

IMPROVING INTEGRITY OF COMMUNICATIONS BETWEEN BLOCKCHAIN NETWORKS AND EXTERNAL DATA SOURCES

TECHNICAL FIELD

[0001] This specification relates to providing data to a blockchain network from an external data source.

BACKGROUND

[0002] Distributed ledger systems (DLSs), which can also be referred to as consensus networks, and/or blockchain networks, enable participating entities to securely, and immutably store data. DLSs are commonly referred to as blockchain networks without referencing any particular use case. An example of a type of blockchain network can include consortium blockchain networks provided for a select group of entities, which control the consensus process, and includes an access control layer.

[0003] Smart contracts are programs that execute on blockchains. In some instances, the smart contract running on the blockchain requires input from outside of the blockchain to evaluate pre-defined rules and perform corresponding actions. However, the smart contract itself cannot directly access external data sources. Consequently, a relay agent can be used to retrieve external data, and submit the data to the blockchain for processing by the smart contract. This process, however, can result in security issues, such as leakage of secure information (e.g., credentials that might be required to access an external data source).

[0004] Although techniques have been proposed for addressing security issues associated with data retrieval from external data sources, a more effective solution to address the security issues would be advantageous.

SUMMARY

[0005] This specification describes technologies for retrieval of data from external data sources for processing within a blockchain network.

[0006] Embodiments of this specification are directed to a relay system that coordinates communication from a user computing device through a blockchain network to an Internet-based data source that is external to the blockchain network. More particularly, embodiments of this specification enable the user computing device to encrypt confidential information

that may be required to access the Internet-based data using a public key of a relay system node that is used to query the Internet-based data source. In some embodiments, the relay system node encrypts a response using a private key, and the response is verified by a relay system smart contract within the blockchain network using the public key. In some embodiments, the relay node executes a trusted execution environment (TEE), and the public key and the private key are provided through an attestation process of the TEE.

[0007] This specification also provides one or more non-transitory computer-readable storage media coupled to one or more processors and having instructions stored thereon which, when executed by the one or more processors, cause the one or more processors to perform operations in accordance with embodiments of the methods provided herein.

[0008] This specification further provides a system for implementing the methods provided herein. The system includes one or more processors, and a computer-readable storage medium coupled to the one or more processors having instructions stored thereon which, when executed by the one or more processors, cause the one or more processors to perform operations in accordance with embodiments of the methods provided herein.

[0009] It is appreciated that methods in accordance with this specification may include any combination of the aspects and features described herein. That is, methods in accordance with this specification are not limited to the combinations of aspects and features specifically described herein, but also include any combination of the aspects and features provided.

[0010] The details of one or more embodiments of this specification are set forth in the accompanying drawings and the description below. Other features and advantages of this specification will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a diagram illustrating an example of an environment that can be used to execute embodiments of this specification.

[0012] FIG. 2 is a diagram illustrating an example of a conceptual architecture in accordance with embodiments of this specification.

[0013] FIG. 3 is a diagram illustrating an example of a system in accordance with embodiments of this specification.

[0014] FIG. 4 is a signal flow illustrating an example of a process in accordance with embodiments of this specification.

[0015] FIG. 5 is a signal flow illustrating an example of a process in accordance with embodiments of this specification.

[0016] FIG. 6 is a flow chart illustrating an example of a process that can be executed in accordance with embodiments of this specification.

[0017] FIG. 7 is a diagram illustrating an example of modules of an apparatus in accordance with embodiments of this specification.

[0018] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0019] This specification describes technologies for enhancing the integrity of requests to and responses from data sources that are external to a blockchain network. Embodiments of this specification are directed to a relay system that coordinates communication from a user computing device through a blockchain network to an Internet-based data source that is external to the blockchain network. More particularly, embodiments of this specification enable the user computing device to encrypt confidential information that may be required to access the Internet-based data using a public key of a relay system node that is used to query the Internet-based data source. In some embodiments, the relay system node encrypts a response using a private key, and the response is verified by a relay system smart contract within the blockchain network using the public key. In some embodiments, the relay node executes a trusted execution environment (TEE), and the public key and the private key are provided through an attestation process of the TEE.

[0020] The subject matter described in this specification as implemented in particular embodiments realizes one or more of the following technical advantages. For example, embodiments of this specification ensure the integrity of requests submitted to relay system nodes for querying data sources that are external to a blockchain network. As another example, embodiments of this specification ensure the integrity of responses provided back to the blockchain network from the external data sources. Accordingly, embodiments of the present disclosure improve the integrity of communications between a blockchain network,

and components of a relay system that is used to retrieve data that is external to the blockchain network. In this manner, potential attack channels for malicious users are mitigated to enhance security.

[0021] The relay system described above facilitates avoids direct contact between the user and the relay system node, thereby avoiding exposing a position or access point of the relay system node. As such, the relay system node is less likely to be found and attacked by malicious actors over the network using, for example, distributed denial of service (DDoS) attacks. This improves a security of the relay system node, thereby further improving a security of the communication between the blockchain and the relay system node.

[0022] To provide further context for embodiments of this specification, and as introduced above, distributed ledger systems (DLSs), which can also be referred to as consensus networks (e.g., made up of peer-to-peer nodes), and blockchain networks, enable participating entities to securely, and immutably conduct transactions, and store data. Although the term blockchain is generally associated with particular networks, and/or use cases, blockchain is used herein to generally refer to a DLS without reference to any particular use case.

[0023] A blockchain is a data structure that stores transactions in a way that the transactions are immutable. Thus, transactions recorded on a blockchain are reliable and trustworthy. A blockchain includes one or more blocks. Each block in the chain is linked to a previous block immediately before it in the chain by including a cryptographic hash of the previous block. Each block also includes a timestamp, its own cryptographic hash, and one or more transactions. The transactions, which have already been verified by the nodes of the blockchain network, are hashed and encoded into a Merkle tree. A Merkle tree is a data structure in which data at the leaf nodes of the tree is hashed, and all hashes in each branch of the tree are concatenated at the root of the branch. This process continues up the tree to the root of the entire tree, which stores a hash that is representative of all data in the tree. A hash purporting to be of a transaction stored in the tree can be quickly verified by determining whether it is consistent with the structure of the tree.

[0024] Whereas a blockchain is a decentralized or at least partially decentralized data structure for storing transactions, a blockchain network is a network of computing nodes that manage, update, and maintain one or more blockchains by broadcasting, verifying and

validating transactions, etc. As introduced above, a blockchain network can be provided as a public blockchain network, a private blockchain network, or a consortium blockchain network. Embodiments of this specification are described in further detail herein with reference to a consortium blockchain network. It is contemplated, however, that embodiments of this specification can be realized in any appropriate type of blockchain network.

[0025] In general, a consortium blockchain network is private among the participating entities. In a consortium blockchain network, the consensus process is controlled by an authorized set of nodes, which can be referred to as consensus nodes, one or more consensus nodes being operated by a respective entity (e.g., a financial institution, insurance company). For example, a consortium of ten (10) entities (e.g., financial institutions, insurance companies) can operate a consortium blockchain network, each of which operates at least one node in the consortium blockchain network.

[0026] In some examples, within a consortium blockchain network, a global blockchain is provided as a blockchain that is replicated across all nodes. That is, all consensus nodes are in perfect state consensus with respect to the global blockchain. To achieve consensus (e.g., agreement to the addition of a block to a blockchain), a consensus protocol is implemented within the consortium blockchain network. For example, the consortium blockchain network can implement a practical Byzantine fault tolerance (PBFT) consensus, described in further detail below.

[0027] FIG. 1 is a diagram illustrating an example of an environment 100 that can be used to execute embodiments of this specification. In some examples, the environment 100 enables entities to participate in a consortium blockchain network 102. The environment 100 includes computing devices 106, 108, and a network 110. In some examples, the network 110 includes a local area network (LAN), wide area network (WAN), the Internet, or a combination thereof, and connects web sites, user devices (e.g., computing devices), and back-end systems. In some examples, the network 110 can be accessed over a wired and/or a wireless communications link. In some examples, the network 110 enables communication with, and within the consortium blockchain network 102. In general the network 110 represents one or more communication networks. In some cases, the computing devices 106, 108 can be nodes of a cloud computing system (not shown), or each computing device 106,

108 can be a separate cloud computing system including a number of computers interconnected by a network and functioning as a distributed processing system.

[0028] In the depicted example, the computing systems 106, 108 can each include any appropriate computing system that enables participation as a node in the consortium blockchain network 102. Examples of computing devices include, without limitation, a server, a desktop computer, a laptop computer, a tablet computing device, and a smartphone. In some examples, the computing systems 106, 108 host one or more computer-implemented services for interacting with the consortium blockchain network 102. For example, the computing system 106 can host computer-implemented services of a first entity (e.g., user A), such as a transaction management system that the first entity uses to manage its transactions with one or more other entities (e.g., other users). The computing system 108 can host computer-implemented services of a second entity (e.g., user B), such as a transaction management system that the second entity uses to manage its transactions with one or more other entities (e.g., other users). In the example of FIG. 1, the consortium blockchain network 102 is represented as a peer-to-peer network of nodes, and the computing systems 106, 108 provide nodes of the first entity, and second entity respectively, which participate in the consortium blockchain network 102.

[0029] FIG. 2 depicts an example of an architecture 200 in accordance with embodiments of this specification. The example conceptual architecture 200 includes participant systems 202, 204, 206 that correspond to Participant A, Participant B, and Participant C, respectively. Each participant (e.g., user, enterprise) participates in a blockchain network 212 provided as a peer-to-peer network including a plurality of nodes 214, at least some of which immutably record information in a blockchain 216. Although a single blockchain 216 is schematically depicted within the blockchain network 212, multiple copies of the blockchain 216 are provided, and are maintained across the blockchain network 212, as described in further detail herein.

[0030] In the depicted example, each participant system 202, 204, 206 is provided by, or on behalf of Participant A, Participant B, and Participant C, respectively, and functions as a respective node 214 within the blockchain network. As used herein, a node generally refers to an individual system (e.g., computer, server) that is connected to the blockchain network 212, and enables a respective participant to participate in the blockchain network. In the

example of FIG. 2, a participant corresponds to each node 214. It is contemplated, however, that a participant can operate multiple nodes 214 within the blockchain network 212, and/or multiple participants can share a node 214. In some examples, the participant systems 202, 204, 206 communicate with, or through the blockchain network 212 using a protocol (e.g., hypertext transfer protocol secure (HTTPS)), and/or using remote procedure calls (RPCs).

[0031] Nodes 214 can have varying degrees of participation within the blockchain network 212. For example, some nodes 214 can participate in the consensus process (e.g., as miner nodes that add blocks to the blockchain 216), while other nodes 214 do not participate in the consensus process. As another example, some nodes 214 store a complete copy of the blockchain 216, while other nodes 214 only store copies of portions of the blockchain 216. For example, data access privileges can limit the blockchain data that a respective participant stores within its respective system. In the example of FIG. 2, the participant systems 202, 204, and 206 store respective, complete copies 216', 216'', and 216''' of the blockchain 216.

[0032] A blockchain (e.g., the blockchain 216 of FIG. 2) is made up of a chain of blocks, each block storing data. Examples of data include transaction data representative of a transaction between two or more participants. While transactions are used herein by way of non-limiting example, it is contemplated that any appropriate data can be stored in a blockchain (e.g., documents, images, videos, audio). Examples of a transaction can include, without limitation, exchanges of something of value (e.g., assets, products, services, currency). The transaction data is immutably stored within the blockchain. That is, the transaction data cannot be changed.

[0033] Before storing in a block, the transaction data is hashed. Hashing is a process of transforming the transaction data (provided as string data) into a fixed-length hash value (also provided as string data). It is not possible to un-hash the hash value to obtain the transaction data. Hashing ensures that even a slight change in the transaction data results in a completely different hash value. Further, and as noted above, the hash value is of fixed length. That is, no matter the size of the transaction data the length of the hash value is fixed. Hashing includes processing the transaction data through a hash function to generate the hash value. An example of a hash function includes, without limitation, the secure hash algorithm (SHA)-256, which outputs 256-bit hash values.

[0034] Transaction data of multiple transactions are hashed and stored in a block. For example, hash values of two transactions are provided, and are themselves hashed to provide another hash. This process is repeated until, for all transactions to be stored in a block, a single hash value is provided. This hash value is referred to as a Merkle root hash, and is stored in a header of the block. A change in any of the transactions will result in change in its hash value, and ultimately, a change in the Merkle root hash.

[0035] Blocks are added to the blockchain through a consensus protocol. Multiple nodes within the blockchain network participate in the consensus protocol, and perform work to have a block added to the blockchain. Such nodes are referred to as consensus nodes. PBFT, introduced above, is used as a non-limiting example of a consensus protocol. The consensus nodes execute the consensus protocol to add transactions to the blockchain, and update the overall state of the blockchain network.

[0036] In further detail, the consensus node generates a block header, hashes all of the transactions in the block, and combines the hash value in pairs to generate further hash values until a single hash value is provided for all transactions in the block (the Merkle root hash). This hash is added to the block header. The consensus node also determines the hash value of the most recent block in the blockchain (i.e., the last block added to the blockchain). The consensus node also adds a nonce value, and a timestamp to the block header.

[0037] In general, PBFT provides a practical Byzantine state machine replication that tolerates Byzantine faults (e.g., malfunctioning nodes, malicious nodes). This is achieved in PBFT by assuming that faults will occur (e.g., assuming the existence of independent node failures, and/or manipulated messages sent by consensus nodes). In PBFT, the consensus nodes are provided in a sequence that includes a primary consensus node, and backup consensus nodes. The primary consensus node is periodically changed. Transactions are added to the blockchain by all consensus nodes within the blockchain network reaching an agreement as to the world state of the blockchain network. In this process, messages are transmitted between consensus nodes, and each consensus nodes proves that a message is received from a specified peer node, and verifies that the message was not modified during transmission.

[0038] In PBFT, the consensus protocol is provided in multiple phases with all consensus nodes beginning in the same state. To begin, a client sends a request to the primary consensus

node to invoke a service operation (e.g., execute a transaction within the blockchain network). In response to receiving the request, the primary consensus node multicasts the request to the backup consensus nodes. The backup consensus nodes execute the request, and each sends a reply to the client. The client waits until a threshold number of replies are received. In some examples, the client waits for $f+1$ replies to be received, where f is the maximum number of faulty consensus nodes that can be tolerated within the blockchain network. The final result is that a sufficient number of consensus nodes come to an agreement on the order of the record that is to be added to the blockchain, and the record is either accepted, or rejected.

[0039] In some blockchain networks, cryptography is implemented to maintain privacy of transactions. For example, if two nodes want to keep a transaction private, such that other nodes in the blockchain network cannot discern details of the transaction, the nodes can encrypt the transaction data. An example of cryptography includes, without limitation, symmetric encryption, and asymmetric encryption. Symmetric encryption refers to an encryption process that uses a single key for both encryption (generating ciphertext from plaintext), and decryption (generating plaintext from ciphertext). In symmetric encryption, the same key is available to multiple nodes, so each node can en-/de-crypt transaction data.

[0040] Asymmetric encryption uses keys pairs that each include a private key, and a public key, the private key being known only to a respective node, and the public key being known to any or all other nodes in the blockchain network. A node can use the public key of another node to encrypt data, and the encrypted data can be decrypted using other node's private key. For example, and referring again to FIG. 2, Participant A can use Participant B's public key to encrypt data, and send the encrypted data to Participant B. Participant B can use its private key to decrypt the encrypted data (ciphertext) and extract the original data (plaintext). Messages encrypted with a node's public key can only be decrypted using the node's private key.

[0041] Asymmetric encryption is used to provide digital signatures, which enables participants in a transaction to confirm other participants in the transaction, as well as the validity of the transaction. For example, a node can digitally sign a message, and another node can confirm that the message was sent by the node based on the digital signature of Participant A. Digital signatures can also be used to ensure that messages are not tampered with in transit. For example, and again referencing FIG. 2, Participant A is to send a message

to Participant B. Participant A generates a hash of the message, and then, using its private key, encrypts the hash to provide a digital signature as the encrypted hash. Participant A appends the digital signature to the message, and sends the message with digital signature to Participant B. Participant B decrypts the digital signature using the public key of Participant A, and extracts the hash. Participant B hashes the message and compares the hashes. If the hashes are same, Participant B can confirm that the message was indeed from Participant A, and was not tampered with.

[0042] In some instances, a smart contract executing within the blockchain network requires input from outside of the blockchain network to evaluate pre-defined rules and perform corresponding actions. By way of non-limiting example, a stock quote might be needed for the smart contract to base a decision on, the stock quote coming from a data source external to the blockchain network. As another non-limiting example, account information for an account that is maintained outside of the blockchain network might be needed to for the smart contract to base a decision on. However, the smart contract itself cannot directly query external data sources.

[0043] Traditional approaches include use of a relay agent to retrieve external data, and submit the data to the blockchain for processing by the smart contract. This process, however, can result in security issues, such as leakage of secure information (e.g., credentials that might be required to access an external data source). For example, traditional approaches can use TEE to prove that the relay agent has performed the specified query request honestly. However, and due to the openness of the blockchain, all query requests are visible to all users (nodes) in the blockchain network. Consequently, there is a risk of permission leakage for query requests that require access to external data sources requiring access control (e.g., queries). For example, there is a risk that request strings can be intercepted, modified and replayed, resulting in information leakage, or other problems.

[0044] In one traditional approach that uses SGX, the TA, or portion of the TA, executing in an enclave (enclave program) functions as a relay node to access external data sources. For example, the enclave program can send a query request (e.g., HTTPS request) to an Internet-based data source, and can provide the response to the smart contract that initiated the request. In some examples, a privacy field function is provided, which can be used encrypt sensitive information (e.g., access credentials) using the public key of the

enclave. In some examples, the relay node uses the private key of the enclave to decrypt the privacy field, invokes the HTTPS client to access the target Internet-based data source, receive the requested data, and use the private key to digitally sign the returned data. After the digital signature, the data is returned to the smart contract that had initiated the request.

[0045] Such a traditional approach, however, has disadvantages. An example disadvantage of directly encrypting the privacy field is that the request with the privacy field ciphertext does not have integrity protection. For example, the user carries the encrypted API key field in the request for requesting all authorization information of the Internet-based data source. An attacker can intercept the communication. Although the attacker cannot directly decrypt the plaintext of the API key information, the attacker can modify the request to use the same privacy field to construct a request for accessing information, and send it to the relay node. This can result in leakage of sensitive information (e.g., credentials).

[0046] In view of the above context, embodiments of the present specification are directed to querying external data sources (e.g., Internet-based data sources) using a relay system and TEE. More particularly, and as described in further detail herein, embodiments of this specification provide for authorization request integrity check, while protecting sensitive information (e.g., credentials). In this manner, and as described in further detail herein, embodiments of this specification address disadvantages of traditional approaches, such as preventing user rights from leaking.

[0047] FIG. 3 is a diagram illustrating an example of a system 300 in accordance with embodiments of this specification. As shown, system 300 includes a blockchain 302, a relay system controller 308, a relay system node 310, an attestation service 312, and a network 314 (e.g., Internet). In the depicted example, the blockchain 302 includes a client smart contract 304 and a relay system smart contract 306. In general, the relay system smart contract 306, the relay system controller 308, and the relay system node 310 provide a relay system that enables data that is external to the blockchain 302 to be retrieved, and used within the blockchain 302.

[0048] In some embodiments, the relay system node 310 is implemented using a TEE technology (e.g., Intel SGX). In general, the attestation service 312 verifies a legitimacy of the relay system node 310 for the client smart contract 304. An example of an attestation service includes IAS, described above. As described herein, the relay system smart contract

306, the relay system controller 308, and the relay system node 310 operate together as a relay system to relay data or requests from the client smart contract 304 to the network 314 (e.g., an external data source that is accessible through the network 314), and to relay data or request results from the network 314 to the client smart contract 304.

[0049] The client smart contract 304 is a smart contract that operates as a requester that requests data or service from the network 314. In some embodiments, an offline owner of the client smart contract 304, for example, a client or user (not shown), may send a data or request to or generate the data or service request at the client smart contract 304. The data or request may be a datagram element. The client smart contract 304 is communicatively coupled to the relay system smart contract 306. For example, the client smart contract 304 may send a request to the relay system smart contract 306 and receive a request result from the relay system smart contract 306.

[0050] As noted above, the relay system smart contract 306, the relay system controller 308, and the relay system node 310 operate together as a relay system to relay the data or requests from the client smart contract 304 to the network 314 and relay data or request results from the network 314 to the client smart contract 304. The relay system smart contract 306 is a smart contract that acts as a front end of the blockchain 302 within the relay system. The relay system smart contract 306 includes or operates as an application program interface (API) to the client smart contract 304 for processing and relaying the requests from the client smart contract 304 to the other components of the relay system (e.g., the relay system controller 308), and for processing and relaying request results from the relay system controller 308 to the client smart contract 304. In some embodiments, the relay system smart contract 306 verifies signatures associated with the request results before relaying the request results to the client smart contract 304. In short, the relay system smart contract 306 is a smart contract that provides an interface between the blockchain 302 and relay system components that are external to the blockchain 302 (e.g., the relay system controller 308). The relay system smart contract 306 accepts requests from components executing within the blockchain 302 (e.g., the client smart contract 304), and returns corresponding responses.

[0051] The relay system controller 308 includes any suitable computer, processor, module, or computing element to relay requests from the relay system smart contract 306 to the relay system node 310 and to relay request results from the relay system node 310 to the

relay system smart contract 306. As such, the relay system controller 308 operates as a monitoring entity that monitors the state of the relay system smart contract 306, because the relay system smart contract 306 does not have direct connectivity to the network 314.

[0052] The relay system controller 308 also relays attestation evidence 320 that indicates a legitimacy of the relay system node 310 from the relay system node 310 to the attestation service 312. In some embodiments, the attestation evidence 320 includes a measurement value 322 of the relay system node 310 and a signature 326 of the relay system node 310. The measurement value 322 of the relay system node 310 may include a hash value of an initial state of the relay system node 310. The signature 326 of the relay system node 310 included in the attestation evidence 320 may include the measurement value 322 of the relay system node 310 that is signed using an attestation key of the relay system node 310.

[0053] In some embodiments, the attestation key of the relay system node 310 includes an enhanced privacy identification (EPID) private key. EPID is an algorithm provided by Intel for attestation of a trusted system, while preserving privacy. In general, each of the members (e.g., a computer or a server) of a network is assigned an EPID private key for signing the attestation evidence, and a verifier of the attestation evidence in the network stores an EPID public key that is paired with the EPID private keys of the other members of the network. Each of the members can generate a signature of the attestation evidence using its own EPID private key, and the verifier can verify the signatures of the other members using the EPID public key. As such, the EPID keys can be used to prove that a device, such as a computer or a server, is a genuine device.

[0054] The attestation evidence 320 may further include a public key 324 that is generated by the relay system node 310. If the attestation evidence 320 includes the public key 324 that is generated by the relay system node 310, the signature 326 of the relay system node 310 includes the measurement value 322, and the public key 324 that are signed using the attestation key of the relay system node 310.

[0055] The relay system node 310 includes any suitable server, computer, module, or computing element to ingest and fulfill requests from the blockchain 302. For example, the relay system node 310 may receive and handle off-chain service requests from clients and query external data source in the network 314, for example such as, HTTPS-enabled Internet services. Before handling the requests from clients or client smart contract 304, the relay

system node 310 may generate the attestation evidence 320, and send the attestation evidence 320 to the attestation service 312 for verifying a legitimacy of the relay system node 310. In some embodiments, the relay system node 310 generates a key pair including a public key 324 and a private key, and includes the public key 324 in the attestation evidence 320. The public key 324 may be further relayed by the relay system controller 308 to the relay system smart contract 306 for future communication between the relay system smart contract 306 and the relay system node 310. For example, the relay system node 310 may use the private key to sign request results, and the relay system smart contract 306 can use the public key 324 to verify the signed request results.

[0056] The attestation service 312 includes any suitable server, computer, module, or computing element to verify the legitimacy of the attestation evidence 320 that is forwarded by the relay system controller 308 from the relay system node 310. As noted above, the attestation evidence 320 includes a measurement value 322 of the relay system node 310, a signature 326 of the relay system node 310, and/or a public key 324 generated by the relay system node 310. Upon receiving the attestation evidence 320, the attestation service 312 verifies the signature 326 of the relay system node 310 in the attestation evidence 320, and generates an attestation verification report (AVR) 330.

[0057] The attestation service 312 verifies the signature 326 in the attestation evidence 320 using an attestation key of the attestation service 312. In some embodiments, the attestation key of the attestation service 312 includes an EPID public key that is paired with the EPID private key that the relay system node 310 used to sign the attestation evidence 320. After verifying the signature in the attestation evidence 320, the attestation service 312 generates the AVR 330 that includes the attestation evidence 320, a verification result 334 indicating whether the signature 326 in the attestation evidence 320 is valid, and a signature 336 of the attestation service 312.

[0058] In some embodiments, the AVR 330 includes the attestation evidence 320 excluding the signature 326 of the relay system node 310. For example, the AVR 330 may include the measurement value 322 of the relay system node 310, the public key 324 generated by the relay system node 310, the verification result 334, and the signature 336 of the attestation service 312. In some embodiments, the signature 336 of the attestation service 312 includes the attestation evidence 320 and the verification result 334 that are signed using

a report signing key (e.g., a private key that the attestation service 312 uses to sign the attestation verification report) of the attestation service 312. Note that the report signing key can be different from the attestation key of the attestation service 312.

[0059] FIG. 4 depicts an example of a signal flow 400 in accordance with embodiments of this specification. The signal flow 400 represents an attestation verification process. For convenience, the process will be described as being performed by a system of one or more computers, located in one or more locations, and programmed appropriately in accordance with this specification. For example, a distributed system (e.g., the blockchain system 100 of FIG. 1; the system 300 of FIG. 3), appropriately programmed, can perform the process.

[0060] Generally, in operation, the relay system controller 308 receives attestation evidence from a relay system node 310, and sends the attestation evidence to the attestation service 312 to verify the attestation evidence. The relay system controller 308 receives an AVR from the attestation service 312 that indicates a legitimacy of the relay system node 310 based on a verification on a signature of the relay system node 310 in the attestation evidence. The relay system controller 308 further relays the AVR including a signature of the attestation service 312 to the relay system smart contract 306.

[0061] In the example of FIG. 4, the relay system controller 308 sends (410) an attestation request (e.g., a challenge) to the relay system node 310. The attestation request is sent to the relay system node 310 to request attestation evidence that indicates a legitimacy or validity of the relay system node 310. In some embodiments, the attestation evidence includes a measurement value of the relay system node 310 and a signature of the relay system node 310. The measurement value of the relay system node 310 may include a hash value of an initial state of the relay system node 310. For example, the measurement value of the relay system node 310 may include a hash value of a process code that is implemented on the relay system node 310.

[0062] In some embodiments, prior to sending the attestation request to the relay system node 310, the relay system controller 308 obtains the measurement value of the relay system node 310 and sends the measurement value to the relay system smart contract 306 for future use. For example, the relay system smart contract 306 may store the measurement value of the relay system node 310 and compare the stored measurement value to a measurement

value in an AVR that the relay system controller 308 will forward from the attestation service 312 to the relay system smart contract 306.

[0063] In response to the attestation request, the relay system node 310 generates (412) attestation evidence. As noted above, the attestation evidence indicates a legitimacy or validity of the relay system node 310, and can include a measurement value of the relay system node 310 and a signature of the relay system node 310. In some embodiments, the attestation evidence further includes a public key that is generated by relay system node 310. For example, the relay system node 310 may generate a random cryptographic key pair including a private key and a public key using a predetermined key generation algorithm, for example such as, Rivest-Shamir-Adleman (RSA) algorithm. In some examples, the public key is provided in the attestation evidence that will be sent to the relay system smart contract 306, and can be used for future communication between the relay system smart contract 306 and the relay system node 310. For example, the relay system node 310 may use the private key to sign a request result and the relay system smart contract 306 can use the public key to verify the signed request result.

[0064] In some embodiments, the measurement value of the relay system node 310 includes a hash value of an initial state of the relay system node 310. The signature of the relay system node 310 in the attestation evidence includes the measurement value and the public key generated by the relay system node 310 that are signed using an attestation key of the relay system node 310. In some embodiments, the attestation key of the relay system node 310 includes an EPID private key. Attestation evidence that is signed using an EPID private key can be verified by a verifier using an EPID public key that is paired with the EPID private key to prove a genuineness of a device that generates the attestation evidence.

[0065] The relay system node 310 sends (414) the attestation evidence to the relay system controller 308. The attestation evidence that is sent to the relay system controller 308 can include a measurement value of a relay system node 310, a public key that is generated by the relay system node 310, and a signature of the relay system node 310 including the measurement value and the public key that are signed using an EPID private key of the relay system node 310.

[0066] The relay system controller 308 forwards (416) the attestation evidence sent from the relay system node 310 to the attestation service 312. In some embodiments, the relay

system controller 308 sends an attestation verification request to the attestation service 312. The attestation verification request includes the attestation evidence sent from the relay system node 310, and some supplemental information, such as, for example, a descriptor that indicates whether the relay system node 310 uses the SGX platform service.

[0067] The attestation service 312 verifies (418) the attestation evidence in response to receiving the attestation evidence forwarded by the relay system controller 308. As noted, the attestation evidence includes a measurement value of the relay system node 310, a public key that is generated by the relay system node 310, and a signature of the relay system node 310. The attestation service 312 may verify the attestation evidence by verifying the signature of the relay system node 310 in the attestation evidence using an attestation key of the attestation service 312. For example, the attestation service 312 may verify the signature of the relay system node 310 using an EPID public key of the attestation verification server that is paired with an EPID private key the relay system node 310 uses to sign the attestation evidence.

[0068] If the attestation service 312 determines that the signature of the relay system node 310 in the attestation evidence is valid, the attestation service 312 may determine that the relay system node 310 is a genuine or legitimate device. If the attestation service 312 determines that the signature of the relay system node 310 in the attestation evidence is invalid, the attestation service 312 may determine that the relay system node 310 is not genuine or is an illegitimate device, and reject any subsequent data and requests from the relay system node 310.

[0069] The attestation service 312 generates (420) an AVR based on a verification of the attestation evidence. In some embodiments, the AVR can include the attestation evidence of the relay system node 310, an attestation verification result, and a digital signature of the attestation service 312. In some embodiments, the AVR may include the attestation evidence of the relay system node 310 excluding the signature of the relay system node 310. For example, the AVR may include the measurement value of the relay system node 310, the public key generated by the relay system node 310, the attestation verification result, and the signature of the attestation service 312.

[0070] The attestation verification result in the AVR indicates whether the signature of the relay system node 310 is valid. For example, the attestation verification result may

include a value of “valid,” or “OK” that indicates the signature of relay system node 310 is valid or a value of “invalid” that indicates the signature is invalid.

[0071] In some embodiments, the signature of the attestation service 312 includes the attestation evidence and the attestation verification result that are signed using a report signing key. The report signing key may be a private key that the attestation service 312 uses to sign the AVR. In some embodiments, the report signing key is generated by the attestation service 312 using a predetermined key generated algorithm. For example, the report signing key may be generated using the RSA-Secure Hash Algorithm (SHA) 256. Note that the report signing key is different from the attestation key (e.g., EPID public key) that the attestation service 312 uses to verify the attestation evidence.

[0072] In some embodiments, the attestation service 312 sends (422) the AVR to the relay system controller 308. As noted above, the AVR includes a cryptographically signed report of verification of identity of the relay system node 310, and can include the attestation evidence of the relay system node 310, an attestation verification result, and a digital signature of the attestation service 312.

[0073] In some embodiments, the relay system controller 308 forwards (424) the AVR to the relay system smart contract 306 after receiving the AVR from the attestation service 312. The relay system smart contract 306 verifies (426) the AVR. For example, the relay system smart contract 306 may verify the signature of the attestation service 312 in the AVR. In some embodiments, the relay system smart contract 306 verifies the signature of the attestation service 312 using a report signing certificate. The report signing certificate may be an X.509 digital certificate. The report signing certificate may include a public key that is generated by the attestation service 312 and that is paired with the report signing key the attestation service 312 uses to sign the AVR. If the relay system smart contract 306 verifies that the signature of the attestation service 312 in the AVR is valid, the relay system smart contract 306 determines that the AVR is indeed sent by the attestation service 312. If the relay system smart contract 306 determines that the signature of the attestation service 312 in the AVR is invalid, the relay system smart contract 306 determines that the attestation verification report is not genuine, and will reject the AVR. The relay system smart contract 306 may further inspect the attestation verification result in the AVR to determine whether the attestation evidence of the relay system node 310 is valid. In some embodiments, the

relay system smart contract 306 further compares the measurement value in the attestation evidence with a measurement value that is pre-stored in the relay system smart contract 306 to determine whether the attestation evidence is valid.

[0074] The relay system smart contract 306 registers (428) the relay system node 310 as a valid or legitimate device in response to determining that the AVR is genuine and that the attestation evidence of the relay system node 310 is valid. The relay system smart contract 306 may further store the public key that is included in the attestation evidence in the service and that is generated by the relay system node 310. The public key will be used by the relay system smart contract 306 for future communication between the relay system smart contract 306 and the relay system node 310.

[0075] FIG. 5 depicts an example of a signal flow 500 in accordance with embodiments of this specification. The signal flow 500 represents a process for verifying requests sent to an external data source in accordance with embodiments of the present disclosure. For convenience, the process will be described as being performed by a system of one or more computers, located in one or more locations, and programmed appropriately in accordance with this specification. For example, a distributed system (e.g., the blockchain system 100 of FIG. 1; the system 300 of FIG. 3), appropriately programmed, can perform the process.

[0076] Generally, in operation, a user 502 generates a request that will be relayed to the relay system node 310 through the client smart contract 304, the relay system smart contract 306, and the relay system controller 308. The relay system node 310 verifies the request before sending the request to an Internet-based data source 504.

[0077] In further detail, the user 502 generates (510) a request for data or service from the Internet-based data source 504. For example, the request may be an access request for an account of the user 502. The access request may include a plaintext portion, such as, for example, a web address, and a confidential data portion, such as, for example, credentials (e.g., a user name, a password) of the account of the user 502. The confidential data portion in the access request can be encrypted, such that malicious actors over the network cannot obtain the personal information of the user account to infiltrate the user account. However, the confidential data portion, although still encrypted, may be obtained by the malicious actors and combined with a different plaintext portion, such as, for example, a second web address. For example, the second web address can be under the same domain of the first web

address, and the encrypted, confidential data portion could be used to access personal data of the user 502 on the second web address (e.g., such an attack would be successful, if the user 502 uses the same user name and password on the second web address as the first web address).

[0078] As described herein, embodiments of this specification mitigate such attacks by improving the integrity of the requests. In some embodiments, to improve integrity of the request and security of personal data, the request generated by the user 502 includes a plaintext data element, and an encrypted combination of a confidential data element and a hash value of the plaintext data element. For example, user 502 may use a computing device (e.g., the computing device the user 502 uses to interface with the blockchain network) to compute a hash value of the plaintext data element and concatenate the hash value to the confidential data element. The user 502 may further encrypt the concatenated hash value and the confidential data element using a public key that is generated and sent to the user 502 by the relay system node 310. For example:

$$R \rightarrow [P, PK_{RSN}(C||H)]$$

where:

R is the request issued by the computing device of the user to the blockchain network,

P is a plaintext portion (e.g., URL of data source that is to be queried);

PK_{RSN} is the public key of the relay system node that queries the data source;

C is the confidential information (e.g., credentials) used to access the data source;

H is the hash of the plaintext portion P ; and

$||$ represents concatenation of C and H , which concatenation is encrypted using PK_{RSN} .

The encrypted concatenation of the hash value and the confidential data element can be decrypted by the relay system node 310 using a private key that is paired with the public key.

[0079] In some embodiments, the user 502 encrypts the hash value and the confidential data element separately using the public key. For example, the user 502 may encrypt the hash value using the public key and encrypt the confidential data element using the public

key. The user 502 combines (e.g., concatenates) the encrypted hash value and the encrypted confidential data element. For example:

$$R \rightarrow [P, (PK_{RSN}(C)||PK_{RSN}(H))]$$

where:

R is the request issued by the computing device of the user to the blockchain network,

P is a plaintext portion (e.g., URL of data source that is to be queried);

PK_{RSN} is the public key of the relay system node that queries the data source;

C is the confidential information (e.g., credentials) used to access the data source;

H is the hash of the plaintext portion P ; and

$||$ represents concatenation of encrypted C and encrypted H , which are each encrypted using PK_{RSN} .

The encrypted of the hash value and the encrypted confidential data element of the concatenation can be decrypted by the relay system node 310 using the private key that is paired with the public key.

[0080] The user 502 sends (512) the request to the client smart contract 304. For example, user 502 may submit the request to blockchain 302, and the blockchain 302 assigns the request to the client smart contract 304 that is associated with user 502. The client smart contract 304 forwards (514) the request to the relay system smart contract 306 after receiving the request from user 502. The relay system smart contract 306 forwards (516) the request to the relay system controller 308 after receiving the request from the client smart contract 304. The relay system controller 308 forwards (518) the request to the relay system node 310 after receiving the request from the relay system contract 306.

[0081] In some embodiments, the relay system node 310 obtains (520) the confidential data element and the hash value of the plaintext data element from the request using a private key of the relay system node 310. As noted above, the request includes a plaintext data element, and a combination of a confidential data element and a hash value of the plaintext data element that is encrypted using a public key of the relay system node 310. The relay system node 310 stores a private key that is paired with the public key the user 502 uses to

encrypt the hash value of the plaintext text data element and the confidential data element in the request. The relay system node 310 can use the private key to decrypt the encrypted combination of the hash value and the confidential data element to obtain the hash value of the plaintext data element and the confidential data element.

[0082] The relay system node 310 computes (522) a hash value of the plaintext data element in the request. For example, the relay system node 310 may obtain the plaintext data element in the request and apply a predetermined hash function to the plaintext data element to compute the hash value of the plaintext data element. The relay system node 310 compares (524) the hash value of the plaintext data element as determined at 522 with the hash value of the plaintext data element as obtained at 520. The relay system node 310 determines whether the two hash values match. If the hash values match, the relay system node 310 determines that the plaintext data element in the request has not been tampered. If the two hash values do not match, the relay system node 310 may determine that the plaintext data element has been tampered with (e.g., by a malicious actor).

[0083] The relay system node 310 verifies (526) whether the request is genuine based on the comparison of the two hash values as performed at 524. For example, if the hash value of the plaintext data element as determined at 522 matches the hash value of the plaintext data element as obtained at 520, the relay system node 310 determines that the request is intact (e.g., not tampered with). If the two hash values do not match, the relay system node 310 determines that the request has been tampered with, or is otherwise not intact. If the relay system node 310 determines that the request is not intact, the relay system node 310 may reject the request and will not query the Internet-based data source 504.

[0084] In some embodiments, in response to determining that the request is intact, the relay system node 310 sends (528) the request to the Internet-based data source 504 to obtain a request result. In some embodiments, the relay system node 310 constructs a new request that includes the plaintext data element and the confidential data element and queries the Internet-based data source 504 using the new request. For example, the new request may include a plaintext data element including a web address where the user 502 wants to access an account, and a confidential data element including credentials (e.g., user name and password) of the user 502 to log into the account. In some examples, the Internet-based data

source 504 processes (530) the request, and returns (532) a request result to the relay system node 310.

[0085] The relay system node 310 signs (534) the request result that is received from the Internet-based data source 504, and sends (536) the signed request result to the relay system controller 308. For example, the relay system node 310 may generate a signature that includes the request result that is signed using the private key of the relay system node 310. The private key that the relay system node 310 uses to sign the request result is the same as the private key that the relay system node 310 previously used to decrypt the encrypted confidential data element and hash value of the plaintext data element in the request. The relay system node 310 may combine (e.g., concatenate) the signature with the request result and send them to the relay system controller 308. In some embodiments, the relay system node 310 computes a hash value of the request result and signs the hash value using the private key of the relay system node 310. The relay system node 310 combines the request result with the signed hash value of the request result. In this manner, the relay system smart contract 306 can verify the request result by extracting the hash value of the request result using its public key, computing a hash value of the request result, and determining whether the two hash values match, as described herein.

[0086] The relay system controller 308 forwards (538) the signed request result to the relay system smart contract 306. The relay system smart contract 306 verifies (540) the signed request result after receiving it from the relay system controller 308. In some embodiments, the relay system smart contract 306 verifies the signed request by verifying the signature included in the signed request result using its public key. For example, if the signed request result includes the request result and a signed hash value of the request result, the relay system smart contract 306 may obtain the hash value of the request result using its public key, computing a hash value of the request result, and determining whether the two hash values match. If the two hash values match, the relay system smart contract 306 determines that the request result is valid. If the two hash values do not match, the relay system smart contract 306 determines that the request result is invalid and may reject the request result.

[0087] The relay system smart contract 306 sends (542) the request result to the client smart contract 304 after verifying the signed request result that is received from the relay

system controller 308. For example, the relay system smart contract 306 sends the request result to the client smart contract 304, if the relay system smart contract 306 determines that the signature of the relay system node 310 in the signed request result is valid. The client smart contract 304 provides (544) the request result to the user 502 after receiving the request result from the relay system smart contract 306.

[0088] FIG. 6 is a flow chart illustrating an example of a process 600 that can be executed in accordance with embodiments of this specification. In some embodiments, the example process 600 may be performed using one or more computer-executable programs executed using one or more computing devices. In some examples, the example process 600 can be performed by a relay system for retrieving data that is external to a blockchain network (e.g., the relay system smart contract 306, the relay system controller 308, the relay system node 310 of FIG. 3).

[0089] A request is received (602). For example, the relay system node 310 of FIG. 3 receives the request, which originated from the user device 502 of FIG. 5. In some examples, and as described herein, the user device 502 generates the request to include a first portion and a second portion, the first portion including plaintext data and the second portion including encrypted data, the encrypted data including access data and a first hash value, the first hash value being generated as a hash of the plaintext data using a public key of the relay system node 310. The client smart contract 304, the relay system smart contract 306, and the relay system controller 308 forwards the request to the relay system node.

[0090] Plaintext is determined (604). For example, the relay system node 310 decrypts the encrypted data using its private key to determine the first hash value (as plaintext). A hash is computed (608). For example, the relay system node 310 processes the plaintext data of the first portion to provide a second hash value. It is determined whether the request is valid (608). For example, the relay system node 310 compares the first hash value and the second hash value. If the first hash value is the same as the second hash value, the request is valid. That is, it is determined that the integrity of the request is intact. If the first hash value is not the same as the second hash value, the request is invalid. That is, it is determined that the integrity of the request has been compromised. If the request is not valid, an error is indicated (610), and the example process 600 ends.

[0091] If the request is valid, a query is sent to the data source (612). For example, the relay system node 310 constructs the query (e.g., new request) that includes the plaintext data element and the confidential data element of the request it had received (e.g., original request). For example, the new request may include a plaintext data element including a web address where the user 502 wants to access an account, and a confidential data element including credentials (e.g., user name and password) of the user 502 to log into the account. The relay system node 310 queries the Internet-based data source 504 using the query.

[0092] A result is received from the data source (614). In some examples, the Internet-based data source 504 processes the request, and returns a request result (e.g., data value(s)) to the relay system node 310. A response is prepared (616), and the response is sent (618). For example, the relay system node 310 may generate a signature that includes the request result that is signed using the private key of the relay system node 310. The private key that the relay system node 310 uses to sign the request result is the same as the private key that the relay system node 310 previously used to decrypt the encrypted data in the original request. The relay system node 310 may combine (e.g., concatenate) the signature with the request result and send them to the relay system controller 308. In some embodiments, the relay system node 310 computes a hash value of the request result and signs the hash value using the private key. The relay system node 310 combines the request result with the signed hash value of the request result.

[0093] A hash is computed (620). For example, the relay system smart contract 306 calculates a hash value based on the request result (e.g., data value(s)). It is determined whether the response is valid (622). For example, the relay system smart contract obtains the hash value of the request result using the public key, and determines whether it matches the computed hash value. If the two hash values match, the relay system smart contract 306 determines that the request result is valid. If the two hash values do not match, the relay system smart contract 306 determines that the request result is invalid and may reject the request result. If the request is not valid, an error is indicated (624), and the example process 600 ends. If the request is valid, the integrity of the request result is intact, and the request result is provided to the user device 502 for further processing.

[0094] FIG. 7 is a diagram illustrating an example of modules of an apparatus 700 in accordance with embodiments of this specification. The apparatus 700 can be an example

embodiment of a relay system smart contract executing within the blockchain network. In some examples, the relay system smart contract issues requests to and receives responses from one or more components of a relay system that are external to the blockchain network, and that query data sources that are external to the blockchain network.

[0095] The apparatus 700 can correspond to the embodiments described above, and the apparatus 700 includes the following: a receiving module 702 that receives a request for data from the data source, the request including a first portion and a second portion, the first portion including plaintext data and the second portion including encrypted data, the encrypted data including access data and a first hash value, the first hash value being generated as a hash of the plaintext data by a user computing device that submits the request; a transmitting module 704 that transmits the request to at least one relay system component external to the blockchain network; a receiving module 706 that receives a result from the at least one relay system component, the result including result data and a second hash value, the result data being retrieved using the access data and the second hash value being generated based on the result data and digitally signed using a private key of a relay system component; and a verifying module 708 that verifies an integrity of the result based on a public key of the at least one relay system component, a digital signature of the result and the second hash value. In response to verifying the integrity of the result, the transmitting module 704 transmits the result to the user computing device.

[0096] The system, apparatus, module, or unit illustrated in the previous embodiments can be implemented by using a computer chip or an entity, or can be implemented by using a product having a certain function. A typical embodiment device is a computer, and the computer can be a personal computer, a laptop computer, a cellular phone, a camera phone, a smartphone, a personal digital assistant, a media player, a navigation device, an email receiving and sending device, a game console, a tablet computer, a wearable device, or any combination of these devices.

[0097] For an embodiment process of functions and roles of each module in the apparatus, references can be made to an embodiment process of corresponding steps in the previous method. Details are omitted here for simplicity.

[0098] Because an apparatus embodiment basically corresponds to a method embodiment, for related parts, references can be made to related descriptions in the method embodiment.

The previously described apparatus embodiment is merely an example. The modules described as separate parts may or may not be physically separate, and parts displayed as modules may or may not be physical modules, may be located in one position, or may be distributed on a number of network modules. Some or all of the modules can be selected based on actual demands to achieve the objectives of the solutions of the specification. A person of ordinary skill in the art can understand and implement the embodiments of the present application without creative efforts.

[0099] Referring again to FIG. 7, it can be interpreted as illustrating an internal functional module and a structure of a data retrieving apparatus. The data retrieving apparatus can be an example of a blockchain node executing a relay system smart contract. An execution body in essence can be an electronic device, and the electronic device includes the following: one or more processors; and one or more computer-readable memories configured to store an executable instruction of the one or more processors. In some embodiments, the one or more computer-readable memories are coupled to the one or more processors and have programming instructions stored thereon that are executable by the one or more processors to perform algorithms, methods, functions, processes, flows, and procedures, as described in this specification.

[0100] The techniques described in this specification produce one or more technical effects. For example, embodiments of this specification ensure the integrity of requests submitted to relay system nodes for querying data sources that are external to a blockchain network. As another example, embodiments of this specification ensure the integrity of responses provided back to the blockchain network from the external data sources. Accordingly, embodiments of the present disclosure improve the integrity of communications between a blockchain network, and components of a relay system that is used to retrieve data that is external to the blockchain network. In this manner, potential attack channels for malicious users are mitigated to enhance security.

[0101] As another example, the relay system of this specification facilitates avoiding a direct contact between the user and the relay system node, thereby avoiding exposing a position or access point of the relay system node. As such, the relay system node is less likely to be found and attacked by malicious actors over the network in many forms, for example such as, distributed denial of service (DDoS) attacks. This improves a security of

the relay system node, thereby further improving a security of the communication between the blockchain network and the relay system node.

[0102] Described embodiments of the subject matter can include one or more features, alone or in combination: the relay system component decrypts the encrypted data using the private key to provide the first hash value, calculates a hash value based on the plaintext data included in the request, and compares the first hash value to the hash value to verify that the plaintext data is absent any change in response to receiving the request; the relay system component transmits a query request to the data source in response to verifying the request; the at least one relay system component includes a relay system node that receives the request from a relay system controller; the plaintext data include a uniform resource locator (URL) of the data source; the at least one relay system component executes a trusted execution environment (TEE), and the private key and the public key of the relay system component are provisioned during an attestation process of the TEE; the relay system controller executes the attestation process with the relay system node and an attestation service; and the data source includes an Internet-based data source.

[0103] Embodiments of the subject matter and the actions and operations described in this specification can be implemented in digital electronic circuitry, in tangibly-embodied computer software or firmware, in computer hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. Embodiments of the subject matter described in this specification can be implemented as one or more computer programs, e.g., one or more modules of computer program instructions, encoded on a computer program carrier, for execution by, or to control the operation of, data processing apparatus. For example, a computer program carrier can include one or more computer-readable storage media that have instructions encoded or stored thereon. The carrier may be a tangible non-transitory computer-readable medium, such as a magnetic, magneto optical, or optical disk, a solid state drive, a random access memory (RAM), a read-only memory (ROM), or other types of media. Alternatively, or in addition, the carrier may be an artificially generated propagated signal, e.g., a machine-generated electrical, optical, or electromagnetic signal that is generated to encode information for transmission to suitable receiver apparatus for execution by a data processing apparatus. The computer storage medium can be or be part of a machine-readable storage device, a machine-readable storage

substrate, a random or serial access memory device, or a combination of one or more of them. A computer storage medium is not a propagated signal.

[0104] A computer program, which may also be referred to or described as a program, software, a software application, an app, a module, a software module, an engine, a script, or code, can be written in any form of programming language, including compiled or interpreted languages, or declarative or procedural languages; and it can be deployed in any form, including as a stand-alone program or as a module, component, engine, subroutine, or other unit suitable for executing in a computing environment, which environment may include one or more computers interconnected by a data communication network in one or more locations.

[0105] A computer program may, but need not, correspond to a file in a file system. A computer program can be stored in a portion of a file that holds other programs or data, e.g., one or more scripts stored in a markup language document, in a single file dedicated to the program in question, or in multiple coordinated files, e.g., files that store one or more modules, sub programs, or portions of code.

[0106] Processors for execution of a computer program include, by way of example, both general- and special-purpose microprocessors, and any one or more processors of any kind of digital computer. Generally, a processor will receive the instructions of the computer program for execution as well as data from a non-transitory computer-readable medium coupled to the processor.

[0107] The term “data processing apparatus” encompasses all kinds of apparatuses, devices, and machines for processing data, including by way of example a programmable processor, a computer, or multiple processors or computers. Data processing apparatus can include special-purpose logic circuitry, e.g., an FPGA (field programmable gate array), an ASIC (application specific integrated circuit), or a GPU (graphics processing unit). The apparatus can also include, in addition to hardware, code that creates an execution environment for computer programs, e.g., code that constitutes processor firmware, a protocol stack, a database management system, an operating system, or a combination of one or more of them.

[0108] The processes and logic flows described in this specification can be performed by one or more computers or processors executing one or more computer programs to perform

operations by operating on input data and generating output. The processes and logic flows can also be performed by special-purpose logic circuitry, e.g., an FPGA, an ASIC, or a GPU, or by a combination of special-purpose logic circuitry and one or more programmed computers.

[0109] Computers suitable for the execution of a computer program can be based on general or special-purpose microprocessors or both, or any other kind of central processing unit. Generally, a central processing unit will receive instructions and data from a read only memory or a random access memory or both. Elements of a computer can include a central processing unit for executing instructions and one or more memory devices for storing instructions and data. The central processing unit and the memory can be supplemented by, or incorporated in, special-purpose logic circuitry.

[0110] Generally, a computer will also include, or be operatively coupled to receive data from or transfer data to one or more storage devices. The storage devices can be, for example, magnetic, magneto optical, or optical disks, solid state drives, or any other type of non-transitory, computer-readable media. However, a computer need not have such devices. Thus, a computer may be coupled to one or more storage devices, such as, one or more memories, that are local and/or remote. For example, a computer can include one or more local memories that are integral components of the computer, or the computer can be coupled to one or more remote memories that are in a cloud network. Moreover, a computer can be embedded in another device, e.g., a mobile telephone, a personal digital assistant (PDA), a mobile audio or video player, a game console, a Global Positioning System (GPS) receiver, or a portable storage device, e.g., a universal serial bus (USB) flash drive, to name just a few.

[0111] Components can be “coupled to” each other by being commutatively such as electrically or optically connected to one another, either directly or via one or more intermediate components. Components can also be “coupled to” each other if one of the components is integrated into the other. For example, a storage component that is integrated into a processor (e.g., an L2 cache component) is “coupled to” the processor.

[0112] To provide for interaction with a user, embodiments of the subject matter described in this specification can be implemented on, or configured to communicate with, a computer having a display device, e.g., a LCD (liquid crystal display) monitor, for displaying information to the user, and an input device by which the user can provide input to the

computer, e.g., a keyboard and a pointing device, e.g., a mouse, a trackball or touchpad. Other kinds of devices can be used to provide for interaction with a user as well; for example, feedback provided to the user can be any form of sensory feedback, e.g., visual feedback, auditory feedback, or tactile feedback; and input from the user can be received in any form, including acoustic, speech, or tactile input. In addition, a computer can interact with a user by sending documents to and receiving documents from a device that is used by the user; for example, by sending web pages to a web browser on a user's device in response to requests received from the web browser, or by interacting with an app running on a user device, e.g., a smartphone or electronic tablet. Also, a computer can interact with a user by sending text messages or other forms of message to a personal device, e.g., a smartphone that is running a messaging application, and receiving responsive messages from the user in return.

[0113] This specification uses the term “configured to” in connection with systems, apparatus, and computer program components. For a system of one or more computers to be configured to perform particular operations or actions means that the system has installed on it software, firmware, hardware, or a combination of them that in operation cause the system to perform the operations or actions. For one or more computer programs to be configured to perform particular operations or actions means that the one or more programs include instructions that, when executed by data processing apparatus, cause the apparatus to perform the operations or actions. For special-purpose logic circuitry to be configured to perform particular operations or actions means that the circuitry has electronic logic that performs the operations or actions.

[0114] While this specification contains many specific embodiment details, these should not be construed as limitations on the scope of what is being claimed, which is defined by the claims themselves, but rather as descriptions of features that may be specific to particular embodiments. Certain features that are described in this specification in the context of separate embodiments can also be realized in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiments can also be realized in multiple embodiments separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially be claimed as such, one or more features from a claimed combination can in

some cases be excised from the combination, and the claim may be directed to a subcombination or variation of a subcombination.

[0115] Similarly, while operations are depicted in the drawings and recited in the claims in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system modules and components in the embodiments described above should not be understood as requiring such separation in all embodiments, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products.

[0116] Particular embodiments of the subject matter have been described. Other embodiments are within the scope of the following claims. For example, the actions recited in the claims can be performed in a different order and still achieve desirable results. As one example, the processes depicted in the accompanying figures do not necessarily require the particular order shown, or sequential order, to achieve desirable results. In some cases, multitasking and parallel processing may be advantageous.