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(54) **COMMUNICATION MONITORING SYSTEM IN CONTROL NETWORK**

(71) Applicant: **NAGOYA INSTITUTE OF TECHNOLOGY**, Nagoya-shi, Aichi (JP)

(72) Inventors: **Yoshihiro HASHIMOTO**, Nagoya-shi (JP); **Toshiaki HONDA**, Machida-shi (JP)

(73) Assignee: **NAGOYA INSTITUTE OF TECHNOLOGY**, Nagoya-shi, Aichi (JP)

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(57) **ABSTRACT**

A monitoring system comprises a router unit and a monitoring unit. The router unit includes an acquisition unit obtaining a packet encrypted with a first encryption key by a first communication device and sent from the first communication device, the monitoring unit includes a decryption unit decrypting the packet obtained by the acquisition unit with a first decryption key corresponding to the first encryption key and a recording unit recording information based on the decrypted packet, the router unit includes a transfer unit transmitting the encrypted packet to a second communication device, the router unit and the monitoring unit function as OPC UA application integrated within encrypted communications, are equipped with OPC UA server/client functionalities, capable of OPC UA encryption/decryption, and make an inquiry to an OPC UA server as a proxy for an OPC UA client.

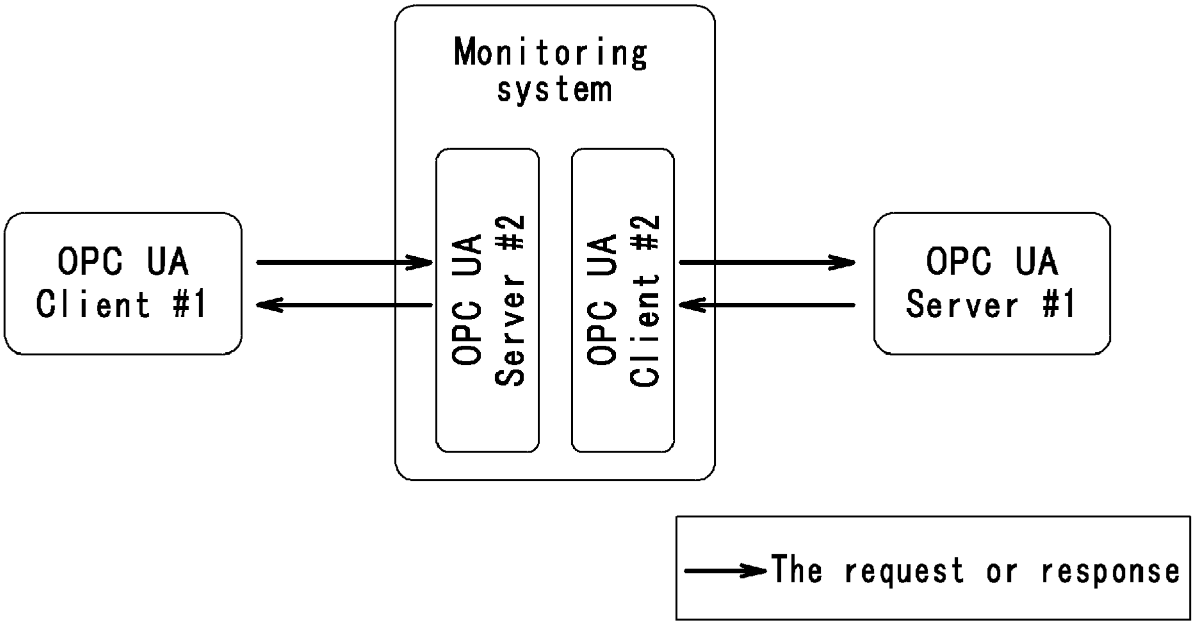


FIG. 1A

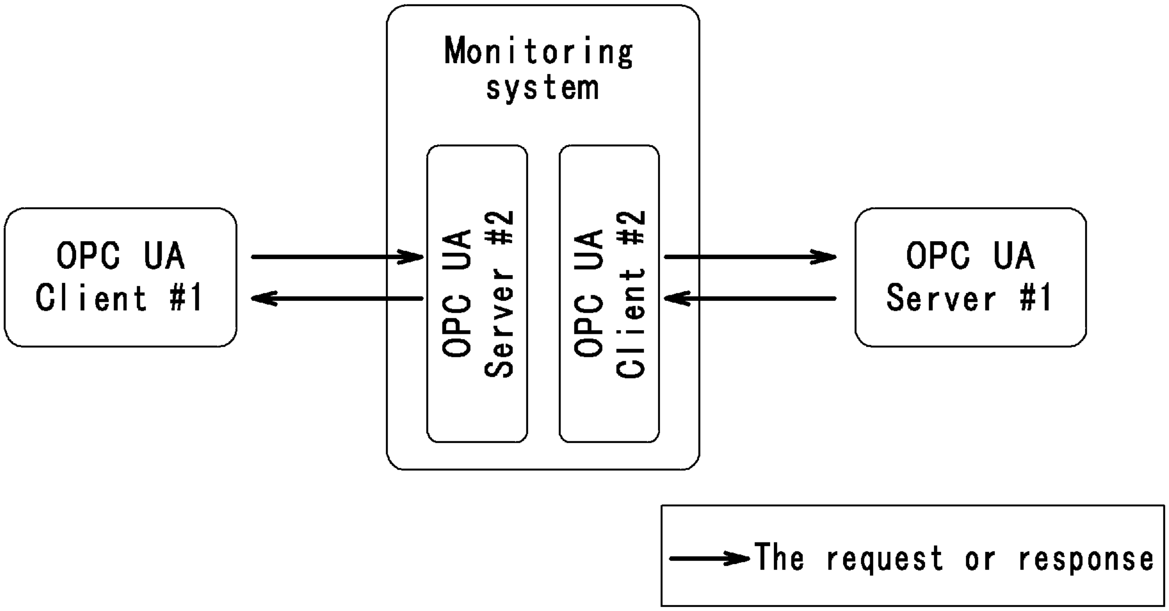

Monitoring system
OPC UA Client #1
OPC UA Server #2
OPC UA Client #2
OPC UA Server #1
The request or response

FIG. 1B

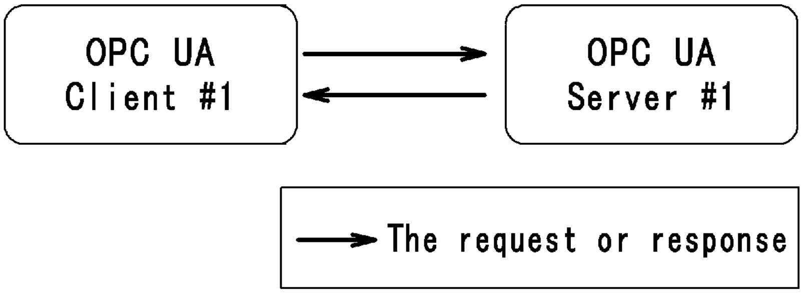

OPC UA Client #1
OPC UA Server #1
The request or response

FIG. 2A

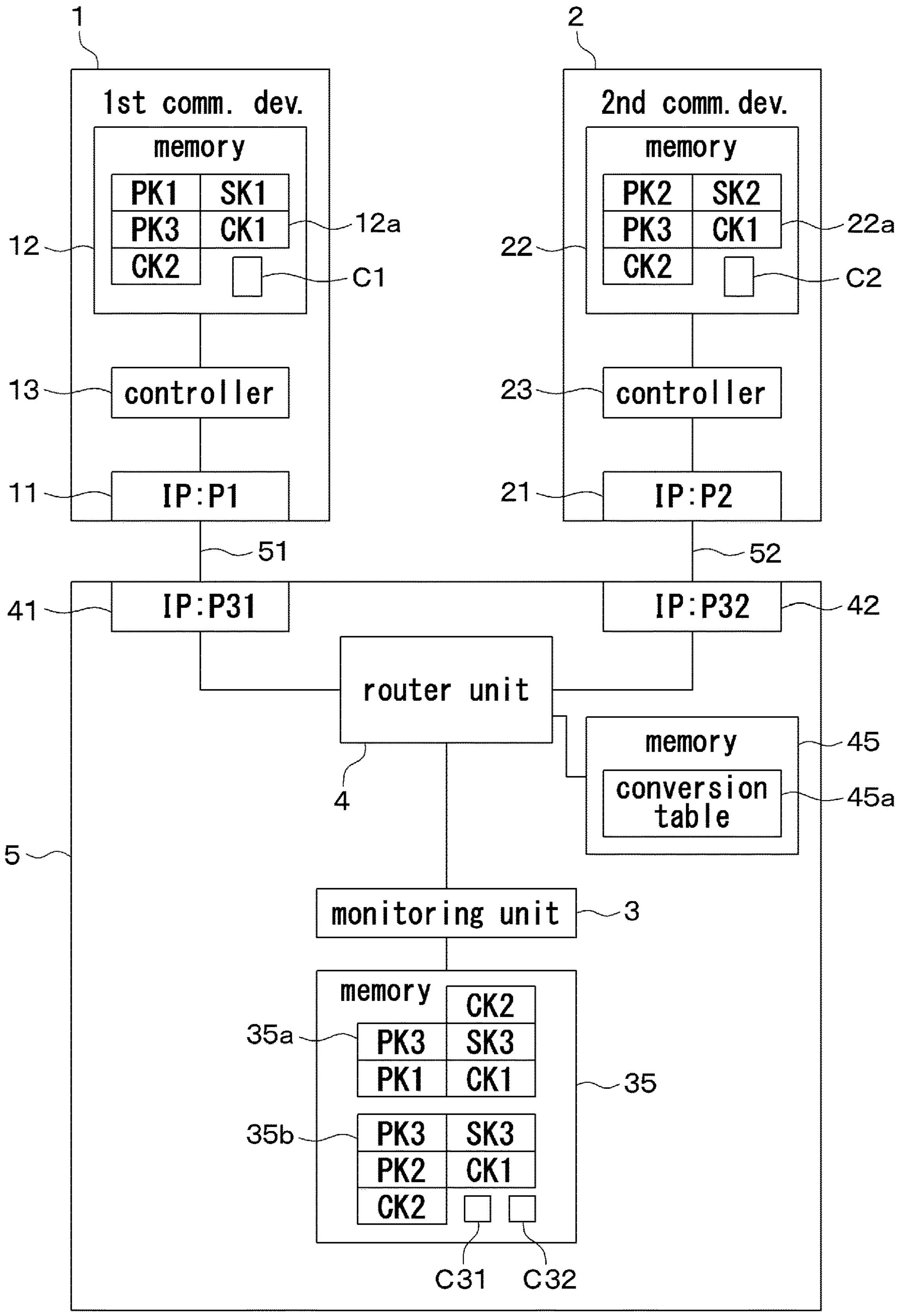

1
2
1st comm. dev.
memory
PK1
SK1
PK3
CK1
CK2
12a
12
C1
2nd comm. dev.
memory
PK2
SK2
PK3
CK1
CK2
22a
22
C2
13
controller
23
controller
11
IP:P1
21
IP:P2
51
52
41
IP:P31
IP:P32
42
router unit
memory
45
conversion table
45a
4
5
monitoring unit
3
memory
CK2
35a
PK3
SK3
PK1
CK1
35
35b
PK3
SK3
PK2
CK1
CK2
C31
C32

FIG. 2B

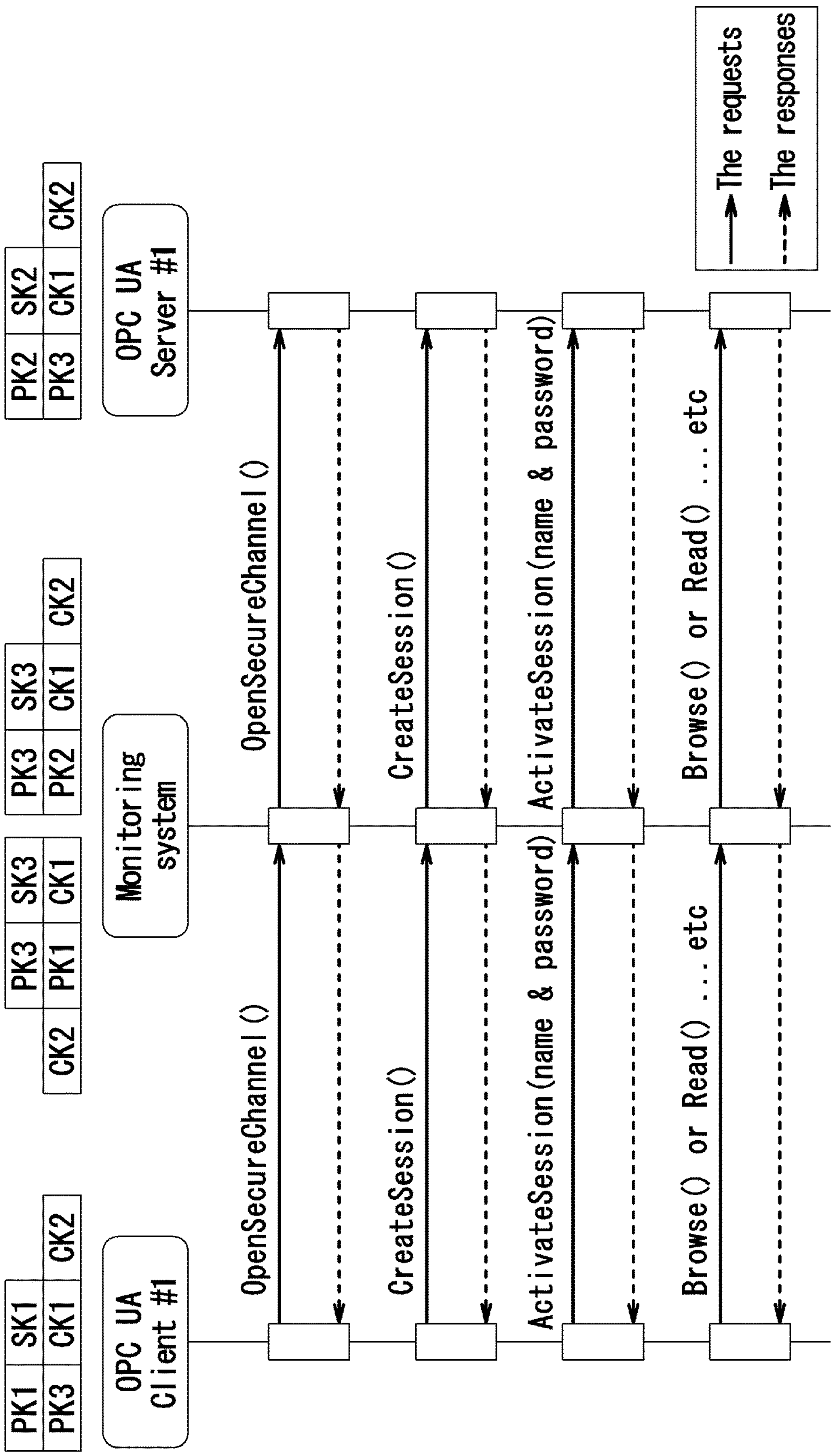

PK1
SK1
PK3
CK1
CK2
OPC UA Client #1
key management (for Client #1)
PK3
SK3
PK1
CK1
CK2
key management (for Server #1)
PK3
SK3
PK2
CK1
CK2
Monitoring system
PK2
SK2
PK3
CK1
CK2
OPC UA Server #1
OpenSecureChannel()
CreateSession()
ActivateSession(name & password)
Browse() or Read() ... etc
OpenSecureChannel()
CreateSession()
ActivateSession(name & password)
Browse() or Read() ... etc
The requests
The responses

FIG. 3A

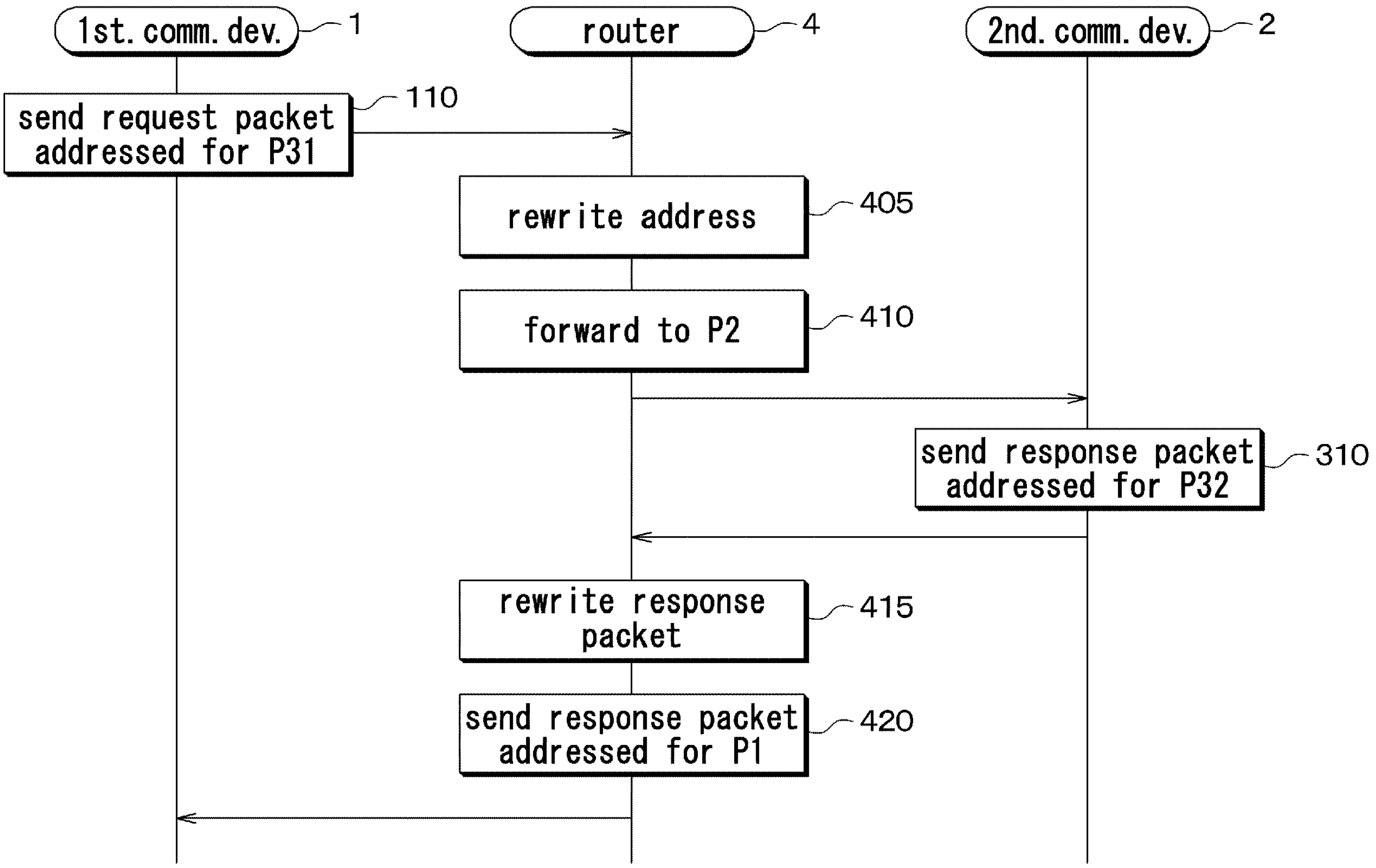

1st. comm. dev.
1
router
4
2nd. comm. dev.
2
send request packet addressed for P31
110
rewrite address
405
forward to P2
410
send response packet addressed for P32
310
rewrite response packet
415
send response packet addressed for P1
420

FIG. 3B

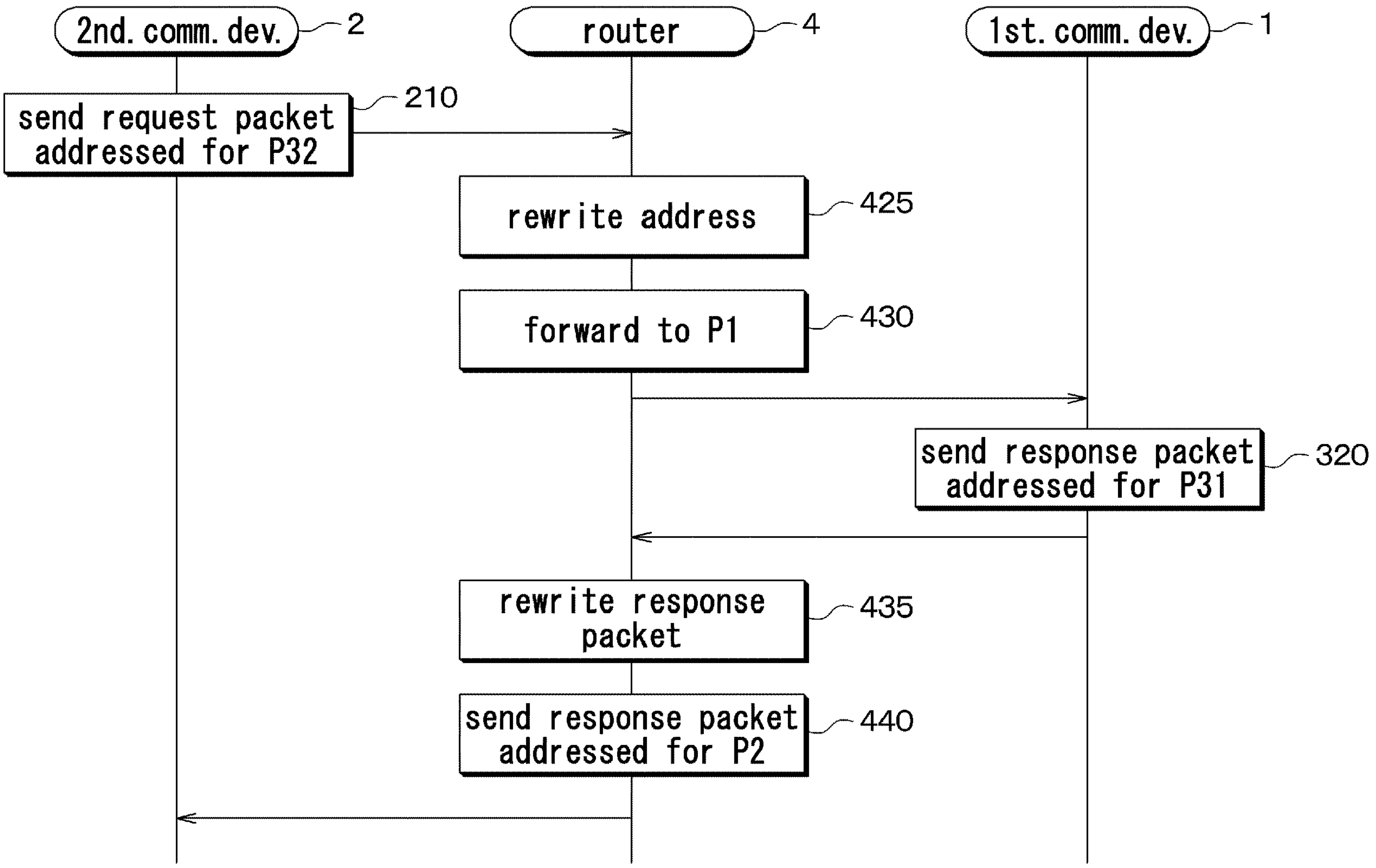

2nd. comm. dev.
2
router
4
1st. comm. dev.
1
send request packet addressed for P32
210
rewrite address
425
forward to P1
430
send response packet addressed for P31
320
rewrite response packet
435
send response packet addressed for P2
440

FIG. 4A

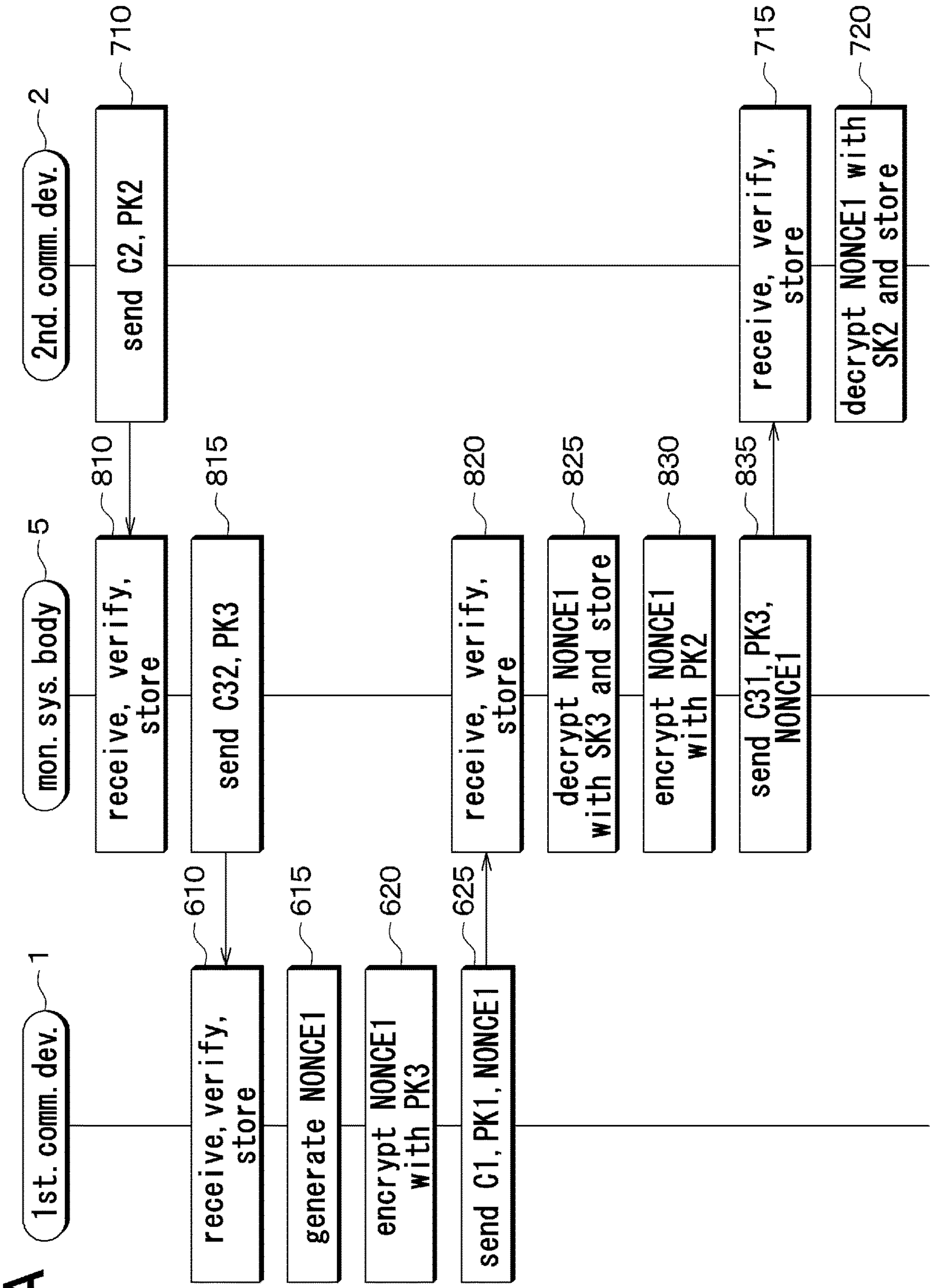

1st. comm. dev.
1
mon. sys. body
5
2nd. comm. dev.
2
send C2, PK2
710
810
receive, verify, store
815
send C32, PK3
610
receive, verify, store
615
generate NONCE1
620
encrypt NONCE1 with PK3
625
send C1, PK1, NONCE1
820
receive, verify, store
825
decrypt NONCE1 with SK3 and store
830
encrypt NONCE1 with PK2
835
send C31, PK3, NONCE1
715
receive, verify, store
720
decrypt NONCE1 with SK2 and store

FIG. 4B

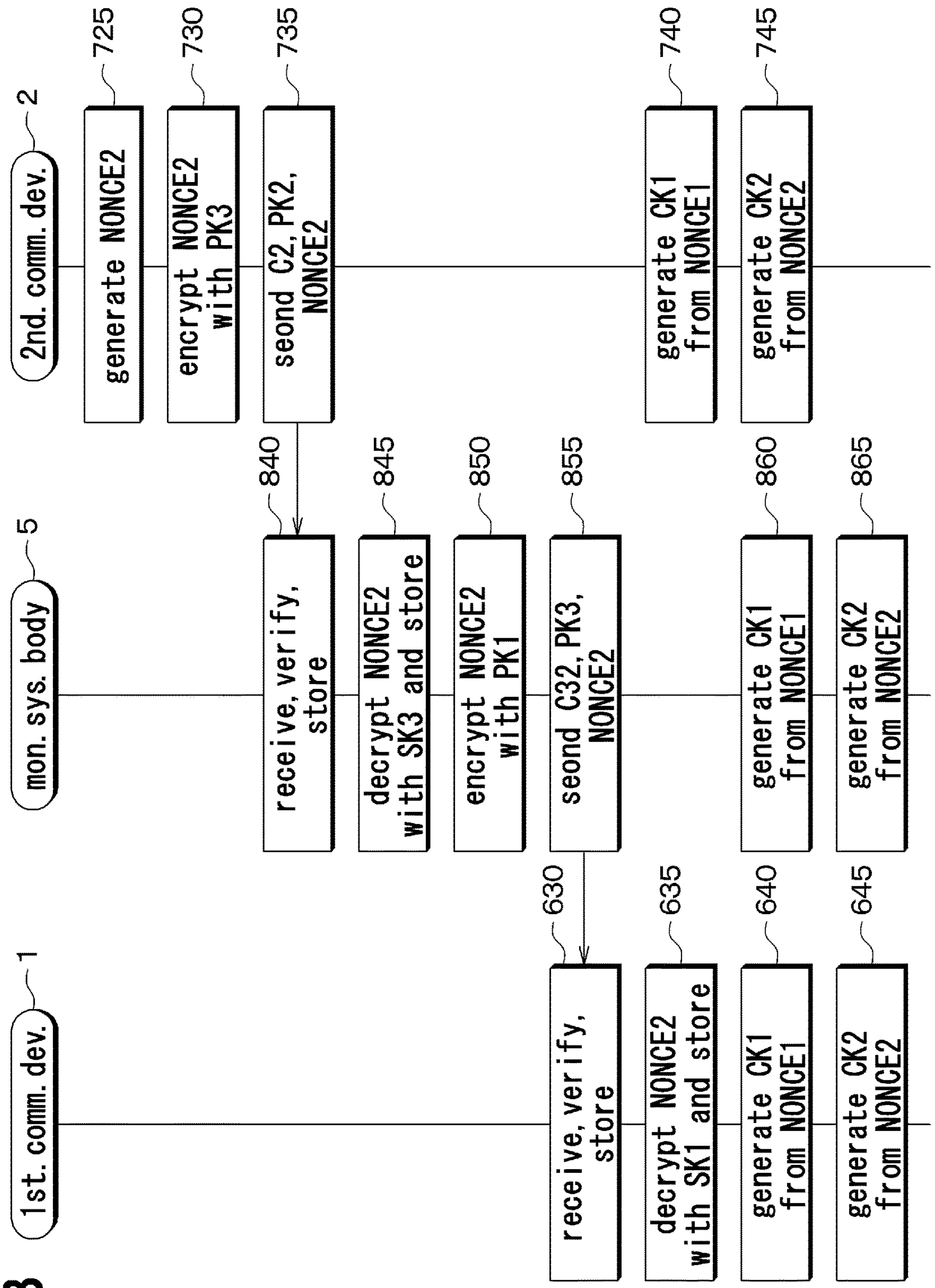

1st. comm. dev.
1
mon. sys. body
5
2nd. comm. dev.
2
generate NONCE2
725
encrypt NONCE2 with PK3
730
seond C2, PK2, NONCE2
735
receive, verify, store
840
decrypt NONCE2 with SK3 and store
845
encrypt NONCE2 with PK1
850
seond C32, PK3, NONCE2
855
receive, verify, store
630
decrypt NONCE2 with SK1 and store
635
generate CK1 from NONCE1
740
generate CK2 from NONCE2
745
generate CK1 from NONCE1
860
generate CK2 from NONCE2
865
generate CK1 from NONCE1
640
generate CK2 from NONCE2
645

FIG. 5

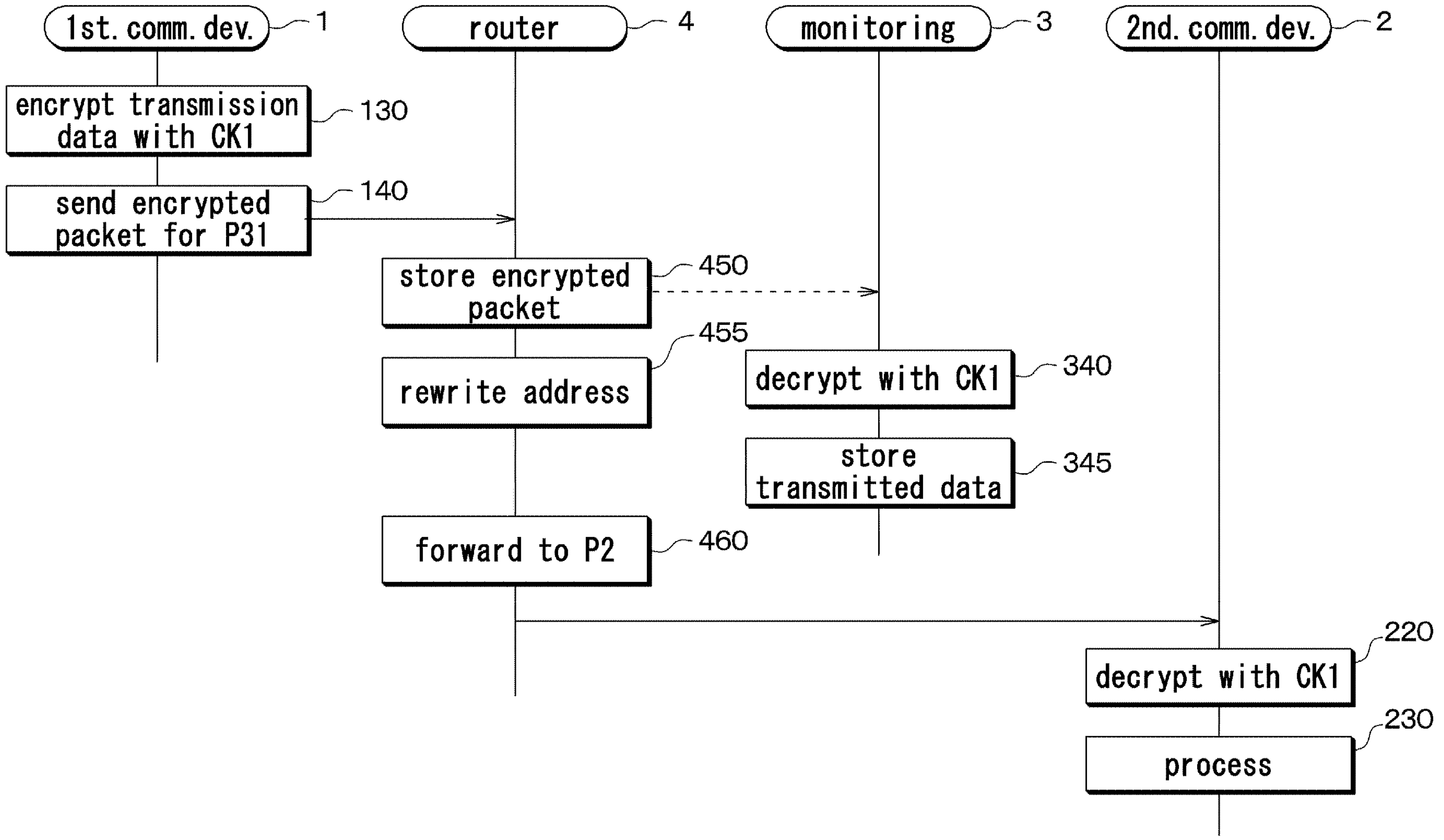

1st. comm. dev.
1
router
4
monitoring
3
2nd. comm. dev.
2
encrypt transmission data with CK1
130
send encrypted packet for P31
140
store encrypted packet
450
rewrite address
455
decrypt with CK1
340
store transmitted data
345
forward to P2
460
decrypt with CK1
220
process
230

FIG. 6

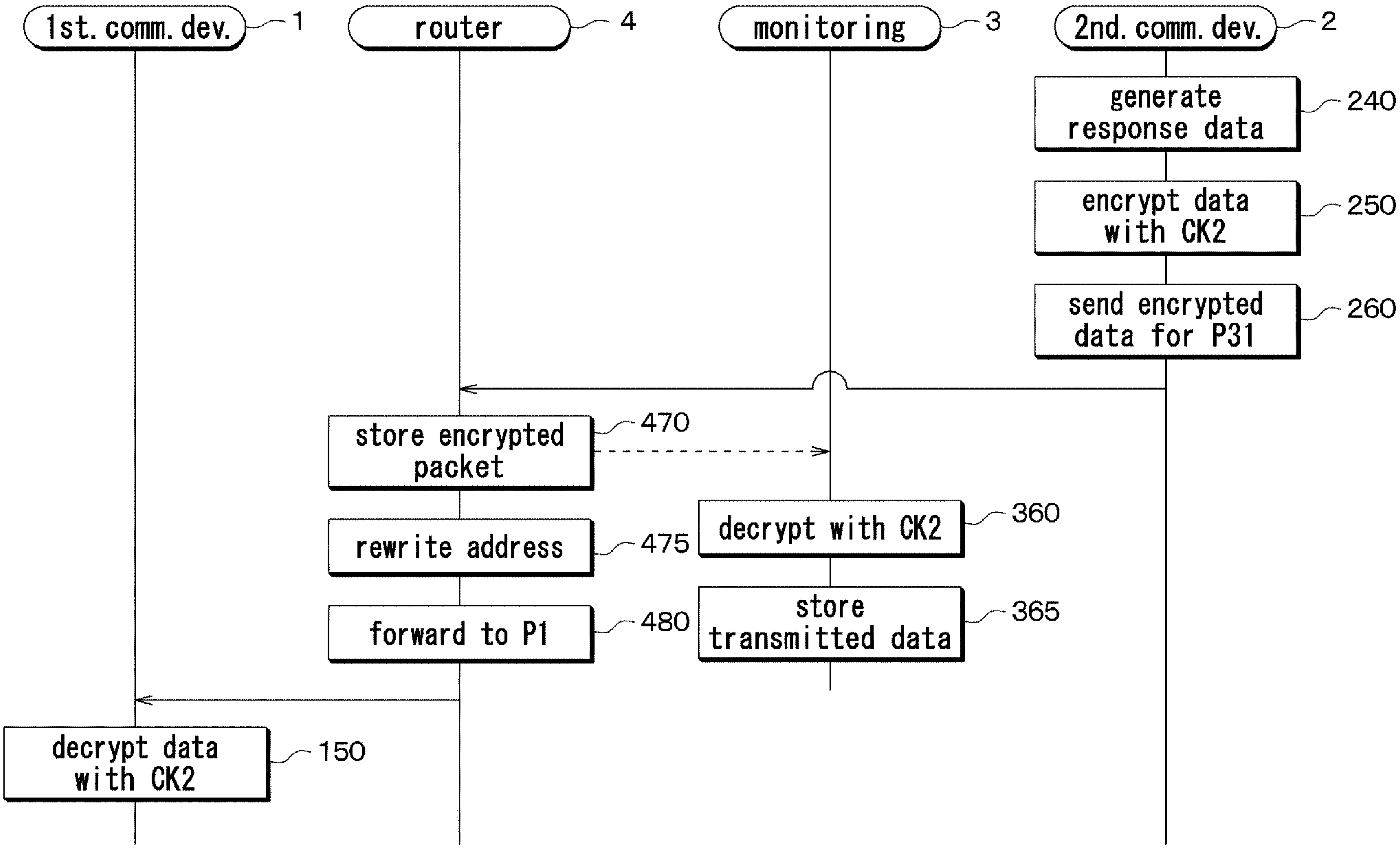
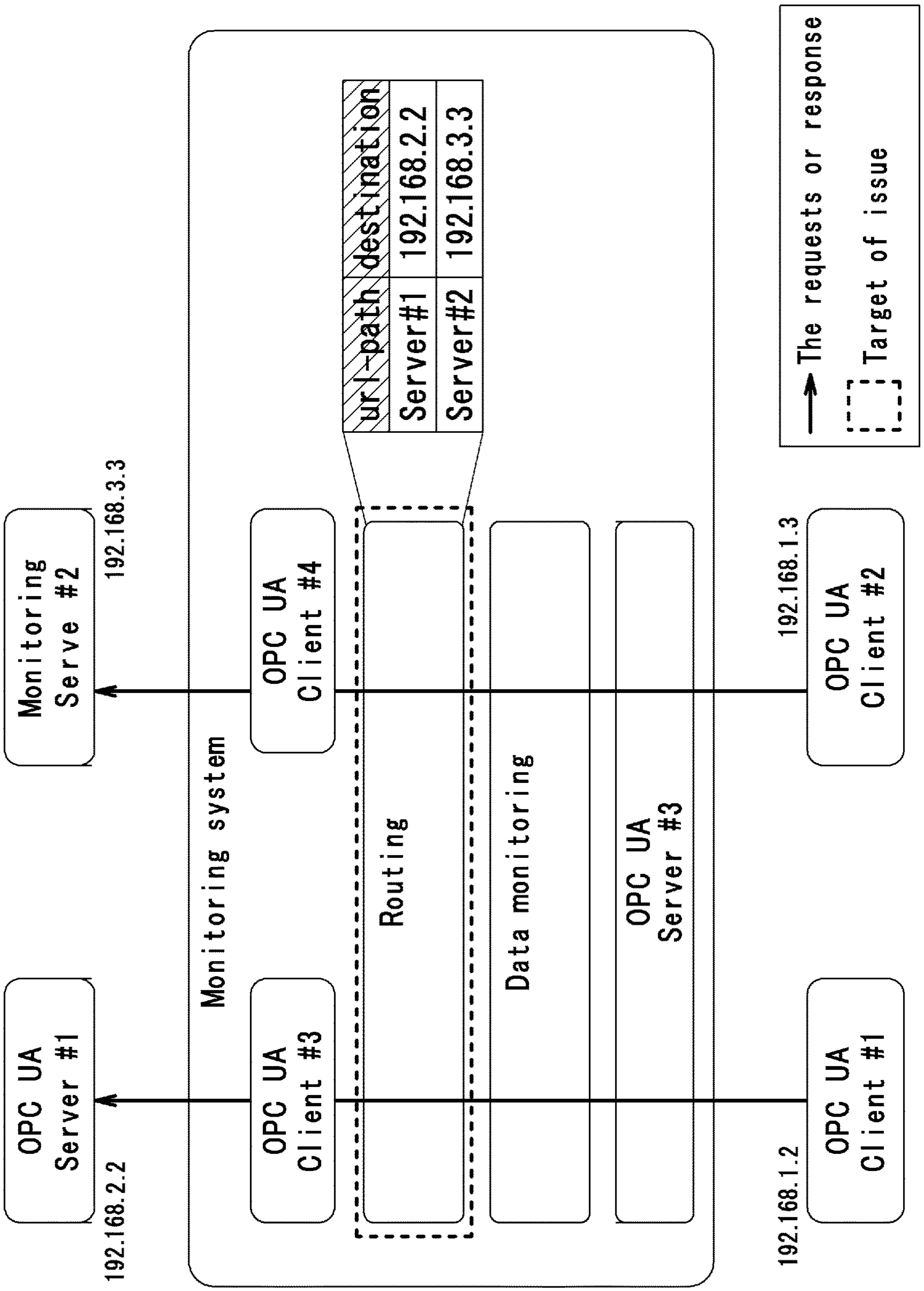

1st. comm. dev.
1
router
4
monitoring
3
2nd. comm. dev.
2
generate response data
240
encrypt data with CK2
250
send encrypted data for P31
260
store encrypted packet
470
rewrite address
475
forward to P1
480
decrypt with CK2
360
store transmitted data
365
decrypt data with CK2
150

FIG. 7



url-path	destination
Server#1	192.168.2.2
Server#2	192.168.3.3

COMMUNICATION MONITORING SYSTEM IN CONTROL NETWORK

TECHNICAL FIELD

[0001] The present invention relates to a communication monitoring system in a control network.

BACKGROUND ART

[0002] In recent years, cyber attacks on critical infrastructures have been on the rise. Consequently, networks establishing Industrial Control Systems (ICS) also need to address security incidents. ICSs are utilized in gas pipelines, power plants, chemical and petrochemical plants, among others. Cyber incidents targeting ICSs pose not only security concerns but also safety and business issues. The repercussions, whether accidents in manufacturing facilities, customers' damages due to improper product shipments, or even temporary service halts in production, are highly impactful.

[0003] As a solution in such cases, attention has been drawn to OPC UA (Open Platform Communications Unified Architecture), a platform-independent communication protocol enabling secure communication within ICS. In 2018, OPC UA added the specification for Pub/Sub (Publish/Subscriber) communication, allowing not only one-to-one client/server communication but also multicast communication based on publish/subscribe. This expansion accommodates industrial use cases requiring real-time responsiveness and simultaneous instructions to the field. Consequently, OPC UA is becoming a standard in the industrial sector. Among the highly anticipated features of OPC UA within ICS is data confidentiality, driving the promotion of network encryption (e.g., see non-patent literature 1)

PRIOR ART LITERATURE

Patent Literature

Non-Patent Literature 1

[0004] Japan OPC Consortium Technical Committee, "Inquiry on OPC UA Security Functions and Evaluation Results by the German Federal Ministry of Technology Security Department," [online], [searched on Jul. 22, 2019], Internet <URL: https://jp.opcfoundation.org/wp-content/uploads/sites/2/2017/12/OPC-Day2017_04_OPC_UAsec.pdf >

[0005] In OPC UA, actual data exchange is encrypted using a symmetric key encryption method, but it is necessary to exchange this encryption key beforehand using asymmetric key encryption. Therefore, the encryption key is strictly managed within the OPC UA application. In other words, it is extremely difficult for a third person to intercept the encrypted network without stealing the encryption key

SUMMARY OF THE INVENTION

Technical Problem

[0006] OPC UA incorporates internet technologies that have been cultivated over the years in an internet environment rampant with cyber attacks. Payload portions of packets transmitted and received within the network is encrypted. In the case of OPC UA, public key encryption is used for connection sequences at the start of communications, while symmetric key encryption is used for actual data exchange. In public key encryption, exchange of a common key occurs, and since the common key is updated each time at the initiation of OPC UA communications, it is not reused. Therefore, it is extremely challenging for a third party to decrypt the OPC UA network by guessing the common key.

[0007] However, when networks are encrypted and the encryption keys used for encryption become more complex, it implies that the contents of communications become undetectable. In the case of ICS, there exist many machines that send commands to controllers. If an ICS employing OPC UA for encrypted communication is compromised by cyber attackers, there is a possibility that normal data exchanges might be transmitted to the controllers as malicious data exchanges. Monitoring an encrypted OPC UA network is challenging using conventional port mirroring. Acquiring packets via port mirroring and using packet analysis tools like Wireshark allows for the analysis of plaintext (unencrypted) packets, but Wireshark currently lacks decryption capability of encrypted transfer data.

[0008] If Wireshark were to implement decryption capabilities, it would be necessary to decrypt data encrypted by the public key encryption used in the earlier mentioned common key exchange. In this case, a private key corresponding to a public key used by both the OPC UA server and client would be necessary. Given a feature of ICS dealing with critical infrastructure control systems, exposing the private key from devices externally poses a very high risk of security incidents. Therefore, a method of acquiring the private key externally and decrypting is difficult.

[0009] In consideration of the above, it is a goal to enable a device different from communication devices to monitor data encrypted by one of the communication devices and sent to another one of the communication devices within a control network.

Solution to Problem

[0010] An invention solving the above problem is as follows:

[1]A monitoring system for monitoring communication between a first communication device (**1**) and a second communication device (**2**) in a control network, comprising: a router unit (**4**) capable of communication with the first communication device and the second communication device, and a monitoring unit (**3**) recording information regarding content of communication between the first communication device and the second communication device, wherein: the router unit includes an acquisition unit (**450**, **470**) obtaining a packet encrypted with a first encryption key (CK**1**) by the first communication device and sent from the first communication device, the monitoring unit includes a decryption unit (**340**) decrypting the packet obtained by the acquisition unit with a first decryption key (CK**1**) corresponding to the first encryption key and a recording unit (**345**) recording information based on the decrypted packet, the router unit includes a transfer unit (**460**) transmitting the encrypted packet to the second communication device, the router unit and the monitoring unit function as OPC UA application (hereinafter may be also referred to as an OPC UA proxy) integrated within encrypted communications, are equipped with OPC UA server/client functionalities, operate as an OPC UA application, capable of OPC UA encryption/decryption that is the first communication device, and make an inquiry to an OPC UA server that is the second communication device as a proxy for an OPC UA client that is the

first communication device. It is noted that "OPC UA encryption/decryption" refers to "encryption and decryption of OPC UA."

[2] The monitoring system according to [1], wherein the first communication device, the second communication device, and the monitoring unit are all capable of communication through the router unit, wherein the acquisition unit within the router unit alters a destination address of the packet and sends them from the transfer unit, the packet originating from the first communication device has a source address being an address of the first communication device (**1**) and the destination address being an address (P**31**) of the router unit and reaches the router unit, at the initiation of communication, the acquisition unit possesses a common key shared between the OPC UA client and the OPC UA server.

[3] The monitoring system according to [2], wherein the router unit and the monitoring unit are capable of communication with each other, the router unit includes a request packet transfer unit (**405**, **410**) rewriting, at the initiation of communication, a destination address of a specific request packet sent from the first communication device from an address (P**31**) of the router unit to an address (P**2**) of the second communication device and sending the rewritten packet to the second communication device, the second communication device includes a response unit (**310**) sending to the router unit a response packet in response to the request packet sent by the request packet transfer unit, by setting a destination address to an address (P**32**) of the router unit and by setting a source address to the address (P**2**) of the second communication device, and the router unit changes the source address of the response packet sent by the response unit from the address (P**2**) of the second communication device to an address (P**31**) of the router unit and sends the response packet to the first communication device.

[4] The monitoring system according to [3], wherein the request packet from the first communication device includes an electronic certificate of the first communication device, and the corresponding response packet contains an electronic certificate of the monitoring unit.

[5] The monitoring system according to [4], wherein the request packet from the first communication device includes a public key (PK**1**) corresponding to a private key (SK**1**) owned by the first communication device, and the response packet includes a public key (PK**3**) corresponding to a private key (SK**3**) owned by the monitoring unit.

[6] The monitoring system according to [5], wherein a request packet from the second communication device includes a public key (PK**2**) corresponding to a private key (SK**2**) owned by the second communication device, and a corresponding response packet includes a public key (PK**3**) corresponding to a private key (SK**3**) owned by the monitoring unit.

[7] The monitoring system according to [6], wherein the first communication device and the monitoring unit share a common key, and the second communication device and the monitoring unit also share a common key.

[8] The monitoring system according to any one [1] to [7], wherein packet routing information between the first communication device, the second communication device, and the router unit is specified using a URL.

[9] The monitoring system according to any one of [1] to [8], wherein the first encryption key and the first decryption key are obtained by the first communication device, the second communication device, and the monitoring unit based on information (NONCE**1**) shared among the first communication device, the second communication device, and the monitoring unit through communication using asymmetric key encryption.

[0011] The monitoring system according to any one of [1] to [9], wherein the router unit obtains a packet encrypted with a second encryption key (CK**2**) at the second communication device and sent from the second communication device, the monitoring unit decrypts, using a second decryption key (CK**2**) corresponding to the second encryption key, the packet obtained from the second communication device and encrypted with the second encryption key at the second communication device and records information based on the decrypted packet, and the router unit sends the packet encrypted with the second encryption key by the second communication unit to the first communication device.

[0012] Parenthesized reference symbols attached to each constituent element indicate one example of correspondence relationship between the constituent element and specific constituent elements described in the embodiments described later.

BRIEF DESCRIPTION OF DRAWINGS

[0013] FIG. **1**A Basic configuration of a communication monitoring system.

[0014] FIG. **1**B Diagram illustrating a general connection configuration of an OPC UA system.

[0015] FIG. **2**A Block diagram illustrating a configuration of the communication monitoring system.

[0016] FIG. **2**B Diagram depicting a communication sequence of OPC UA server/client and monitoring OPC UA application.

[0017] FIG. **3**A Diagram illustrating the communication procedure between the first communication device and the monitoring unit acting as an agent for the second communication device.

[0018] FIG. **3**B Diagram illustrating the communication procedure between the second communication device and the monitoring unit acting as an agent for the first communication device.

[0019] FIG. **4**A Diagram illustrating the procedure for generating common keys CK**1** and CK**2**.

[0020] FIG. **4**B Diagram illustrating the procedure for generating common keys CK**1** and CK**2**.

[0021] FIG. **5** Diagram illustrating the procedure where the monitoring unit and the router unit relay and record data transmitted from the first communication device to the second communication device.

[0022] FIG. **6** Diagram illustrating the procedure where the monitoring unit and the router unit relay and record data transmitted from the second communication device to the first communication device.

[0023] FIG. **7** Diagram depicting establishment of seamless OPC UA communication.

DESCRIPTION OF EMBODIMENTS

[0024] By referring FIG. **1**A, a basic configuration of a communication monitoring system in one embodiment of the present invention is explained. In the case of communication between a Client #1 and a Server #1, the Client #1 sends a request to the Server #2, and the Server #2 receives the request. A Client #2 is created as a proxy (i.e., an OPC

UA application), forwarding the request to the Server #1. The response follows the same flow in reverse.

[0025] During this time, the system retains information necessary for generating a common key used in data exchange. The system holds, as targets of monitoring, the requests/responses transferred through the OPC UA proxy without delaying the transfer, and decrypts them later for monitoring. On the other hand, a general communication monitoring system has a connection configuration as shown in FIG. **1**B, in which a connection between a Client #1 and a Server #1 are made without creating a Client #2 as a proxy.

[0026] The embodiment of the basic configuration of the communication monitoring system in FIG. **1**A is illustrated in FIG. **2**A. This monitoring system includes a monitoring system body **5** equipped with a monitoring unit **3** and a router unit **4** to monitor the communication between a first communication device **1** and a second communication device **2**.

[0027] The monitoring unit **3**, the router unit **4**, and network connecting them can be made as virtual realization in a single computer. Software like Kernel-based Virtual Machine (KVM) can be used to realize these virtually.

[0028] Alternatively, the monitoring unit **3** and the router unit **4** may be realized on separate computers. In this case, the monitoring unit **3** acts as a monitoring device, and the router unit **4** acts as a router. The network between the monitoring unit **3** and the router unit **4** becomes a tangible entity. In the example shown in FIG. **2**A, communication between the first communication device **1**, the second communication device **2**, and the monitoring unit **3** is possible only through the router unit **4**, but in other scenarios, direct communication without the router unit **4** might also be possible.

[0029] The first communication device **1** and the second communication device **2** are devices connected to industrial control network. For instance, the first communication device **1** could be an aforementioned OPC server (i.e., the Server #1), and the second communication device **2** could be an OPC client like SCADA (i.e., the Client #1). Conversely, the first communication device **1** could be an OPC client like SCADA (i.e., the Client #1), and the second communication device **2** could be an OPC server (i.e., the Server #1). Additionally, for instance, the second communication device **2** could be a controller (e.g., PLC) managing actuators.

[0030] As shown in FIG. **2**A, the first communication device **1** comprises a network interface **11**, memory **12**, and a control unit **13**. The network interface **11** is an interface circuit used to communicate with the router unit **4** via LAN **51**. An IP address P**1** is assigned to the network interface **11**.

[0031] The memory **12** is non-transitory tangible storage medium and includes a RAM, a ROM and a flash memory and the like. The RAM is rewritable non-volatile memory. The ROM is un-rewritable volatile memory. The flash memory is rewritable volatile memory. The ROM or the flash memory holds programs executed by the control unit **13**. The flash memory stores key information **12***a* for the first communication device **1**. The key information **12***a* includes a private key SK**1**, public keys PK**1**, PK**3**, and common keys CK**1**, CK**2**. The private key SK**1** may be stored in a TPM (Trusted Platform Module) to prevent reading from outside of the TPM. SK**1** is a private key for the first communication device **1**, while PK**1** is the public key corresponding to SK**1**. The public key PK**3** corresponds to the private key SK**3** of the monitoring unit **3**. The public key PK**1** corresponding to the private key SK**1** is stored in the monitoring unit **3**.

[0032] Moreover, the memory **12** stores a certificate C**1**. The certificate C**1** is an electronic certificate that authenticates the legitimacy of the first communication device **1**. For instance, the certificate C**1** may contain the IP address of the first communication device **1**, public key PK**1** or other data identifying the first communication device **1**

[0033] The control unit **13** is a calculation circuit that performs processing described below by reading programs from the ROM or the flash memory. It uses the RAM as a workspace and utilizes data from the ROM and the flash memory during the processing described below. In the processing, the control unit **13** may receive signals from unillustrated input devices and sensors and control unillustrated display devices and industrial actuators (e.g., robots). Hereinafter, processes conducted by the control unit **13** will be explained as performed by the first communication device **1** for simplicity:

[0034] The second communication device **2** consists of a network interface **21**, memory **22**, and a control unit **23**. The network interface **21** is an interface circuit communicating with the router unit **4** via LAN **52**. An IP address P**2** is assigned to the network interface **21**.

[0035] The memory **22** is non-transitory tangible storage medium and has a RAM, a ROM and a flash memory and the like. The ROM or the flash memory stores programs executed by the control unit **23**. The flash memory stores key information **22***a* of the second communication device **2**. The key information **22***a* includes a private key SK**2**, public keys PK**2**, PK**3**, and common keys CK**1**, CK**2**. SK**2** is a private key for the second communication device **2**, and PK**2** is the public key corresponding to SK**2**. The private key SK**2** may be stored in a TPM (Trusted Platform Module) to prevent reading from outside of the TPM. The public key PK**3** is a public key of the monitoring unit **3**. The public key PK**3** corresponding to the private key SK**3** is stored in the monitoring unit **3**. The public key PK**2** corresponding to the private key SK**2** is stored in the monitoring unit **3**. The memory **22** includes a certificate C**2**. The certificate C**2** is an electronic certificate authenticating the legitimacy of the second communication device **2**. The certificate C**2** may contain the IP address of the second communication device **2** and the public key PK**2**. The certificate C**2** may contain other data identifying the second communication device **2**.

[0036] The control unit **23** is a calculation circuit reading programs from the ROM or the flash memory to execute processing described below. The control unit **23** uses the RAM as a workspace and uses data in the ROM and the flash memory during the processing described below. The control unit **23** may receive signals from unillustrated input devices and sensors and control unillustrated display devices and industrial actuators (e.g., robots). Hereinafter, processes conducted by the control unit **23** will be explained as performed by the second communication device **2** for simplicity.

[0037] The monitoring unit **3** includes memory **35**. The memory **35** is non-transitory tangible storage medium and has a RAM, a ROM and a flash memory and the like. The ROM or the flash memory stores programs executed by a control unit (not illustrated). The flash memory stores key information **35***a*, **35***b* of the monitoring unit **3**.

[0038] The key information **35***a* includes the private key SK**3**, the public keys PK**3**, PK**1**, and the common keys CK**1**, CK**2**. SK**3** is a private key of the monitoring unit **3**, and PK**3** is the corresponding public key. The private key SK**3** may be stored in a TPM (Trusted Platform Module) to prevent reading from outside of the TPM. The key information **35***a* is used for communication between the monitoring unit **3** and the first communication device **1**. The key information **35***a* is used by the monitoring unit **3** so that the monitoring unit **3** acts as a proxy for the second communication device **2** in communicating with the first communication device **1**. The public key PK**1** is a public key of the first communication device **1**. The public key PK**3** corresponding to the private key SK**2** is stored in the first communication device **1**.

[0039] The key information **35***b* includes the private key SK**3**, the public keys PK**3**, PK**2**, and common keys CK**1**, CK**2**. SK**3** is a private key of the monitoring unit **3**, and PK**3** is the corresponding public key. The key information **35***b* is used for communication between the monitoring unit **3** and the second communication device **2**. The key information **35***b* is used by the monitoring unit **3** so that the monitoring unit **3** acts as a proxy for the first communication device **1** in communicating with the second communication device **2**. The public key PK**2** corresponds to the private key SK**2** of the second communication device. The public key PK**3** corresponding to the private key SK**3** is stored in the second communication device **2**.

[0040] As shown above, the common keys CK**1**, CK**2** are stored in the first communication device **1**, the monitoring unit **3**, and the second communication device **2**.

[0041] Additionally, in the memory **35**, certificates C**31** and C**32** are stored. The certificate C**31** is an electronic certificate to be used for the second communication device **2** to validate the monitoring unit **3** as a legitimate communication partner. When the monitoring unit **3** sends the certificate C**31** to the second communication device **2**, the second communication device **2** recognizes the communication with the monitoring unit **3** as the communication with the first communication device **1**. For example, the certificate C**31** may contain the IP address of the first communication device **1**. It may also contain the public key PK**3**. It may also contain other data to be used to for the second communication device **2** to recognize the monitoring unit **3** as a valid communication partner.

[0042] The certificate C**33** is an electronic certificate to be used for the first communication device **1** to validate the monitoring unit **3** as a legitimate communication partner. When the monitoring unit **3** sends the certificate C**32** to the first communication device **1**, the first communication device **1** recognizes the communication with the monitoring unit **3** as the communication with the second communication device **2**. For example, the certificate C**32** may contain the IP address of the second communication device **2**. It may also contain the public key PK**3**. It may also contain other data to be used to for the first communication device **1** to recognize the monitoring unit **3** as a valid communication partner.

[0043] The router unit **4** includes network interfaces **41**, **42** and memory **45**. The network interface **41** is an interface circuit to communicate with the first communication device **1** via the LAN **51**. The Network interface **42** is an interface circuit to communicate with the second communication device **2** via LAN **52**.

[0044] Each network interface of the router unit **4** can be assigned an IP address. IP addresses P**1**, P**2**, P**31**, and P**32** are assigned to the network interfaces **11**, **21**, **41**, and **42**, respectively.

[0045] The memory **45** is a non-transitory tangible storage medium and includes an RAM, an ROM, a flash memory and the like.

[0046] As depicted in FIG. **2**B, a structure of the OPC UA Server/Client and the OPC UA Proxy is as follows. Arrows from Client #1 to the Monitoring system represent request packets, and texts on the arrows denote types of the request packets for OPC UA communication. The request packets sent from Client #1 to the Monitoring system is received by the Monitoring system and the Monitoring system forwards them to the Server #1 after altering their destination.

[0047] [Operation of proxy by the router unit **4**] Hereinafter, the operation of the communication monitoring system with the aforementioned configuration is explained. First, an exemplary scenario is described with reference to FIG. **3**A in which the router unit **4** communicates with the first communication device **1** in place of the second communication device **2** when the first communication device **1** attempts communication with the second communication device **2**.

[0048] Initially, at Step **110**, the communication device **1** creates a request packet destined for communication device **2**. The request packet is a packet requesting a response during communications from the communication device **1** to the communication device **2**. For example, connection requests, acknowledgement requests, disconnection requests, certificate requests, and public key requests are types of request packets. In this request packet, the destination IP address is P**31** and the source IP address is P**1**. The communication device **1** then, at Step **110**, transmits this request packet from the network interface **11** to the LAN **51**.

[0049] At this moment, the router unit **4** receives this packet via the network interface **41**. Upon receiving this packet, at Step **405**, the router unit **4** alters the destination address of this packet. Specifically, since the destination IP address before alteration and the source IP address before alteration are respectively P**31** and P**1**, destination IP address and source IP address is rewritten to P**2** and P**32**, respectively.

[0050] Subsequently, the router unit **4** transmits, at Step **410**, the packet with the altered destination address P**2** and the altered source address P**32** from the network interface **42** to the LAN **52**. The transmitted packet is received by the communication device **2** via the network interface **21**.

[0051] The second communication device **2** that received this packet performs processing according to the content of the transmitted data and creates a response packet. The destination IP address of this response packet is P**32**, and the source IP address of this response packet is P**2**. Then, at Step **310**, the second communication device **2** sends this response packet from the network interface **21** to the LAN **52**.

[0052] At this point, the router unit **4** receives this packet via network interface **42**. Upon receiving this packet, the router unit **4**, at Step **415**, rewrites the packet's destination address. Specifically, since the destination IP address and source IP address before alteration are P**32** and P**2**, respectively; the router unit **4** rewrites the destination IP address and source IP address to P**1** and P**31**, respectively.

[0053] Subsequently, at Step **420**, the router unit **4** sends the packet with the altered destination address P**1** and the altered source addresses P**31** from the network interface **41** to the LAN **51**. The packet sent in this manner is received by the first communication device **1** via the network interface **11**.

[0054] Through this address rewriting by the router unit **4**, the packet reaches the second communication device **2** and the packet is recognized by the second communication device as originated from the Monitoring System. Consequently, the router unit **4** is capable of sending packets on behalf of the second communication device.

[0055] Next, an exemplary scenario is described with reference to FIG. **3**B in which the router unit **4** communicates with the second communication device **2** in place of the first communication device **1** when the second communication device **2** attempts communication with the first communication device **1**. Initially, in Step **210**, the second communication device **2** creates a request packet addressed to the first communication device **1**. The destination IP address of this request packet is P**32**, and the source IP address of this request packet is P**2**. Then, in Step **210**, the second communication device **2** sends this request packet from the network interface **21** to the LAN **52**.

[0056] At this point, the router unit **4** receives this packet via the network interface **42**. Upon receiving this packet, the router unit **4**, in Step **425**, rewrites the packet's destination address. Specifically, since the destination IP address before alteration and the source IP address before alteration are P**32** and P**2**, respectively, the router unit **4** rewrites the destination IP address and the source IP address to P**1** and P**31**, respectively.

[0057] Subsequently, the router unit **4**, in Step **430**, sends the packet with the rewritten destination address P**1** and the rewritten source addresses P**31**, respectively from the network interface **41** to the LAN **51**. The packet sent in this manner is received by the first communication device **1** via the network interface **11**.

[0058] Upon receiving this packet, the first communication device **1** performs processing based on the content of the transmitted data and creates a response packet. The destination IP address of this response packet is P**31**, and the source IP address of this response packet is P**1**. Then, in Step **320**, the first communication device **1** sends this response packet from the network interface **11** to the LAN **51**.

[0059] At this point, the router unit **4** receives this packet via the network interface **41**. Upon receiving this packet, the router unit **4**, in Step **435**, rewrites the packet's destination address. Specifically, since the destination IP address before alteration and the source IP address before alteration are P**31** and P**1**, respectively, the router unit **4** rewrites the destination IP address and the source IP address to P**2** and P**32**, respectively.

[0060] Subsequently, in Step **440**, the router unit **4** sends the packet with the rewritten destination address P**2** and the rewritten source addresses P**32**, respectively from the network interface **42** to the LAN **52**. The packet sent in this manner is received by the second communication device **2** via the network interface **21**.

[0061] Through the address rewriting by the router unit **4**, the packet reaches the first communication device **1** and the packet is recognized by the first communication device **1** as originated from the Monitoring System. Consequently, the router unit **4** can send packets on behalf of the first communication device.

[0062] In FIGS. **3**A and **3**B, when the router unit **4** rewrites destination IP addresses and source IP addresses of the packets, it refers to the conversion table **45***a* stored in the memory **45**. Specifically, it is described in the conversion table **45***a* that the destination IP address P**31** and the source IP address P**1** in a received packet should be rewritten to the destination IP address P**2** and the source IP address P**32**. In addition, it is described in the conversion table **45***a* that the destination IP address P**32** and the source IP address P**2** in a received packet should be rewritten to the destination IP address P**1** and the source IP address P**31**.

[0063] When the router unit **4** rewrites the source IP address in a received packet, it may also alter the 'endpoint description' in the payload of the packet to match the modified source IP address. The 'endpoint description' is an identifier specifying the return destination in OPC UA.

[0064] Next, with reference to FIGS. **4**A and **4**B, generation of the common keys CK**1** and CK**2** is described which uses the address alteration and the forwarding process of the router **4** shown in FIGS. **3**A and **3**B. This generation process occurs at a beginning of a session and the generated common keys CK**1** and CK**2** are retained until the end of the session. During the session, a series of bidirectional communications takes place.

[0065] Before the processes in FIGS. **4**A and **4**B, the first communication device **1** possesses the private key SK**1**, the public key PK**1**, and the certificate C**1** in the memory **12**; the second communication device **2** possesses the private key SK**2**, the public key PK**2**, and the certificate C**2** in the memory **22**: while the monitoring unit **3** possesses the private key SK**3**, the public key PK**3**, and the certificate C**31**, C**32** in the memory **35**.

[0066] While FIGS. **4**A and **4**B depict a scenario in which the second communication device **2** initiates a session, it's also possible for the first communication device **1** to initiate a session. In the latter case, in FIGS. **4**A and **4**B, the roles of the first communication device **1** and the second communication device **2** are interchanged.

[0067] Initially, at Step **710**, the second communication device **2** sends a packet containing the certificate C**2** and the public key PK**2** stored in the memory **22** to the router unit **4** of the monitoring system body **5**. Then, at Step **810**, the monitoring system body **5** receives, verifies, and stores this packet. Specifically, the router unit **4** receives and forwards this packet to the monitoring unit **3**; the monitoring unit **3** uses the certificate C**2** in the packet to verify the legitimacy of the second communication device **2**; and the monitoring unit **3** records the public key PK**2** in the key information **35***b* of the memory **35**.

[0068] Furthermore, at Step **815**, the monitoring system body **5** replaces the certificate C**2** and the public key PK**2** in the payload of this packet with the certificate C**32** and the public key PK**3** in the memory **35**, respectively, and sends the packet to the first communication device **1**. For example, the router unit **4** requests the certificate C**32** and the public key PK**3** from the monitoring unit **3**. and the monitoring unit **3** then responds by sending the certificate C**32** and the public key PK**3** from the memory **35** to the router unit **4**. Then, the router unit **4** performs the aforementioned replacement. While the packet is sent from the second communication device **2** through the router unit **4** to the first communication device **1**, the procedures for assigning, replacing and the like of the destination IP address and the source IP address for this packet are made as described above with reference to FIG. **3**B.

[0069] Subsequently, at Step **610**, the first communication device **1** receives this packet transmitted from the monitoring system body **5**, verifies the legitimacy of the monitoring unit **3** using the certificate C**32** within the packet, and records the public key PK**3** in the key information **12***a* of the memory **12**.

[0070] Subsequently, the first communication device **1**, at Step **615**, generates a random number NONCE**1**, and at Step **620**, encrypts this random number NONCE**1** using the public key PK**3** in the key information **12***a* in the memory **12**. Furthermore, at Step **625**, the first communication device **1** sends a packet containing the certificate C**1** in the memory **12**, public key PK**1** in the memory **12**, and the encrypted random number NONCE**1** to the router unit **4** of the monitoring system body **5**. The monitoring system body **5** receives, verifies, and stores the packet at Step **820**. Specifically, the router unit **4** receives the packet and forwards it to the monitoring unit **3**. Then the monitoring unit **3** uses the certificate C**1** in the packet to verify the legitimacy of the first communication device **1** and stores the public key PK**1** in the key information **35***a* of the memory **35**.

[0071] Furthermore, at Step **825**, the monitoring unit **3** of the monitoring system body **5** decrypts the random number NONCE**1** in the payload of this packet using the private key SK**3** in the memory **35** and saves the decrypted random number NONCE**1** in the memory **35**. Then, at Step **830**, the monitoring unit **3** encrypts the decrypted random number NONCE**1** using the public key PK**2** in the memory **35** and sends the encrypted random number NONCE**1**, the certificate C**31** in the memory **35** and the public key PK**3** in the memory **35** to the router unit **4**.

[0072] Then, at Step **835**, the router unit **4** in the monitoring system body **5** replaces the certificate C**1**, public key PK**1**, and the encrypted random number NONCE**1** in the packet received at Step **820** with the certificate C**31** received from the monitoring unit **3**, the public key PK**3** received from the monitoring unit **3**, and the encrypted random number NONCE**1**, respectively. Subsequently, the router unit **4** sends the packet with the replaced content to the second communication device **2**.

[0073] While the packet is sent from the first communication device **1** through the router unit **4** to the second communication device **2**, the procedures for assigning, replacing and the like of the destination IP address and the source IP address for this packet are made as described above with reference to FIG. **3**B.

[0074] Next, the second communication device **2**, at Step **715**, receives the packet sent from the monitoring system body **5**, verifies the legitimacy of the monitoring unit **3** using the certificate C**31** in the packet, and records the public key PK**3** in the key information **22***a* of the memory **22**. Then, at Step **720**, the second communication device **2** decrypts the random number NONCE in the received packet using the private key SK**2** and stores the decrypted random number NONCE**1** in the memory **22**.

[0075] Following this the second communication device **2** generates at Step **725** in FIG. **4**B a random number NONCE**2** and encrypts at Step **730** this random number NONCE**2** using the public key PK**3** in the key information **22***a*. Further at Step **735**, the second communication device **2** sends a packet containing the certificate C**2** in the memory **22**, the public key PK**2** in the memory **22** and the encrypted random number NONCE**2** to the router unit **4** of the monitoring system body **5**. The monitoring system body **5** receives, verifies, and stores the packet at Step **840**. Specifically, the router unit **4** receives the packet and forwards it to the monitoring unit **3**. Then the monitoring unit **3** uses the certificate C**2** in the packet to verify the legitimacy of the second communication device **2** and stores the public key PK**2** in the key information **35***a* of the memory **35**.

[0076] Furthermore, at Step **845**, the monitoring unit **3** in the monitoring system body **5** decrypts the random number NONCE**2** in the payload of this packet using the private key SK**3** in the memory **35** and saves the decrypted random number NONCE**2** in the memory **35**. Then, at Step **850**, the monitoring unit **3** encrypts the decrypted random number NONCE**2** using the public key PK**1** in the memory **35** and sends the decrypted NONCE**2**, the certificate C**32** in the memory **35** and the public key PK**3** in the memory **35** to the router **4**.

[0077] Then, at Step **855**, the router unit **4** in the monitoring system body **5** replaces the certificate C**2**, the public key PK**2** and the encrypted random number NONCE**2** in the packet received at Step **840** with the certificate C**32** received from the monitoring unit **3**, the public key PK**3** received from the monitoring unit **3**, and the encrypted random number NONCE**2**, respectively. Subsequently, the router unit **4** sends the packet with the replaced content to the first communication device **1**.

[0078] While the packet is sent from the second communication device **2** through the router unit **4** to the first communication device **1**, the procedures for assigning, replacing and the like of the destination IP address and the source IP address for this packet are made as described above with reference to FIG. **3**B.

[0079] Subsequently, at Step **630**, the first communication device **1** receives this packet sent from the monitoring system body **5**, verifies the legitimacy of the monitoring unit **3** using the certificate C**32** in the packet, and records the public key PK**3** in the key information **22***a* of the memory **22**. Following this, at Step **635**, the first communication device **1** decrypts the random number NONCE**2** in the received packet using the private key SK**1** and stores the decrypted random number NONCE**2** in the memory **12**.

[0080] Through this packet exchange, both of the decrypted random number NONCE**1** and random number NONCE**2** are saved in each of the first communication device **1**, the second communication device **2**, and the monitoring system body **5**. Based on the random number NONCE**1** and the random number NONCE**2**, the common keys CK**1** and CK**2** are generated, respectively.

[0081] Specifically, at Step **640** following Step **635**, the first communication device **1** generates the common key CK**1** from the random number NONCE**1** and records the common key CK**1** in the key information **12***a* of the memory **12**. Furthermore, at Step **645**, the first communication device **1** generates the common key CK**2** from the random number NONCE**2** and records the common key CK**2** in the key information **12***a*.

[0082] Additionally, at Step **740** following Step **735**, the second communication device **2** generates the common key CK**1** from the random number NONCE and records the common key CK**1** in the key information **22***a* of the memory **22**. Further at Step **745**, the communication device **2** generates the common key CK**2** from the random number NONCE**2** and records the common key CK**2** in the key information **22***a*.

[0083] Additionally, at Step **860** following Step **855**, the monitoring unit **3** of the monitoring system body **5** generates the common key CK**1** from the random number NONCE**1** and records the common key CK**1** in the key information **35***a* and **35***b* of the memory **35**. Furthermore, at Step **865**, the monitoring unit **3** generates the common key CK**2** from the random number NONCE**2** and records the common key CK**2** in the key information **35***a* and **35***b*.

[0084] The algorithm for generating the common key CK**1** from the random number NONCE**1** is the same for the first communication device **1**, the second communication device **2**, and the monitoring unit **3**. Moreover, the algorithm for generating the common key CK**1** from the random number NONCE**1** ensures that if the value of the random number NONCE**1** varies, the generated value of the common key CK**1** also varies. Therefore, the same value of the random number NONCE**1** results in the generation of the same value of the common key CK**1** using the same algorithm in the first communication device **1**, the second communication device **2**, and the monitoring unit **3**.

[0085] The algorithm for generating the common key CK**2** from the random number NONCE**2** is the same for the first communication device **1**, the second communication device **2**, and the monitoring unit **3**. Also, the algorithm for generating the common key CK**2** from the random number NONCE**2** ensures that if the value of the random number NONCE**2** varies, the generated values of the common key CK**2** also varies. Hence, the same value of the random number NONCE**2** results in the generation of the same value of the common key CK**2** using the same algorithm in the first communication device **1**, the second communication device **2**, and the monitoring unit **3**. Additionally, note that the algorithms for generating the common key CK**1** from the random number NONCE**1** and for generating the common key CK**2** from the random number NONCE**2** may be the same or different. The values of the common keys CK**1** and CK**2** are different since the values of the random number NONCE**1** and the random number NONCE**2** are different.

[0086] After the common keys CK**1** and CK**2** are generated, the common key CK**1** is used for encrypting and decrypting the payload in packets sent from the first communication device **1** to the second communication device **2** through the monitoring system body **5**. The common key CK**2** is used for encrypting and decrypting the payload in packets sent from the second communication device **2** to the first communication device **1** through the monitoring system body **5**.

[Operation of Relay by Monitoring Unit **3**]

[0087] Hereinafter, referring to FIGS. **5** and **6**, a scenario is described where the monitoring unit **3** communicates with the first communication device **1** instead of the second communication device **2** when both the first communication device **1** and the second communication device **2** attempt to exchange data in a session after the common keys CK**1** and CK**2** are generated. A case is described where a packet is sent from the first communication device **1** to the second communication device **2** and, based on the content of the packet, a packet is subsequently sent from the second communication device **2** to the first communication device **1**. However, even if the roles of the first communication device **1** and the second communication device **2** are reversed, equivalent processing is achieved.

[0088] Hereinafter, this scenario is described. Initially, at Step **130**, the first communication device **1** creates transmission data for sending to the second communication device **2** and encrypts the created transmission data. The content of the transmission data may be, for example, instructions for making the second communication device **2** perform a specific action (e.g. controlling an actuator).

[0089] Symmetric key encryption method is used in this encryption. In OPC-UA, as mentioned earlier, a hybrid approach is adopted where an asymmetric key encryption method is employed as described above in establishing session, exchanging common keys and the like, and a symmetric key encryption method using session-specific common keys generated in each session is employed in exchanging data.

[0090] The transmitting device (in Step **130**, the first communication device **1**) encrypts the data (i.e., payload) in the packet for transmission using an encryption method according to a procedure specified by the hybrid approach.

[0091] During the encryption of the data at Step **130**, the data are encrypted using the common key CK**1**.

[0092] The destination of this packet is the second communication device **2**. However, the actual destination IP address of this packet is P**31**, and the source IP address is P**1**.

[0093] Then, the router unit **4** receives this packet via the network interface **41**. Upon receiving this packet, the router unit **4**, at Step **450**, forwards the packet to the monitoring unit **3**. Upon receiving this packet, the monitoring unit **3**, at Step **340**, decrypts the payload of this packet using the common key CK**1**. While the monitoring unit **3** possesses two common keys CK**1**, CK**2**, the monitoring unit **3** uses CK**2** as the common key for decryption at this point based on the information that the source IP address of the packet is P**1**,

[0094] At Step **345**, the monitoring unit **3** records the plaintext transmission data (i.e., content to be communicated) decrypted in the preceding Step **340** in the memory **35**. During this process, if there is an anomaly in the transmitted data, the anomaly may be notified to an operator of the monitoring unit **3**. The notification method may include sending an email or activating an unillustrated notification device. The monitoring unit **3** may determine the presence of anomalies in the transmitted data, for example, by assessing if instructions contained in the transmitted data are predetermined abnormal instructions. The procedures from Step **450** to Step **455** and the transition from Step **450** to Step **340** are performed through parallel processing.

[0095] Furthermore, at Step **455**, the router unit **4** rewrites the packet's destination address. Specifically, since the destination IP address before alteration and the source IP address before alteration are P**31** and P**1**, respectively, the destination IP address and the source IP address are rewritten to P**2** and P**32**, respectively:

[0096] Subsequently, the router unit **4** sends the packet with the rewritten destination address P**2** and source addresses P**32** from the network interface **42** to LAN**52**. This packet, thus transmitted, is received by the second communication device **2** via the network interface **21**.

[0097] Upon receiving this packet, the second communication device **2**, at Step **220**, decrypts the payload of this packet using the common key CK**1**. Consequently, the second communication device **2** obtains the plaintext transmission data.

[0098] Subsequently, at Step **230**, the second communication device **2** performs processing based on the content of this transmission data. For example, if the transmission data contains control instructions, the second communication device **2** controls an actuator according to the instructions.

[0099] In this way, packets sent from the first communication device **1** to the second communication device **2** allow for content monitoring.

[0100] Subsequently, after Step **230**, the second communication device **2**, at Step **240** in FIG. **6**, generates response data. For example, if the transmission data includes control instructions and the second communication device **2** controlled an actuator based on the instructions at Step **230**, the communication device **2** makes the response data include result of the control of the actuator. Subsequently, at Step **250**, the second communication device **2** encrypts the response data created at Step **240** using the common key CK**2**. The common key CK**2** used at this time is created in updating a session mentioned above, and is shared between the first communication device **1**, the second communication device **2**, and the monitoring unit **3**.

[0101] Next, at Step **260**, the second communication device **2** creates a packet having the data encrypted at the preceding Step **250** as a payload and having the source address as P**2** and the destination address as P**32**, and sends this packet from the network interface **21** to the LAN**52**.

[0102] The target of this packet is the first communication device **1**. However, the actual destination IP address is P**1**, and the source IP address remains as described above.

[0103] Subsequently, the router unit **4** receives this packet via the network interface **42**. Upon receiving the packet, the router unit **4** rewrites at Step **475** the packet's destination address according to the conversion table **45***a*. Specifically, since the destination IP address before alteration is P**1**, the destination IP address is rewritten to P**31** as shown in FIG. **2**A.

[0104] Subsequently, the router unit **4** sends the packet with the rewritten destination address P**1** and the source address P**31** from the network interface **41** to the LAN**51**. The packet transmitted in this manner is received by the first communication device **1** via the network interface **11**.

[0105] Upon receiving this packet, the first communication device **1**, at Step **150**, decrypts the payload of this packet using the common key CK**2**. Consequently, the first communication device **1** obtains the plaintext response data.

[0106] This packet is sent from the router unit **4** to the monitoring unit **3**. Thus, at Step **470**, the packet is forwarded by the router unit **4** to the monitoring unit **3**.

[0107] Upon receiving this packet, the monitoring unit **3**, at Step **360**, decrypts the payload of this packet using the common key CK**2**. Although the monitoring unit **3** possesses two common keys CK**1** and CK**2**, the monitoring unit **3** uses at this point CK**2** as the common key for decryption based on the information that the packet's source IP address is P**2**. This decryption yields the plaintext response data.

[0108] Subsequently, at Step **365**, the monitoring unit **3** records the decrypted plaintext response data (i.e., content to be communicated) in the memory **35**. At this time, if there is a predetermined anomaly in the content of the response data, the monitoring unit **3** may alert the operator about the anomaly as is done at Step **345**. The procedures from Step **470** to Step **475** and from Step **450** to Step **360** are performed in parallel.

[0109] The common key CK**2** is a cryptographic key shared among the first communication device **1**, the second communication device **2**, and the monitoring unit **3**. The common key CK**2** used at this time is generated in updating a session and shared among the first communication device **1**, the second communication device **2**, and the monitoring unit **3**.

[0110] In this embodiment, as shown in the processes in FIG. **3**A, when the monitoring unit **3** receives a request packet addressed from the first communication device **1** to the second communication device **2**, the monitoring unit **3** sends a response packet to the first communication device**1** that is the source of this request packet. In addition, as shown in the processes in FIG. **3**B, when the monitoring unit **3** receives a request packet addressed from the second communication device **2** to the first communication device **1**, the monitoring unit **3** sends a response packet to the second communication device**2** that is the source of this request packet. In short, on receiving a request packet which needs a response, the monitoring unit **3** responds to the first communication device **1** as a proxy for the second communication device **2** in the processes in FIG. **3**A and responds to the second communication device **1** as a proxy for the first communication device **1** in the processes in FIG. **3**B

[0111] Furthermore, in the processes depicted in FIG. **5**, the monitoring unit **3** selects payloads of packets that need to reach the second communication device **2** among packets that are sent from the first communication device **1** for the second communication device **2** and forwards the selected payloads directly without decryption to the second communication device **2**. In addition, in the processes depicted in FIG. **6**, the monitoring unit **3** selects payloads of packets that need to reach the first communication device **1** among packets that are sent from the second communication device **2** for the first communication device **1** and forwards the selected payloads directly without decryption to the first communication device **1**.

[0112] Thus, for packets for setting up communications or acknowledging communications, the monitoring unit **3** handles them between the monitoring unit **3** and each of the communication devices **1** and **2** as shown in FIGS. **3**A and **3**B, while serves as a relay point for data communication packets as depicted in FIGS. **5** and **6**.

[0113] As explained, the first communication device **1** and the second communication device **2** do not communicate directly with each other but communicate via the router unit **4**. While the first communication device **1** transmits packets targeted for the second communication device **2**, these packets are sent to the monitoring unit **3** by the router unit **4**. To enable decryption of encrypted data from the first communication device **1** at the monitoring unit **3**, encryption with a key shared between the first communication device **1** and the monitoring unit **3** is performed by the first communication device **1**. Wile, alteration of destination addresses is done at the router unit **4** (Steps **450**, **455**), the packet received by the monitoring unit **3** is decrypted using the key shared between the first communication device **1** and the monitoring unit **3** and then recorded (Step **345**).

[0114] For example, if the second communication device **2** serves as the aforementioned controller, considering that the controller is designed to obey even dangerous instructions, monitoring the content of communications in the control network for potentially dangerous instructions is required. If a malicious intruder gains access to the legitimate first communication device **1** capable of sending instructions to the controller and makes it transmit malicious instructions, it poses a risk of accidents occurring. To monitor if such communication is happening, interpretation of the content of the payloads in the packets is necessary. However, when the payloads are encrypted, even if packets are intercepted midway, the content of the payloads becomes incomprehensible. The aforementioned monitoring unit **3** and the router unit **4** address this issue.

[0115] Moreover, the information monitored by the monitoring unit **3** is desired to be stored securely even if attackers intrude into the control network, evading attacks. In this embodiment, the aforementioned monitoring unit **3** and router unit **4** enable monitoring and recording of the encrypted content of the communication without revealing the presence of the monitoring unit **3**.

[0116] Additionally, since communication is bidirectional, encryption and decryption are performed in the reverse direction. The shared key CK**1** used for encryption by the first communication device **1** is shared among the first communication device **1**, the second communication device **2**, and the monitoring unit **3**. Therefore, even if communication packets from the first communication device **1** directly reach the second communication device **2**, they can be decrypted.

[0117] As such, encrypted packets sent from the first communication device **1** for the second communication device **2** can be decrypted at the second communication device and monitored, just because the encrypted packets pass the monitoring unit **3** and router unit **4**. When conducting encrypted communication among three or more communication devices, not only between the first communication device **1** and the second communication device **2**, all communication is routed through the router unit **4**, and the common keys CK**1** and CK**2** used for encryption/decryption among all communication devices and the monitoring unit **3** are shared.

[0118] In this embodiment, the router unit **4** serves as an acquisition unit by executing Steps **450** and **455**, serves as a forwarding unit by executing Steps **460** and **465**, and serves as a request packet transfer unit by executing Steps **405** and **410**. Additionally, the monitoring unit **3** serves as a decryption unit by executing Step **340** and serves as a recording unit by executing Step **345**. Furthermore, the common key CK**1** corresponds to the first encryption key and the common key CK**1** corresponds to the first decryption key. In addition, the common key CK**2** corresponds to the second encryption key, and the common key CK**2** corresponds to the second decryption key:

Other Embodiments

[0119] The present invention is not limited to the above-described embodiments and can be appropriately modified. Additionally, in the embodiments described above, the elements constituting the embodiments are not necessarily essential unless explicitly stated as essential or considered essential in principle. Moreover, specific numbers, values, quantities, ranges, etc., mentioned regarding the components of the embodiments are not limited to those specific numbers unless explicitly stated as essential or inherently limited to a specific number. Particularly, when multiple values are exemplified for a certain quantity, it's possible to adopt values between those multiples unless specified otherwise or inherently impossible. Furthermore, the following variations and other modifications within an equivalent range to the embodiments described above are also allowed. These variations can be applied or not applied independently to the above embodiments. That is, any combination of these variations that does not explicitly contradict each other can be applied to the embodiments above.

(Variation 1)

[0120] In OPC UA proxy, a static "FromTo" table (static table) is maintained in the proxy to facilitate routing. This static table has the advantage of minimal processing overhead due to the unique determination of the "FromTo." The router unit **4** in the aforementioned embodiment corresponds to the OPC UA Proxy, and the conversion table **45***a* corresponds to the static table. Hence, specifying the routing information for packets between the first communication device **1**, the second communication device **2**, and the router unit **4** is achieved through the conversion table **45***a*. However, due to its static nature, manual configuration of the "FromTo" is necessary, leading to increased configuration effort as the number of OPC UA proxies through which it passes increases. Additionally, disadvantage may occur in which manual configuration tends to increase human errors, such as configuration mistakes and the like.

[0121] As depicted in FIG. **7**, routing information may be specified using URLs as follows. In order to specify from the OPC UA Client, the OPC UA Proxy's IP address+port number is designated as the resource section and the OPC UA Server's IP address+port number is designated as the identifier. For example, if connecting from the OPC UA Client #1 (e.g., the first communication device **1**) to the OPC UA Server #1 (e.g., the second communication device **2**) via the OPC UA Proxy (e.g., the router unit **4**), the OPC UA Client #1 specifies "opc.tcp://OPC UA Proxy's IP address/OPC UA Server #1's IP address."

[0122] Subsequently, in the communication initiated by this URL designation between the OPC UA Client #1 and the OPC UA Server #1, the information of this URL is sent from the OPC UA Client #1 to the OPC UA Proxy (the Monitoring System in FIG. **7**). The OPC UA Proxy then, based on the description within this URL, forwards the packet sent from the OPC UA Client #1 to the OPC UA Server #1 and forwards a response packet to the OPC UA Client #1, wherein the response packet is sent from the OPC UA Server #1 to the OPC UA Proxy as a response to the aforementioned packet.

[0123] Here, a URL, abbreviated from Uniform Resource Locator, refers to the subset of URIs that, in addition to identifying a resource, provide a means of locating the resource by describing its primary access mechanism (e.g., its network "location"). A URI, abbreviated from Uniform Resource Identifier, is a compact sequence of characters that identifies an abstract or physical resource.

[0124] Generally, a URL follows the syntax of "protocol"+"resource (remote host)"+"identifier." The protocol specifies a convention name like HTTP or MQTT. The resource points to the remote host, specifying domain names or IP addresses. If necessary, a port number can be specified separated by a colon (:). The identifier typically designates a unique identifier for the location within a target of connection. For TCP communication in OPC UA, the protocol would be specified as "opc.tcp". The resource refers to a domain name or an IP address, and if needed, a port number can be specified separated by a colon (:).

[0125] In other words, the routing method for the destination may be, instead of using a static "From To", a routing method that enables communication between the first communication device **1** and the second communication device **2** in the manner that the "resource (remote host)" of the second communication device **2** is specified as the URL's identifier part. The resource refers to domain names or IP addresses, and if needed, a port number can be specified separated by a colon (:).

(Variation 2)

[0126] In the aforementioned embodiment, the request and response packets constitute the outgoing and incoming packets, respectively, in a single round-trip communication. However, the request and response packets may be an outgoing packet and an incoming packet within a series of multiple round-trip communications forming a session, wherein the incoming packet is one of the incoming packets in the session that comes later than the first incoming packet after the outgoing packet. This is because, in the latter case, the incoming packet constituting the request and response packets is generated due to the transmission of the request packet.

(Variation 3)

[0127] The embodiment above describes a one-to-one communication between the first communication device **1** and the second communication device **2**. However, besides this form of communication, the communication monitoring system is applicable to embodiments where two or more communication devices communicate one-to-one with an equal number of other communication devices. In such a case, two or more communication devices have fixed communication partners.

(Variation 4)

[0128] In the above-described embodiment, the monitoring unit **3** possesses key information **35***a* for communicating with the first communication device **1** and key information **35***b* for communicating with the second communication device **2**. However, it is also possible for the monitoring unit **3** to have a single set of key information for communicating with both the first communication device **1** and the second communication device **2**.

(Variation 5)

[0129] In the above embodiment, the monitoring unit **3**, at Steps **345** and **365**, may transmit data to be recorded in the memory **35** to a recording device in a network different from the control network. The recording unit stores this data transmitted in such a manner on a storage medium. This approach protects the recorded monitoring data from cyber attacks by placing the recording device in a separate network, thereby securely transmitting the monitoring data to the recording unit, securing the forensically valid data.

(Variation 6)

[0130] In the described embodiment, the control units **13** of the first communication device **1**, the control unit **23** of the second communication device **2** and the monitoring unit **3** perform encryption and decryption of data. However, each of the control units **13**, **23**, and monitoring unit **3** in the first communication device **1**, the second communication device **2**, and the monitoring unit **3**, respectively, may utilize separate devices (e.g., TPM security modules) to handle the encryption and decryption processes.

(Variation 7)

[0131] In the above embodiment, two common keys CK**1** and CK**2**, are exemplified as the keys shared among the first communication device **1**, the second communication device **2**, and the monitoring unit **3**. However, a single common key shared among the first communication device **1**, the second communication device **2**, and the monitoring unit **3** would also be acceptable. For example, if the shared common key among the first communication device **1**, the second communication device **2**, and the monitoring unit **3** is solely CK**1**, the data could be encrypted with the common key CK**1** at Step **250** in FIG. **6** and decrypted with the common key CK**1** at Step **360**. In such a scenario, the generation, transmission, and creation of the common key CK**2** based on the random number NONCE**2** in FIG. **4**B would be unnecessary.

(Variation 8)

[0132] In the described embodiment, the first encryption key and the first decryption key are both the same common key CK**1**. However, the first encryption key and the first decryption key could be different. For example, the first encryption key could be a certain public key, while the first decryption key could be a private key corresponding to the public key. In this case, a key pair consisting of the encryption key and the public key may be generated from the common random number NONCE**1** by the first communication device **1**, the second communication device **2**, and the monitoring unit **3**. The same concept applies to the second encryption key and the second decryption key. For example, the second encryption key could be a certain public key, while the second decryption key could be a private key corresponding to the public key.

INDUSTRIAL APPLICABILITY

[0133] OPC UA represents a novel communication technology in the industrial sector. In 2015, the German government introduced OPC UA as the next-generation communication technology to realize Industry 4.0 at the Hanover Fair. As a result, it has been recognized as the standard for communication worldwide, indicating a high likelihood of OPC UA becoming the standard specification in the industrial sector. Consequently, monitoring encrypted communication becomes crucial in the event of PCs or embedded devices being compromised by cyber attacks. The present invention facilitates the monitoring of data flowing on encrypted networks, the directionality of data, or API parameter monitoring by deploying it at the boundaries of zone-separated networks.

[0134] **1** . . . first communication device, **2** . . . second communication device, **3** . . . monitoring unit, **4** . . . router unit, **5** . . . monitoring system main body, **11**, **21**, **41**, **42** . . . network interfaces, **12***a*, **22***a*, **35***a*, **35***b* . . . key information, **51**, **52** . . . LAN, C1, C2, C31, C32 . . . certificates

1. A monitoring system for monitoring communication between a first communication device and a second communication device in a control network, comprising:

a router unit capable of communication with the first communication device and the second communication device, and

a monitoring unit recording information regarding content of communication between the first communication device and the second communication device,

wherein:

the router unit includes an acquisition unit obtaining a packet encrypted with a first encryption key by the first communication device and sent from the first communication device,

the monitoring unit includes a decryption unit decrypting the packet obtained by the acquisition unit with a first decryption key corresponding to the first encryption key and a recording unit recording information based on the decrypted packet,

the router unit includes a transfer unit transmitting the encrypted packet to the second communication device,

the router unit and the monitoring unit function as OPC UA application integrated within encrypted communications, are equipped with OPC UA server/client functionalities, capable of OPC UA encryption/decryption, and make an inquiry to an OPC UA server that is the second communication device as a proxy for an OPC UA client that is the first communication device.

2. The monitoring system according to claim **1**, wherein

the first communication device, the second communication device, and the monitoring unit are all capable of communication through the router unit, wherein the acquisition unit within the router unit alters a destination address of the packet and sends them from the transfer unit,

the packet originating from the first communication device has a source address being an address of the first communication device and the destination address being an address of the router unit and reaches the router unit,

at the initiation of communication, the acquisition unit acquires a common key shared between the OPC UA client and the OPC UA server.

3. The monitoring system according to claim **2**, wherein

the router unit and the monitoring unit are capable of communication with each other,

the router unit includes a request packet transfer unit rewriting, at the initiation of communication, a destination address of a specific request packet sent from the first communication device from an address of the router unit to an address of the second communication device and sending the rewritten packet to the second communication device,

the second communication device includes a response unit sending to the router unit a response packet in response to the request packet sent by the request packet transfer unit, by setting a destination address to an address of the router unit and by setting a source address to the address of the second communication device, and

the router unit changes the source address of the response packet sent by the response unit from the address of the second communication device to an address of the router unit and sends the response packet to the first communication device.

4. The monitoring system according to claim **3**, wherein the request packet from the first communication device includes an electronic certificate of the first communication device, and the corresponding response packet contains an electronic certificate of the monitoring unit.

5. The monitoring system according to claim **4**, wherein the request packet from the first communication device includes a public key corresponding to a private key owned by the first communication device, and the response packet includes a public key corresponding to a private key owned by the monitoring unit.

6. The monitoring system according to claim **5**, wherein a request packet from the second communication device includes a public key corresponding to a private key owned by the second communication device, and a corresponding response packet includes a public key corresponding to a private key owned by the monitoring unit.

7. The monitoring system according to claim **6**, wherein the first communication device and the monitoring unit share a common key, and the second communication device and the monitoring unit also share a common key.

8. The monitoring system according to claim **1**, wherein packet routing information between the first communication device, the second communication device, and the router unit is specified using a URL.

9. The monitoring system according to claim **1**, wherein the first encryption key and the first decryption key are obtained by the first communication device, the second communication device, and the monitoring unit based on information shared among the first communication device, the second communication device, and the monitoring unit through communication using asymmetric key encryption.

10. The monitoring system according to claim **1**, wherein

the router unit obtains a packet encrypted with a second encryption key at the second communication device and sent from the second communication device,

the monitoring unit decrypts, using a second decryption key corresponding to the second encryption key, the packet obtained from the second communication device and encrypted with the second encryption key at the second communication device and records information based on the decrypted packet, and

the router unit sends the packet encrypted with the second encryption key by the second communication unit to the first communication device.

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