management system **110** can query the physical objects database **330** to identify the data associated with the independently operated domain **104** that is affected by the accessed transaction records. The sub-node **340** can generate a new block in the domain database **108**. The new block can contain new transaction records that can represent data associated with the independently operated domain **104** affected by the transaction records accessed from the new block stored in the events database **106** and a hash value associated with the block in the events database **106**. The data management system **110** of the independently operated domain **104** can transmit an alert of the new block to the central computing system **102**.

[0031] In response to the data management system **110** of the independently operated domain **104** accessing the transaction records in the new block stored in the events database **106**, the node **325** can generate a new block which stores the information associated with the data management system **110** accessing the new block. The decision engine **206** can determine that an identified independently operated domain **104**, to which an alert was sent, did not access the transaction records stored in the new block over a specified amount of time. In response to determining the identified independently operated domain **104** that has not accessed the transaction records stored in the new block, has also not generated a new block in the domain database **108**, the decision engine **206** can trigger the sub node **340** to generate a new block in the domain database **108** of the independently operated domain **104**. The new block can store new transaction records representing data affected based on the transaction records stored in the new block in the events database **106**.

[0032] In one embodiment, in response to generating a new block stored in the domain database **108** of an independently operated domain **104**, the data management system **110** of the independently operated domain **104** can query the physical objects database **330** to determine other independently operated domains **104** for which data is affected by the transactions records stored in the new block stored in the domain database **108** of the independently operated domain **104**. The independently operated domain **104** can transmit an alert to the other domains. The alert can include the public and/or private key to the new block stored in the domain database **108**. The other independently operated domains **104** can verify the event received by the central computing system **102** based on accessing the transaction records stored in the new block stored in the domain database **108**. The other independently operated domains **104** can generate new blocks including transaction records in their respective domain databases **108**. The transaction records can represent data affected by transaction records stored in the new block in the domain database **108** of the independently operated domain **104**, which transmitted the alert.

[0033] In one embodiment, the data management system **110** can fail to verify the event. In response to failing to verify the event, the data management system **110** can transmit an alert to the central computing system **102**. The central computing system **102** can delete the new block and/or generate a new block adjusting the transaction records to reflect the data accurately.

[0034] In one embodiment, the central computing system **102** can include an event queue **365**. The event queue can be a data structure configured to receive events. It can be appreciated that the central computing system **102** can receive multiple events contemporaneously. The events can be received by the event queue and processed in a First In First Out (FIFO) order by the decision engine **206**.

[0035] In one embodiment an independently operated domain **104** is configured to receive an alert associated with an event from the central computing system **102**, verify the event, and generate an additional block in a domain database **108**, the additional block containing the one or more transaction records associated with the event. In response to the

independently operated domain generating the additional block, the central computing system can determines another independently operated domain failed to generate an expected sub-block based on the alert and triggers the generation of the expected sub-block in a domain database **108** of the other independently operated domain **104** based on the alert.

[0036] As a non-limiting example, system for resolving data discrepancies **100** can be implemented as in a retail store and/or e-commerce website. For example, the independently operated domains **104** can be domains for storing and processing inventory, sales, purchase orders, or retail store stock rooms. The physical objects can be embodied as products sold at the retail store and/or e-commerce website.

[0037] In one example, one independently operated domain **104** can be embodied as an inventory domain and another independently operated domain can be embodied as an in-transit domain. The in-transit domain can transmit an event associated with shipping of products from a warehouse to a retail store to the central computing system **102**. The central computing system **102** can receive the event.

[0038] The node **325** can generate a new block in the events database **106**. The block can store transaction records associated with the shipment of products from the warehouse. The control engine **320** can query the physical objects database **330** to identify independently operated domains **104** for which data would be affected by the transaction records of the event. The decision engine **104** can identify the inventory domain has an independently operated domain that is affected by the transaction records of the shipment of products from the warehouse to the retail store. The control engine can **320** transmit an alert of the creation of the new block in the events database **106** to the inventory domain. The alert can include the public and private key of the new block.

[0039] The inventory domain can receive the alert. The data management system **110** of the inventory domain, can access the transaction records in the new block stored in the events database **106**. The data management system **110** can verify the occurrence of the event based on the transaction records. In response to verification of the event, the data management system **110** can query the physical objects database **330** to identify the data associated with the inventory domain that is affected by the accessed transaction records. The sub-node **340** can generate a new block in the domain database **108**. The new block can contain new transaction records that represent data associated with the inventory domain affected by the transaction records accessed from the new block stored in the events database **106**. For example, the inventory domain can increase the amount of products at the retail store based on the shipment of products from the warehouse to the retail store.

[0040] Descriptions of some embodiments of blockchain technology are provided with reference to FIGS. **4-8** herein. In some embodiments, blockchain technology may be utilized for resolving data discrepancies in a distributed system as described herein. One or more of the central computing systems and independently operated domains as described herein may comprise a node in a distributed blockchain system storing a copy of the blockchain record. Updates to the blockchain may comprise information associated with events associated with physical objects received by the central computing system, and one or more nodes on the system may be configured to incorporate one or more events into blocks to add to the distributed database.

[0041] Distributed database and shared ledger database generally refer to methods of peer-to-peer record keeping and authentication in which records are kept at multiple nodes in the peer-to-peer network instead of being kept at a trusted party. However, exemplary embodiments of the present disclosure can also utilize a private (trusted) system to maintain the blockchains. A blockchain may generally refer to a distributed database that maintains a growing and ordered list or chain of records in which each block contains a hash of some or all previous records in the chain to secure the record from tampering and unauthorized revision. A hash generally refers to a derivation of original data. In some embodiments, the hash in a block of a blockchain may comprise a cryptographic hash that is difficult to reverse and/or a hash table. Blocks in a blockchain may further be secured by a system involving one or more of a distributed timestamp server, cryptography, public/private key authentication and encryption, proof standard (e.g. proof-of-work, proof-of-stake, proof-of-space), and/or other security, consensus, and incentive features. In some embodiments, a block in a blockchain may comprise one or more of a data hash of the previous block, a timestamp, a cryptographic nonce, a proof standard, and a data descriptor to support the security and/or incentive features of the system.

[0042] In some embodiments, the system for resolving data discrepancies comprises a distributed timestamp server comprising a plurality of nodes configured to generate computational proof of record integrity and the chronological order of its use for content, trade, and/or as a currency of exchange through a peer-to-peer network. In some embodiments, when a blockchain is updated, a node in the distributed timestamp server system takes a hash of a block of items to be timestamped and broadcasts the hash to other nodes on the peer-to-peer network. The timestamp in the block serves to prove that the data existed at the time in order to get into the hash. In some embodiments, each block includes the previous timestamp in its hash, forming a chain, with each additional block reinforcing the ones before it. In some embodiments, the network of timestamp server nodes performs the following steps to add a block to a chain: 1) new activities are broadcasted to all nodes, e.g., resulting from in-field authentication of autonomous electronic devices, 2) each node collects new activities into a block, 3) each node works on finding a difficult proof-of-work for its block, 4) when a node finds a proof-of-work, it broadcasts the block to all nodes, 5) nodes accept the block only if activities are authorized, and 6) nodes express their acceptance of the block by working on creating the next block in the chain, using the hash of the accepted block as the previous hash. In some embodiments, nodes may be configured to consider the longest chain to be the correct one and work on extending it.

[0043] Now referring to FIG. **4**, an illustration of a blockchain according to embodiments of the present disclosure is shown. As mentioned in above, with reference to FIG. **3**, a blockchain comprises a hash chain or a hash tree in which each block added in the chain contains a hash of the previous block. In FIG. **4**, block **0 400** represents a genesis block of the chain and can be generated in response to an event received associated with one or more physical objects. The block **0 400** can include information associated with the event associated with the physical objects and a hash key

and a timestamp. The information associated with the event received associated with one or more physical objects can include information associated with the physical objects and information associated with the event, such as the delivery of the physical object, a quantity of the at least one physical object, name of the at least one physical object, type of the at least one physical object and size of the at least one physical object, and/or transfer of the ownership of physical objects. Block **1 410** can be generated in response to a verification of the event. The block **1 410** can contain a hash of block **0 400**. The block **1 410** can include the information associated with the event and the physical objects. Otherwise, the block **1 410** can include information that an event was not verified. Additional blocks can be generated as additional requests are received and each block that is generated can include a hash of a previous block. For example, block **2 420** can be generated in response to a subsequent request and can contain a hash of block **1 410**, block **3 430** can be generated in response to a yet another subsequent request and can contain a hash of block **2 420**, and so forth. Continuing down the chain, block N contains a hash of block N−1. In some embodiments, the hash may comprise the header of each block. Once a chain is formed, modifying or tampering with a block in the chain would cause detectable disparities between the blocks. For example, if block **1** is modified after being formed, block **1** would no longer match the hash of block **1** in block **2**. If the hash of block **1** in block **2** is also modified in an attempt to cover up the change in block **1**, block **2** would not then match with the hash of block **2** in block **3**. In some embodiments, a proof standard (e.g. proof-of-work, proof-of-stake, proof-of-space, etc.) may be required by the system when a block is formed to increase the cost of generating or changing a block that could be authenticated by the consensus rules of the distributed system, making the tampering of records stored in a blockchain computationally costly and essentially impractical. In some embodiments, a blockchain may comprise a hash chain stored on multiple nodes as a distributed database and/or a shared ledger, such that modifications to any one copy of the chain would be detectable when the system attempts to achieve consensus prior to adding a new block to the chain. In some embodiments, a block may generally contain any type of data and record. In some embodiments, each block may comprise a plurality of transaction and/or activity records.

[0044] In some embodiments, the blocks generated by the central computing system can contain rules and data for authorizing different types of actions and/or parties who can take action as described herein. In some embodiments, transaction and block forming rules may be part of the software algorithm on each node. When a new block is being formed, any node on the system can use the prior records in the blockchain to verify whether the requested action is authorized. For example, a block may contain a public key associated with the user of a user device that purchased/acquired the physical object, this design that allows the user to show possession and/or transfer the digital license using a private key. Nodes may verify that the user is in possession of the one or more physical objects and/or is authorized to transfer the one or more physical objects based on prior events when a block containing the transaction is being formed and/or verified. In some embodiments, rules themselves may be stored in the blockchain such that the rules are also resistant to tampering once created and hashed into a block. In some embodiments, the blockchain system may further include incentive features for nodes that provide resources to form blocks for the chain. Nodes can compete to provide proof-of-work to form a new block, and the first successful node of a new block earns a reward.

[0045] Now referring to FIG. **5**, an illustration of blockchain based transactions according to some embodiments is shown. In some embodiments, the blockchain illustrated in FIG. **5** comprises a hash chain protected by private/public key encryption. Transaction A **510** represents an event in a block of a blockchain showing that owner **1** (recipient) (e.g., a central computing system creating a new block with transaction records associated with physical objects, based on a received event). Transaction A **510** contains owner's **1** public key and owner **0**'s signature for the transaction and a hash of a previous block. When owner **1**, central computing system transmits an alert including the public key and private key, to an independently operated domain, of the newly generated block storing the transaction records, and the independently operated domain accesses the transaction record, a block containing transaction B **520** is formed. The record of transaction B **520** comprises the public key of owner **2** (recipient), a hash of the previous block, and owner **1**'s signature for the transaction that is signed with the owner **1**'s private key **525** and verified using owner **1**'s public key in transaction A **510**. If owner **2** (e.g., the independently operated domain) transmits an alert including the public key and private key, to an independently operated domain, of the newly generated block storing the transaction records to owner **3** (a different independently operated domain), a block containing transaction C **530** is formed. The record of transaction C **530** comprises the public key of owner **3** (recipient), a hash of the previous block, and owner **2**'s signature for the transaction that is signed by owner **2**'s private key **535** and verified using owner **2**'s public key from transaction B **620**. In some embodiments, when each event is created, the system may check previous events and the current owner's private and public key signature to determine whether the transaction is valid. In some embodiments, transactions are broadcasted in the peer-to-peer network and each node on the system may verify that the transaction is valid prior to adding the block containing the transaction to their copy of the blockchain. In some embodiments, nodes in the system may look for the longest chain in the system to determine the most up-to-date event to prevent the current owner from double spending the asset. The transactions in FIG. **5** are shown as an example only. In some embodiments, a blockchain record and/or the software algorithm may comprise any type of rules that regulate who and how the chain may be extended. In some embodiments, the rules in a blockchain may comprise clauses of a smart contract that is enforced by the peer-to-peer network.

[0046] Now referring to FIG. **6**, a flow diagram according to some embodiments is shown. In some embodiments, the steps shown in FIG. **6** may be performed by a computer system as described in FIG. **3**, a server, a distributed server, a timestamp server, a blockchain node, and the like. In some embodiments, the steps in FIG. **6** may be performed by one or more of the nodes in a system using blockchain for record keeping.

[0047] In step **601**, a node receives a new activity in response to receiving an event associated with physical objects. The new activity may comprise an update to the record being kept in the form of a blockchain with transac-

tion records. In some embodiments, the new activity may be broadcasted to a plurality of nodes on the network prior to step **601**. For example, the nodes of independently operated domains may be notified. In step **602**, the node works to form a block to update the blockchain. In some embodiments, a block may comprise a plurality of activities or updates and a hash of one or more previous blocks in the blockchain. In some embodiments, the system may comprise consensus rules for individual transactions and/or blocks and the node may work to form a block that conforms to the consensus rules of the system. In some embodiments, the consensus rules may be specified in the software program running on the node. For example, a node may be required to provide a proof standard (e.g. proof of work, proof of stake, etc.) which requires the node to solve a difficult mathematical problem or form a nonce in order to form a block. In some embodiments, the node may be configured to verify that the activity is authorized prior to working to form the block. In some embodiments, whether the activity is authorized may be determined based on records in the earlier blocks of the blockchain itself.

[0048] After step **602**, if the node successfully forms a block in step **605** prior to receiving a block from another node, the node broadcasts the block to other nodes over the network in step **606**. In step **620**, the node then adds the block to its copy of the blockchain. In the event that the node receives a block formed by another node in step **603** prior to being able to form the block, the node works to verify that the activity (e.g., authentication of transfer) recorded in the received block is authorized in step **604**. In some embodiments, the node may further check the new block against system consensus rules for blocks and activities to verify whether the block is properly formed. If the new block is not authorized, the node may reject the block update and return to step **602** to continue to work to form the block. If the new block is verified by the node, the node may express its approval by adding the received block to its copy of the blockchain in step **620**. After a block is added, the node then returns to step **601** to form the next block using the newly extended blockchain for the hash in the new block.

[0049] In some embodiments, in the event one or more blocks having the same block number is received after step **620**, the node may verify the later arriving blocks and temporarily store these block if they pass verification. When a subsequent block is received from another node, the node may then use the subsequent block to determine which of the plurality of received blocks is the correct/consensus block for the blockchain system on the distributed database and update its copy of the blockchain accordingly. In some embodiments, if a node goes offline for a time period, the node may retrieve the longest chain in the distributed system, verify each new block added since it has been offline, and update its local copy of the blockchain prior to proceeding to step **601**.

[0050] Now referring to FIG. **7**, a process diagram, a blockchain update according to some implementations is shown. In step **701**, party A (the central computing system) receives an event associated with physical objects. In some embodiments, Party A may be authenticated by signing the transaction with a private key that may be verified with a public key in the previous transaction associated with the physical objects. In step **702**, the authentication initiated in step **701** is represented as a block. In some embodiments, the transaction may be compared with events in the longest chain in the distributed system to verify part A's authentication. In some embodiments, a plurality of nodes in the network may compete to form the block containing the authentication record. In some embodiments, nodes may be required to satisfy proof-of-work by solving a difficult mathematical problem to form the block. In some embodiments, other methods of proof such as proof-of-stake, proof-of-space, etc. may be used in the system. In step **703**, the block is broadcasted to parties in the network. In step **704**, nodes in the network authenticate party A by examining the block that contains the party A's authentication. In some embodiments, the nodes may check the solution provided as proof-of-work to approve the block. In some embodiments, the nodes may check the transaction against the event in the longest blockchain in the system to verify that the transaction is valid (e.g. party A is in possession of the object to be transferred). In some embodiments, a block may be approved with consensus of the nodes in the network. After a block is approved, the new block **706** representing the authentication is added to the existing chain **705** comprising blocks that chronologically precede the new block **706**. The new block **706** may contain the transaction(s) and a hash of one or more blocks in the existing chain **705**. In some embodiments, each node may then update their copy of the blockchain with the new block and continue to work on extending the chain with additional transactions. In step **707**, when the chain is updated with the new block, the physical objects can be transferred from party A to party B (e.g., from the first mobile autonomous electronic device to the second autonomous electronic device).

[0051] Now referring to FIG. **8**, a system according to some embodiments is shown. A location verification system comprises a plurality of nodes **810** communicating over a network **820**. In some embodiments, the nodes **810** may be comprise a distributed blockchain server and/or a distributed timestamp server. Each node **810** in the system comprises a network interface **811**, a control circuit **812**, and a memory **813**.

[0052] The control circuit **812** may comprise a processor, a microprocessor, and the like and may be configured to execute computer readable instructions stored on a computer readable storage memory **813**. The computer readable storage memory may comprise volatile and/or non-volatile memory and have stored upon it a set of computer readable instructions which, when executed by the control circuit **812**, causes the node **810** update the blockchain **814** stored in the memory **813** based on communications with other nodes **810** over the network **820**. In some embodiments, the control circuit **812** may further be configured to extend the blockchain **814** by processing updates to form new blocks for the blockchain **814**. Generally, each node may store a version of the blockchain **814**, and together, may form a distributed database. In some embodiments, each node **810** may be configured to perform one or more steps described with reference to FIGS. **6-8** herein.

[0053] The network interface **811** may comprise one or more network devices configured to allow the control circuit to receive and transmit information via the network **820**. In some embodiments, the network interface **811** may comprise one or more of a network adapter, a modem, a router, a data port, a transceiver, and the like. The network **820** may comprise a communication network configured to allow one or more nodes **810** to exchange data. In some embodiments, the network **820** may comprise one or more of the Internet,

a local area network, a private network, a virtual private network, a home network, a wired network, a wireless network, and the like. In some embodiments, the system does not include a central server and/or a trusted third party system. Each node in the system may enter and leave the network at any time.

[0054] With the system and processes shown, once a block is formed, the block cannot be changed without redoing the work to satisfy census rules thereby securing the block from tampering. A malicious attacker would need to provide proof standard for each block subsequent to the one he/she seeks to modify, race all other nodes and overtake the majority of the system to affect change to an earlier record in the blockchain.

[0055] In some embodiments, blockchain may be used to support a payment system based on cryptographic proof instead of trust, allowing any two willing parties to transact directly with each other without the need for a trusted third party. A blockchain system uses a peer-to-peer distributed timestamp server to generate computational proof of the chronological order of transactions. Generally, a blockchain system is secure as long as honest nodes collectively control more processing power than any cooperating group of attacker nodes. With a blockchain, the events are computationally impractical to reverse. As such, sellers are protected from fraud and buyers are protected by the routine escrow mechanism.

[0056] In some embodiments, in the peer-to-peer network, the longest chain proves the sequence of events witnessed, proves that it came from the largest pool of processing power, and that the integrity of the document has been maintained. In some embodiments, the network for supporting blockchain based record keeping requires minimal structure. In some embodiments, messages for updating the record are broadcast on a best-effort basis. Nodes can leave and rejoin the network at will and may be configured to accept the longest proof-of-work chain as proof of what happened while they were away.

[0057] FIG. **9** is a block diagram of an example computing device for implementing exemplary embodiments of the present disclosure. Embodiments of the computing device **900** can implement embodiments of the system for resolving data discrepancies. For example, the computing device can be embodied as a portion of the central computing system, independently operated domains and/or third party system. The computing device **900** includes one or more non-transitory computer-readable media for storing one or more computer-executable instructions or software for implementing exemplary embodiments. The non-transitory computer-readable media may include, but are not limited to, one or more types of hardware memory, non-transitory tangible media (for example, one or more magnetic storage disks, one or more optical disks, one or more flash drives, one or more solid state disks), and the like. For example, memory **906** included in the computing device **900** may store computer-readable and computer-executable instructions or software (e.g., applications **930** such as the decision engine **206** and the data management system **110**) for implementing exemplary operations of the computing device **900**. The computing device **900** also includes configurable and/or programmable processor **902** and associated core(s) **904**, and optionally, one or more additional configurable and/or programmable processor(s) **902'** and associated core(s) **904'** (for example, in the case of computer systems having multiple processors/cores), for executing computer-readable and computer-executable instructions or software stored in the memory **906** and other programs for implementing exemplary embodiments of the present disclosure. Processor **902** and processor(s) **902'** may each be a single core processor or multiple core (**904** and **904'**) processor. Either or both of processor **902** and processor(s) **902'** may be configured to execute one or more of the instructions described in connection with computing device **900**.

[0058] Virtualization may be employed in the computing device **900** so that infrastructure and resources in the computing device **900** may be shared dynamically. A virtual machine **912** may be provided to handle a process running on multiple processors so that the process appears to be using only one computing resource rather than multiple computing resources. Multiple virtual machines may also be used with one processor.

[0059] Memory **906** may include a computer system memory or random access memory, such as DRAM, SRAM, EDO RAM, and the like. Memory **906** may include other types of memory as well, or combinations thereof. The computing device **900** can receive data from input/output devices such as, an image capturing device **934**. The image capturing device **934** can capture still or moving images. A user may interact with the computing device **900** through a visual display device **914**, such as a computer monitor, which may display one or more graphical user interfaces **916**, multi touch interface **920** and a pointing device **918**.

[0060] The computing device **900** may also include one or more storage devices **926**, such as a hard-drive, CD-ROM, or other computer readable media, for storing data and computer-readable instructions and/or software that implement exemplary embodiments of the present disclosure (e.g., applications such as the decision engine **206** and the data management system **110**). For example, exemplary storage device **926** can include one or more databases **928** for storing information associated with physical objects and events associated with the physical objects. The databases **928** may be updated manually or automatically at any suitable time to add, delete, and/or update one or more data items in the databases.

[0061] The computing device **900** can include a network interface **908** configured to interface via one or more network devices **924** with one or more networks, for example, Local Area Network (LAN), Wide Area Network (WAN) or the Internet through a variety of connections including, but not limited to, standard telephone lines, LAN or WAN links (for example, 802.11, T1, T3, 56 kb, X.25), broadband connections (for example, ISDN, Frame Relay, ATM), wireless connections, controller area network (CAN), or some combination of any or all of the above. In exemplary embodiments, the central computing system can include one or more antennas **922** to facilitate wireless communication (e.g., via the network interface) between the computing device **900** and a network and/or between the computing device **900** and other computing devices. The network interface **908** may include a built-in network adapter, network interface card, PCMCIA network card, card bus network adapter, wireless network adapter, USB network adapter, modem or any other device suitable for interfacing the computing device **900** to any type of network capable of communication and performing the operations described herein.

[0062] The computing device **900** may run any operating system **910**, such as any of the versions of the Microsoft® Windows® operating systems, the different releases of the Unix and Linux operating systems, any version of the MacOS® for Macintosh computers, any embedded operating system, any real-time operating system, any open source operating system, any proprietary operating system, or any other operating system capable of running on the computing device **900** and performing the operations described herein. In exemplary embodiments, the operating system **910** may be run in native mode or emulated mode. In an exemplary embodiment, the operating system **910** may be run on one or more cloud machine instances.

[0063] FIG. **10** is a flowchart illustrating an exemplary process of an embodiment of the system for resolving data discrepancies in accordance with the present disclosure. In operation **1000**, a central computing system (e.g. central computing system **102** as shown in FIGS. **1** and **3**) can generate a master cryptographically verifiable ledger (e.g. events database **106** as shown in FIGS. **1-3**) represented by a sequence of blocks, each block containing one or more transactions records and each subsequent block containing a hash value associated with the previous block. The central computing system can be in communication with independently operated domains (e.g. independently operated domains **104** as shown in FIGS. **1-3**). In operation **1002**, the central computing system can receive an event (e.g. event **112** as shown in FIG. **1-2**) associated with at least one physical object. In operation **1004**, in response to receiving the event, the central computing system can generate an additional block containing one or more new transaction records associated with the event, in the master cryptographically verifiable ledger.

[0064] In operation **1006**, the central computing system can determine an independently operated domains affected by the one or more transaction records included in the one additional block. In operation **1008**, the central computing system, can transmit an alert the independently operated domain affected by the one or more new transaction records to notify at least one independently operated domain of the generation of the at least one additional block in the master cryptographically verifiable ledger. The independently operated domains are each associated with a sub cryptographically verifiable ledger (e.g. domain database **108** as shown in FIGS. **1-3**) represented by a sequence of sub-blocks. In operation **1010** the first independently operated domain can receive alert and verify the event. In operation **1012**, the independently operated domain can generate an additional sub-block in a first sub cryptographically verifiable ledger associated with the first independently operated domain. The first sub-block can contain the one or more transaction records associated with the event and a hash value associated with the additional block in the master cryptographically verifiable ledger.

[0065] In describing exemplary embodiments, specific terminology is used for the sake of clarity. For purposes of description, each specific term is intended to at least include all technical and functional equivalents that operate in a similar manner to accomplish a similar purpose. Additionally, in some instances where a particular exemplary embodiment includes a multiple system elements, device components or method steps, those elements, components or steps may be replaced with a single element, component or step. Likewise, a single element, component or step may be replaced with multiple elements, components or steps that serve the same purpose. Moreover, while exemplary embodiments have been shown and described with references to particular embodiments thereof, those of ordinary skill in the art will understand that various substitutions and alterations in form and detail may be made therein without departing from the scope of the present disclosure. Further still, other aspects, functions and advantages are also within the scope of the present disclosure.

[0066] Exemplary flowcharts are provided herein for illustrative purposes and are non-limiting examples of methods. One of ordinary skill in the art will recognize that exemplary methods may include more or fewer steps than those illustrated in the exemplary flowcharts, and that the steps in the exemplary flowcharts may be performed in a different order than the order shown in the illustrative flowcharts.

1. A system for resolving data discrepancies in a distributed system, the system comprising:

a central computing system in communication with a plurality of independently operated domains, the central computing system configured to:

generate a master cryptographically verifiable ledger represented by a sequence of blocks, each block containing one or more transactions records and each subsequent block containing a hash value associated with the previous block;

receive an event associated with at least one physical object;

in response to receiving the event, generate at least one additional block containing one or more new events associated with the event, in the master cryptographically verifiable ledger;

determine at least a first one of the plurality of the independently operated domains affected by the one or more new events included in the at least one additional block;

transmit a first alert to at least one independently operated domain affected by the one or more new events to notify at least one independently operated domain of the generation of the at least one additional block in the master cryptographically verifiable ledger;

wherein the plurality of independently operated domains are each associated with a sub cryptographically verifiable ledger represented by a sequence of sub-blocks, and

wherein the first independently operated domain is configured to receive the first alert, verify the event, and generate a at least one additional sub-block in a first sub cryptographically verifiable ledger associated with the first independently operated domain, the first sub-block containing the one or more events associated with the event and a hash value associated with the at least one additional block in the master cryptographically verifiable ledger.

2. The system of claim **1**, wherein the first independently operated domain is configured to transmit a second alert to the central computing system and one or more of the independently operated domains different than the first independently operated domain.

3. The system of claim **2**, wherein in response to receiving the second alert, the central computing system is configured to verify the one or more transactions in the at least one

additional sub-block generated by the first independently operated domain in the at least one sub cryptographically verifiable ledger.

4. The system of claim **2**, wherein the one or more independently operated domains include a second independently operated domain and a third independently operated domain.

5. The system of claim **4**, wherein the third independently operated domain is configured to receive the second alert, verify the event, and generate at least one additional sub-block in a third sub cryptographically verifiable ledger associated with the third independently operated domain, the additional sub-block generated in the third sub cryptographically verifiable ledger containing the one or more events associated with the event, and the third independently operated domain being further configured to transmit a third alert indicating the generation of the at least one additional block in the third sub cryptographically verifiable ledger to the central computing system.

6. The system of claim **5**, wherein in response to receiving the third alert, the central computing system determines the second independently operated domain failed to generate an expected sub-block based on the second alert and triggers the generation of the expected sub-block in a second sub cryptographically verifiable ledger associated with the second independently operated domain based on the second alert.

7. The system of claim **1**, wherein the one or more events are associated with a delivery of the at least one physical object.

8. The system of claim **1**, wherein the one or more events include a quantity of the at least one physical object, name of the at least one physical object, type of the at least one physical object and size of the at least one physical object.

9. The system of claim **1**, wherein the event is the transfer of ownership of the at least one physical object.

10. A method for resolving data discrepancies in a distributed system, the method comprising:

generating, via a central computing system in communication with a plurality of independently operated domains, a master cryptographically verifiable ledger represented by a sequence of blocks, each block containing one or more transactions records and each subsequent block containing a hash value associated with the previous block;

receiving, via the central computing system, an event associated with at least one physical object;

in response to receiving the event, generating, via the central computing system, at least one additional block containing one or more new events associated with the event, in the master cryptographically verifiable ledger;

determining, via the central computing system, at least a first one of the plurality of the independently operated domains affected by the one or more new events included in the at least one additional block;

transmitting, via the central computing system, a first alert to at least one independently operated domain affected by the one or more new events to notify at least one independently operated domain of the generation of the at least one additional block in the master cryptographically verifiable ledger;

wherein the plurality of independently operated domains are each associated with a sub cryptographically verifiable ledger represented by a sequence of sub-blocks, and

wherein the first independently operated domain is configured to receive the first alert, verify the event, and generate a at least one additional sub-block in a first sub cryptographically verifiable ledger associated with the first independently operated domain, the first sub-block containing the one or more events associated with the event and a hash value associated with the at least one additional block in the master cryptographically verifiable ledger.

11. The method of claim **10**, further comprising transmitting, via the first independently operated domain, an second alert to the central computing system and one or more of the independently operated domains different than the first independently operated domain.

12. The method of claim **11**, further comprising:

verifying, via the central computing system, the one or more transactions in the at least one additional sub-block generated by the first independently operated domain in the at least one sub cryptographically verifiable ledger, in response to receiving the second alert.

13. The method of claim **11**, wherein the one or more independently operated domains include a second independently operated domain and a third independently operated domain.

14. The method of claim **13**, further comprising:

receiving, via the third independently operated domain, the second alert;

verifying, via the third independently operated domain, the event; and

generating, via the third independently operated domain, at least one additional sub-block in a third sub cryptographically verifiable ledger associated with the third independently operated domain, the additional sub-block generated in the third sub cryptographically verifiable ledger containing the one or more events associated with the event, and the third independently operated domain being further configured to transmit a third alert indicating the generation of the at least one additional block in the third sub cryptographically verifiable ledger to the central computing system.

15. The method of claim **14**, further comprising:

determining, via the central computing system, the second independently operated domain failed to generate an expected sub-block based on the second alert; and

triggering, via the central computing system, the generation of the expected sub-block in a second sub cryptographically verifiable ledger associated with the second independently operated domain based on the second alert, in response to receiving the third alert.

16. The method of claim **11**, wherein the one or more events are associated with a delivery of the at least one physical object.

17. The method of claim **11**, wherein the one or more events include a quantity of the at least one physical object, name of the at least one physical object, type of the at least one physical object and size of the at least one physical object.

18. The method of claim **11**, wherein the event is the transfer of ownership of the at least one physical object.

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