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(12) **United States Patent**
Suffling

(10) **Patent No.: US 9,473,474 B2**
(45) **Date of Patent: Oct. 18, 2016**

(54) COMMUNICATING AN IDENTITY OF A GROUP SHARED SECRET TO A SERVER

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(72) Inventor: **David Robert Suffling**, Kitchener (CA)

(73) Assignee: **BlackBerry Limited**, Waterloo (CA)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 275 days.

(21) Appl. No.: **14/332,617**

(22) Filed: **Jul. 16, 2014**

(65) **Prior Publication Data**

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Related U.S. Application Data

(62) Division of application No. 13/709,417, filed on Dec. 10, 2012, now Pat. No. 8,832,444.

(60) Provisional application No. 61/605,121, filed on Feb. 29, 2012.

(51) **Int. Cl.**

H04L 29/06	(2006.01)
H04L 9/32	(2006.01)
H04L 9/08	(2006.01)

(52) **U.S. Cl.**

CPC ***H04L 63/061*** (2013.01); ***H04L 9/085*** (2013.01); ***H04L 9/3218*** (2013.01); ***H04L 9/3226*** (2013.01); ***H04L 9/3236*** (2013.01); *H04L 63/1458* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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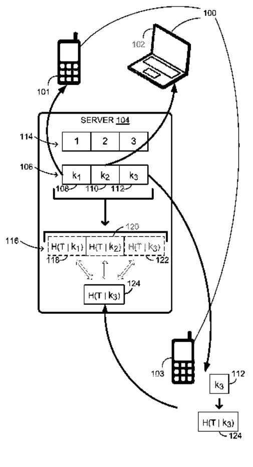
Primary Examiner — Jeffery Williams

(74) *Attorney, Agent, or Firm* — Integral IP; Miriam Paton; Amy Scouten

(57) **ABSTRACT**

An identity is communicated by a client device to a server without requiring the identity to be disclosed to eavesdroppers and without requiring the use of symmetric or asymmetric cryptography. In one example, the identity is an identity of the client device, where the identity has been assigned to the client device by the server through the provisioning of a unique subset of client-identifying keys. In another example, the identity is an identity of a group shared secret that has been provisioned by the server to the client device.

16 Claims, 20 Drawing Sheets



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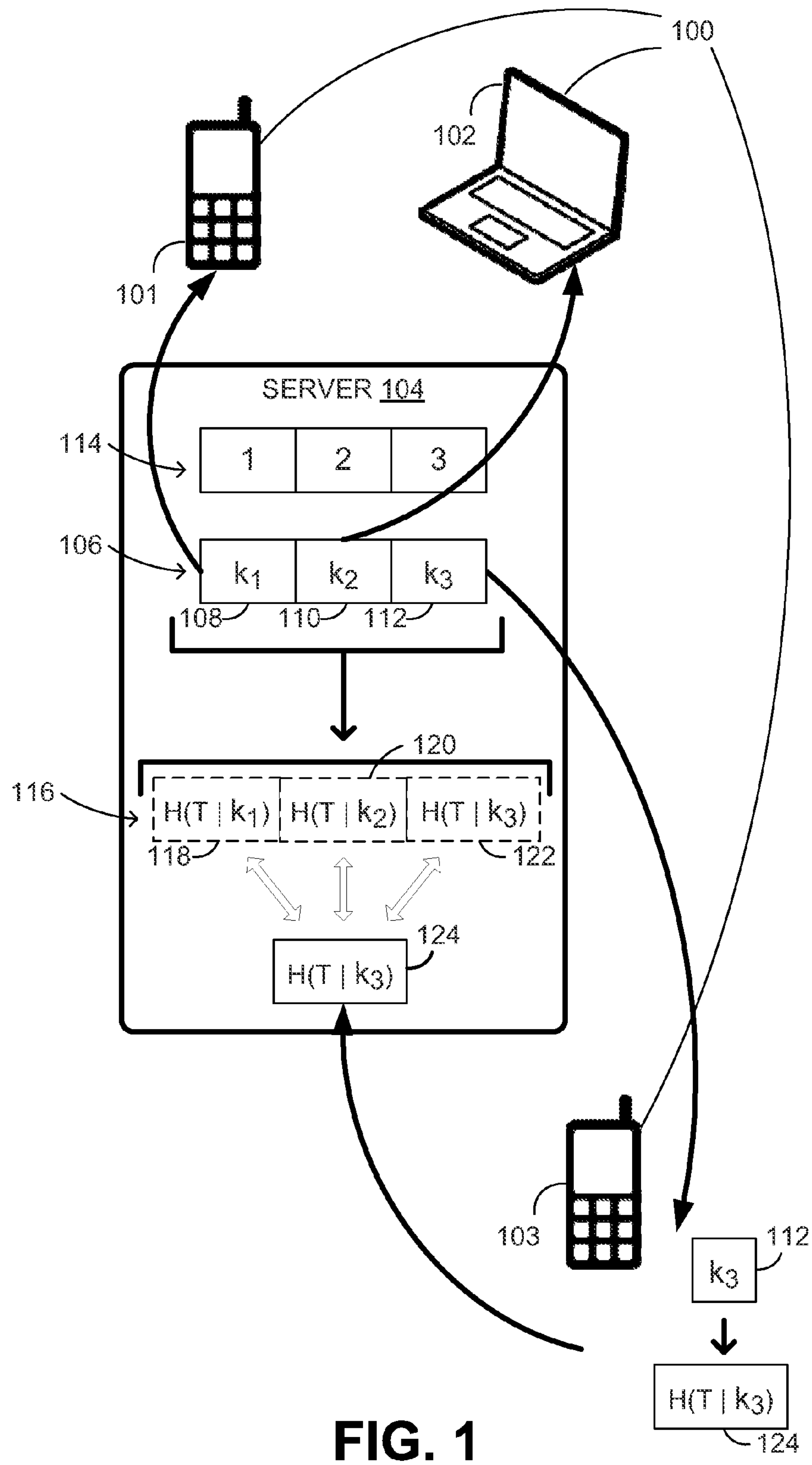

100
102
101
SERVER 104
114
1
2
3
106
k_1
k_2
k_3
108
110
112
120
116
$H(T | k_1)$
$H(T | k_2)$
$H(T | k_3)$
118
122
124
$H(T | k_3)$
103
112
k_3
$H(T | k_3)$
124

FIG. 1

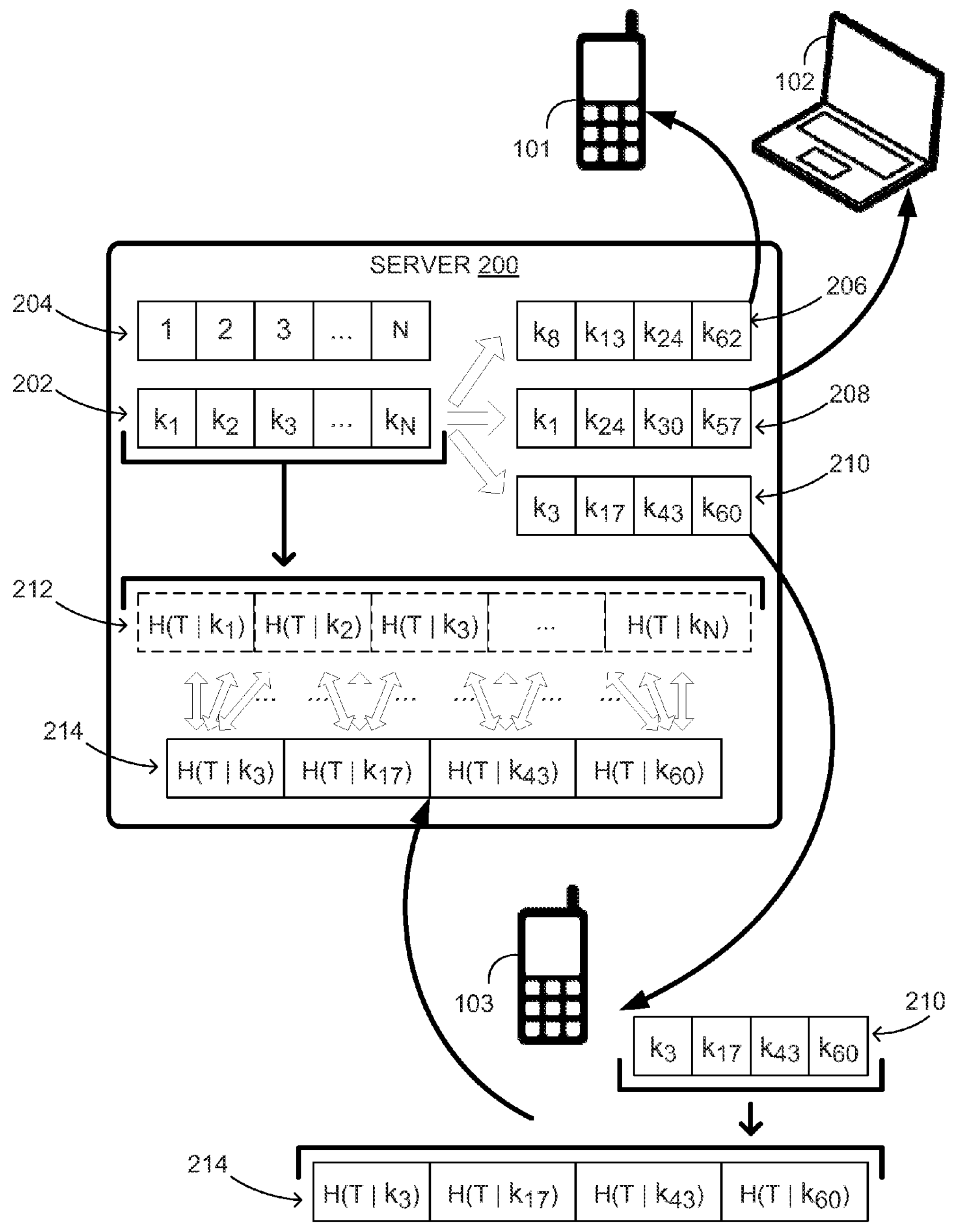

101
102
SERVER 200
204
1
2
3
...
N
202
k_1
k_2
k_3
...
k_N
206
k_8
k_{13}
k_{24}
k_{62}
208
k_1
k_{24}
k_{30}
k_{57}
210
k_3
k_{17}
k_{43}
k_{60}
212
H(T | k_1)
H(T | k_2)
H(T | k_3)
...
H(T | k_N)
214
H(T | k_3)
H(T | k_{17})
H(T | k_{43})
H(T | k_{60})
103
210
k_3
k_{17}
k_{43}
k_{60}
214
H(T | k_3)
H(T | k_{17})
H(T | k_{43})
H(T | k_{60})

FIG. 2

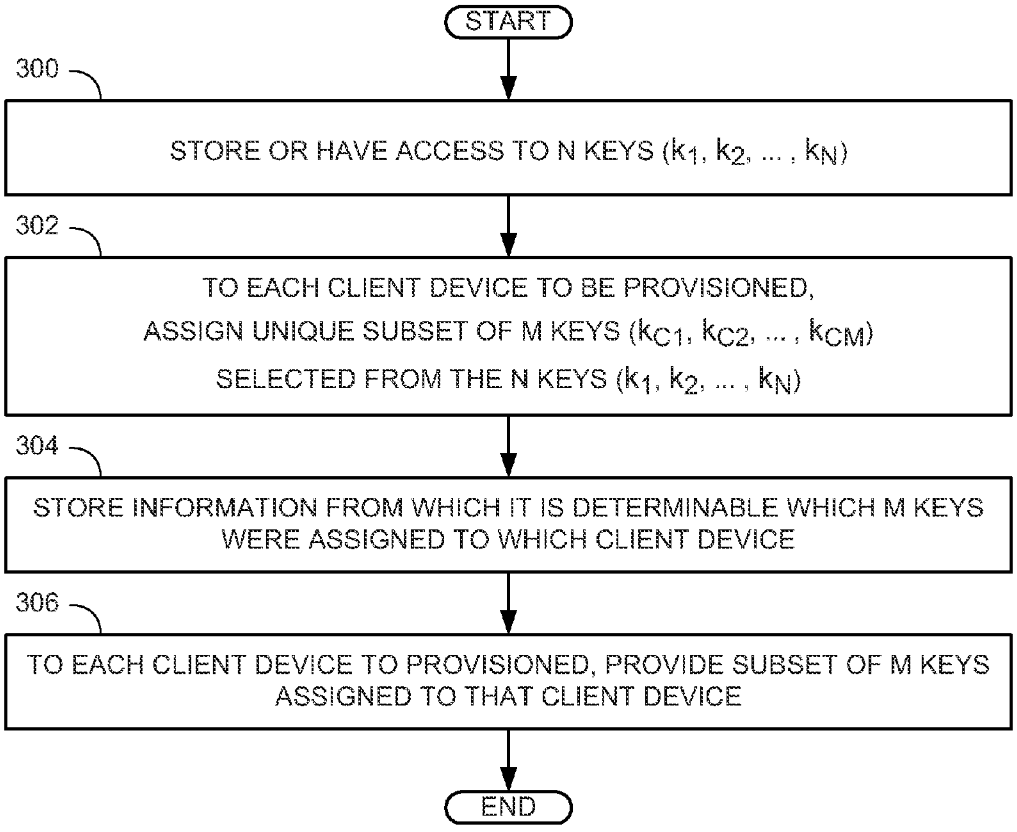

START
300
STORE OR HAVE ACCESS TO N KEYS (k_1, k_2, ... , k_N)
302
TO EACH CLIENT DEVICE TO BE PROVISIONED, ASSIGN UNIQUE SUBSET OF M KEYS (k_{C1}, k_{C2}, ... , k_{CM}) SELECTED FROM THE N KEYS (k_1, k_2, ... , k_N)
304
STORE INFORMATION FROM WHICH IT IS DETERMINABLE WHICH M KEYS WERE ASSIGNED TO WHICH CLIENT DEVICE
306
TO EACH CLIENT DEVICE TO PROVISIONED, PROVIDE SUBSET OF M KEYS ASSIGNED TO THAT CLIENT DEVICE
END

FIG. 3

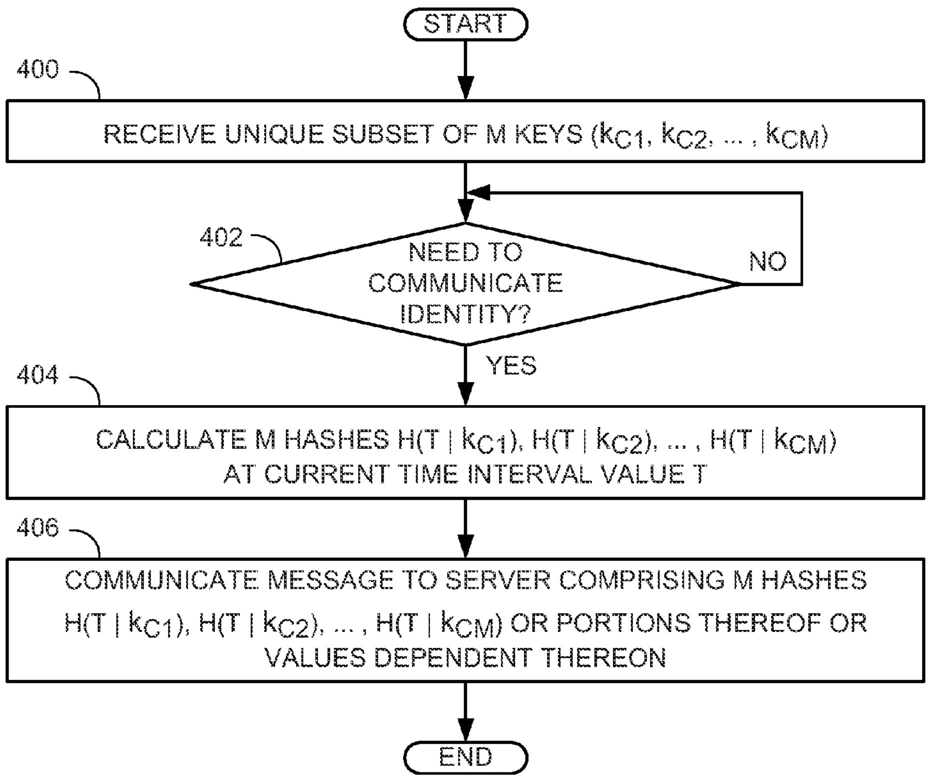

START
400
RECEIVE UNIQUE SUBSET OF M KEYS (k_{C1}, k_{C2}, ... , k_{CM})
402
NEED TO COMMUNICATE IDENTITY?
NO
YES
404
CALCULATE M HASHES H(T | k_{C1}), H(T | k_{C2}), ... , H(T | k_{CM}) AT CURRENT TIME INTERVAL VALUE T
406
COMMUNICATE MESSAGE TO SERVER COMPRISING M HASHES H(T | k_{C1}), H(T | k_{C2}), ... , H(T | k_{CM}) OR PORTIONS THEREOF OR VALUES DEPENDENT THEREON
END

FIG. 4

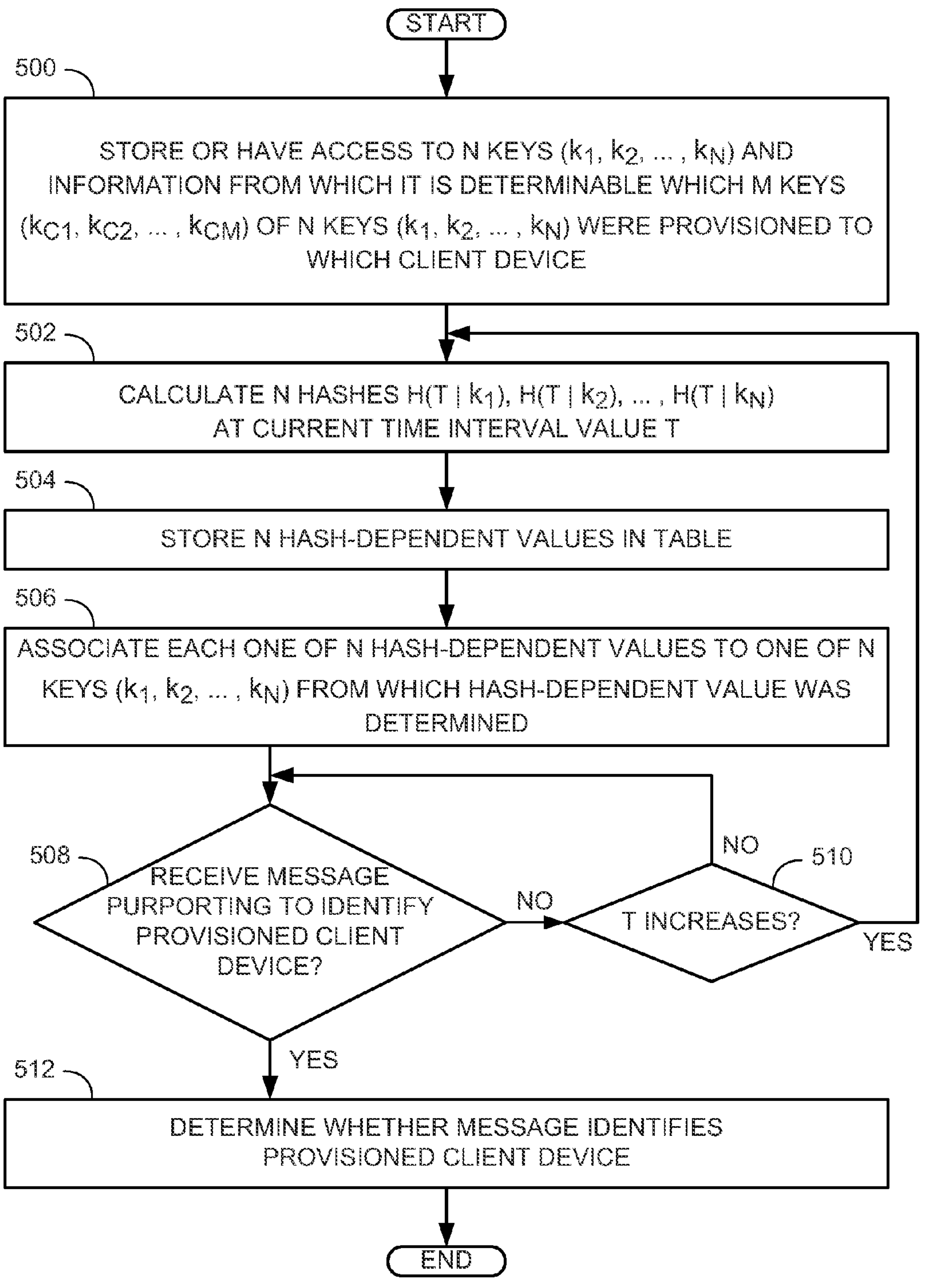

START
500
STORE OR HAVE ACCESS TO N KEYS (k_1, k_2, ... , k_N) AND INFORMATION FROM WHICH IT IS DETERMINABLE WHICH M KEYS (k_{C1}, k_{C2}, ... , k_{CM}) OF N KEYS (k_1, k_2, ... , k_N) WERE PROVISIONED TO WHICH CLIENT DEVICE
502
CALCULATE N HASHES $H(T \mid k_1)$, $H(T \mid k_2)$, ... , $H(T \mid k_N)$ AT CURRENT TIME INTERVAL VALUE T
504
STORE N HASH-DEPENDENT VALUES IN TABLE
506
ASSOCIATE EACH ONE OF N HASH-DEPENDENT VALUES TO ONE OF N KEYS (k_1, k_2, ... , k_N) FROM WHICH HASH-DEPENDENT VALUE WAS DETERMINED
508
RECEIVE MESSAGE PURPORTING TO IDENTIFY PROVISIONED CLIENT DEVICE?
NO
510
T INCREASES?
NO
YES
YES
512
DETERMINE WHETHER MESSAGE IDENTIFIES PROVISIONED CLIENT DEVICE
END

FIG. 5-1

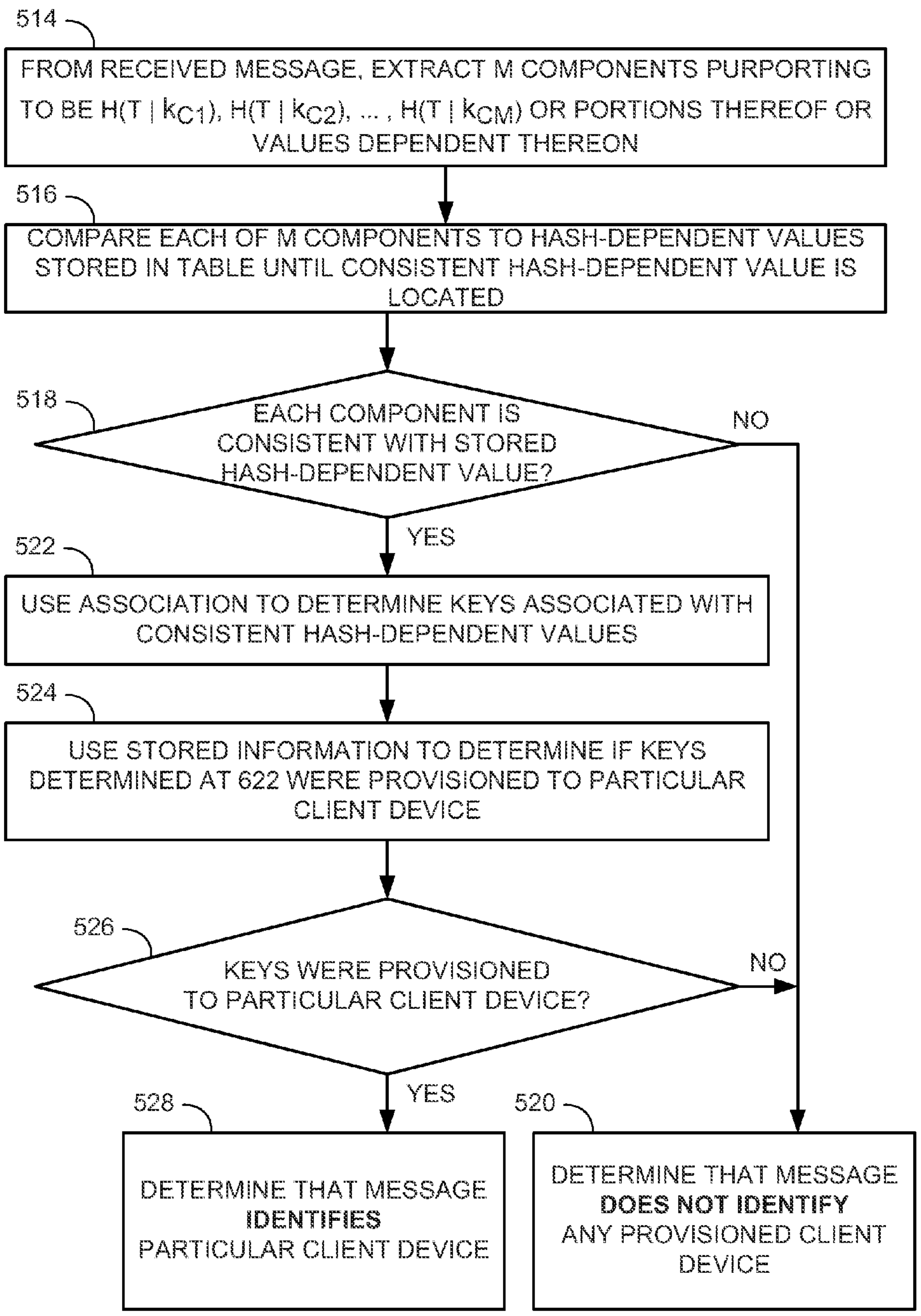
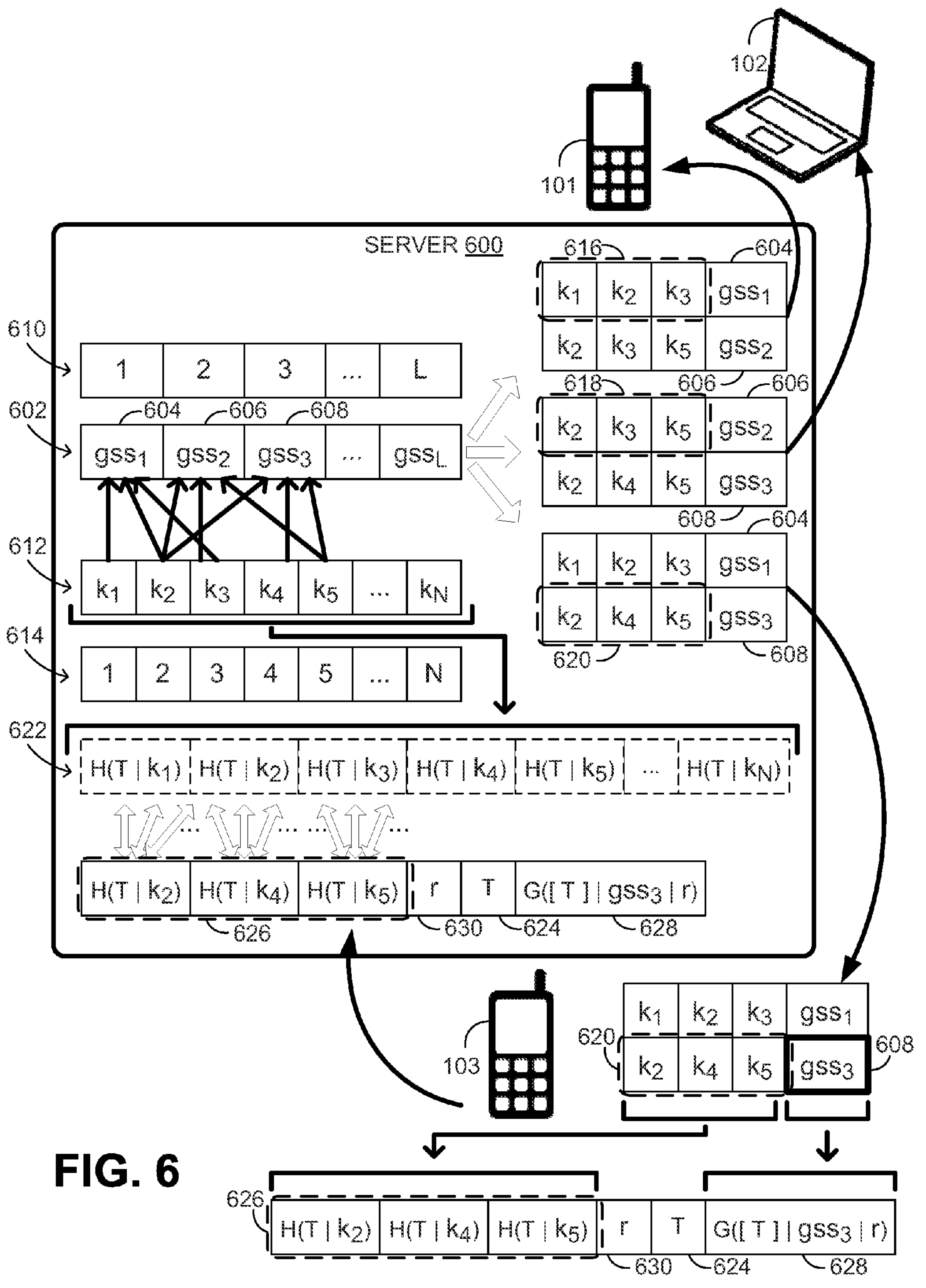

514
FROM RECEIVED MESSAGE, EXTRACT M COMPONENTS PURPORTING TO BE $H(T \mid k_{C1})$, $H(T \mid k_{C2})$, ... , $H(T \mid k_{CM})$ OR PORTIONS THEREOF OR VALUES DEPENDENT THEREON
516
COMPARE EACH OF M COMPONENTS TO HASH-DEPENDENT VALUES STORED IN TABLE UNTIL CONSISTENT HASH-DEPENDENT VALUE IS LOCATED
518
EACH COMPONENT IS CONSISTENT WITH STORED HASH-DEPENDENT VALUE?
NO
YES
522
USE ASSOCIATION TO DETERMINE KEYS ASSOCIATED WITH CONSISTENT HASH-DEPENDENT VALUES
524
USE STORED INFORMATION TO DETERMINE IF KEYS DETERMINED AT 622 WERE PROVISIONED TO PARTICULAR CLIENT DEVICE
526
KEYS WERE PROVISIONED TO PARTICULAR CLIENT DEVICE?
NO
YES
528
DETERMINE THAT MESSAGE **IDENTIFIES** PARTICULAR CLIENT DEVICE
520
DETERMINE THAT MESSAGE **DOES NOT IDENTIFY** ANY PROVISIONED CLIENT DEVICE

FIG. 5-2



102
101
SERVER 600
616
604
610
602
606
608
612
614
618
620
622
626
630
624
628
103
1 2 3 ... L
gss1 gss2 gss3 ... gssL
k1 k2 k3 k4 k5 ... kN
1 2 3 4 5 ... N
H(T | k1) H(T | k2) H(T | k3) H(T | k4) H(T | k5) ... H(T | kN)
H(T | k2) H(T | k4) H(T | k5) r T G([T] | gss3 | r)
k1 k2 k3 gss1
k2 k3 k5 gss2
k2 k4 k5 gss3

FIG. 6

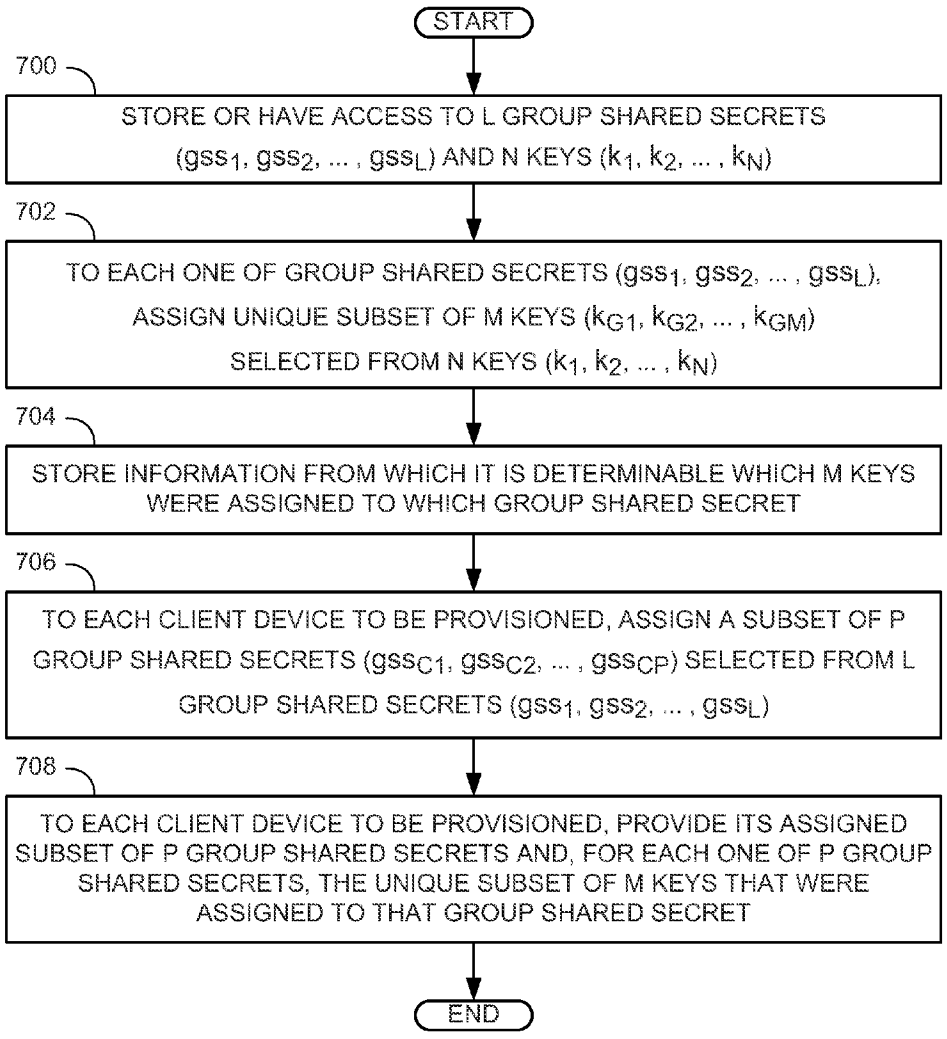

START
700
STORE OR HAVE ACCESS TO L GROUP SHARED SECRETS (gss_1, gss_2, ... , gss_L) AND N KEYS (k_1, k_2, ... , k_N)
702
TO EACH ONE OF GROUP SHARED SECRETS (gss_1, gss_2, ... , gss_L), ASSIGN UNIQUE SUBSET OF M KEYS (k_{G1}, k_{G2}, ... , k_{GM}) SELECTED FROM N KEYS (k_1, k_2, ... , k_N)
704
STORE INFORMATION FROM WHICH IT IS DETERMINABLE WHICH M KEYS WERE ASSIGNED TO WHICH GROUP SHARED SECRET
706
TO EACH CLIENT DEVICE TO BE PROVISIONED, ASSIGN A SUBSET OF P GROUP SHARED SECRETS (gss_{C1}, gss_{C2}, ... , gss_{CP}) SELECTED FROM L GROUP SHARED SECRETS (gss_1, gss_2, ... , gss_L)
708
TO EACH CLIENT DEVICE TO BE PROVISIONED, PROVIDE ITS ASSIGNED SUBSET OF P GROUP SHARED SECRETS AND, FOR EACH ONE OF P GROUP SHARED SECRETS, THE UNIQUE SUBSET OF M KEYS THAT WERE ASSIGNED TO THAT GROUP SHARED SECRET
END

FIG. 7

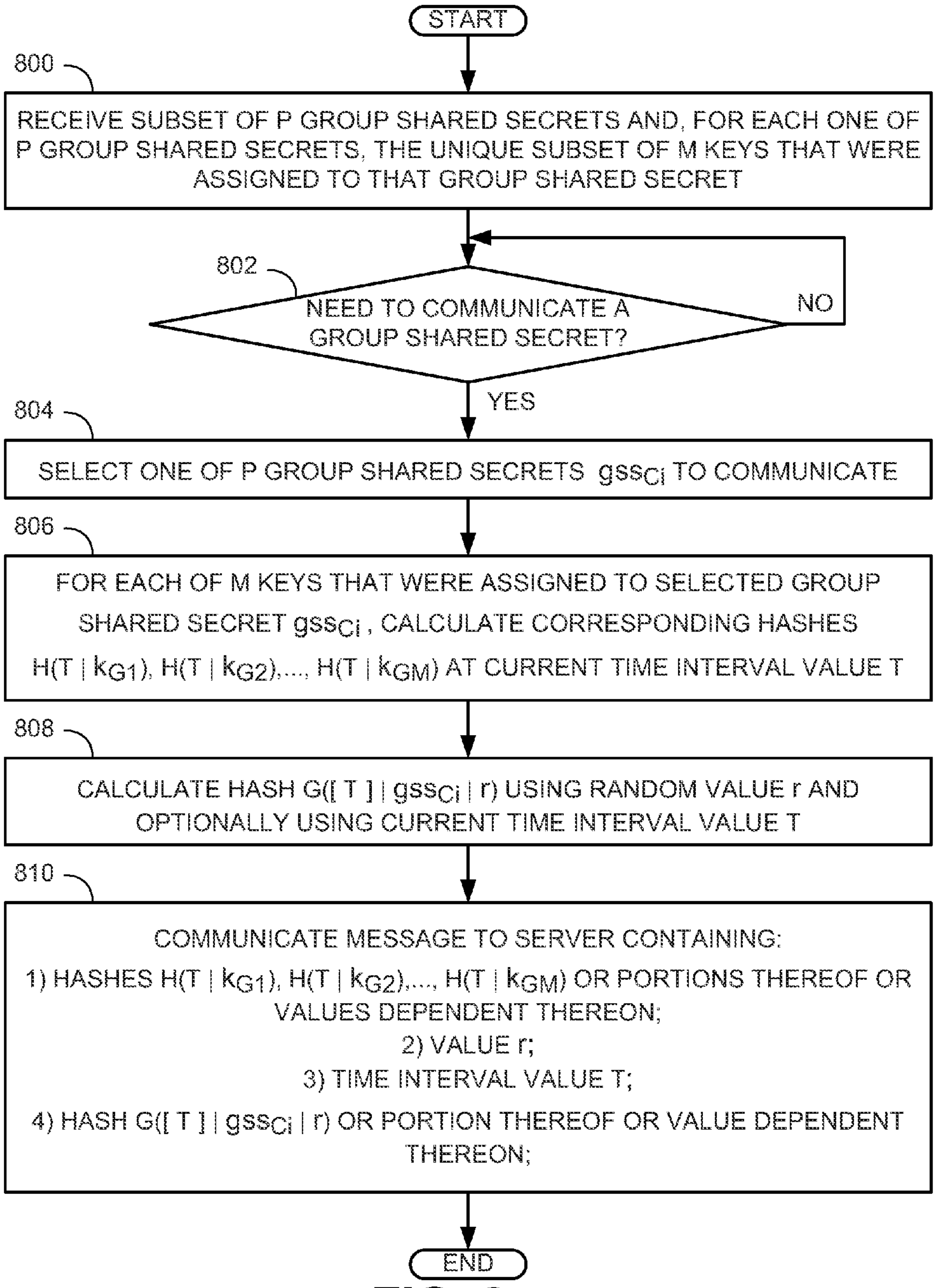

START
800
RECEIVE SUBSET OF P GROUP SHARED SECRETS AND, FOR EACH ONE OF P GROUP SHARED SECRETS, THE UNIQUE SUBSET OF M KEYS THAT WERE ASSIGNED TO THAT GROUP SHARED SECRET
802
NEED TO COMMUNICATE A GROUP SHARED SECRET?
NO
YES
804
SELECT ONE OF P GROUP SHARED SECRETS gss_{Ci} TO COMMUNICATE
806
FOR EACH OF M KEYS THAT WERE ASSIGNED TO SELECTED GROUP SHARED SECRET gss_{Ci}, CALCULATE CORRESPONDING HASHES $H(T \mid k_{G1}), H(T \mid k_{G2}), \ldots, H(T \mid k_{GM})$ AT CURRENT TIME INTERVAL VALUE T
808
CALCULATE HASH $G([\,T\,] \mid gss_{Ci} \mid r)$ USING RANDOM VALUE r AND OPTIONALLY USING CURRENT TIME INTERVAL VALUE T
810
COMMUNICATE MESSAGE TO SERVER CONTAINING:
1) HASHES $H(T \mid k_{G1}), H(T \mid k_{G2}), \ldots, H(T \mid k_{GM})$ OR PORTIONS THEREOF OR VALUES DEPENDENT THEREON;
2) VALUE r;
3) TIME INTERVAL VALUE T;
4) HASH $G([\,T\,] \mid gss_{Ci} \mid r)$ OR PORTION THEREOF OR VALUE DEPENDENT THEREON;
END

FIG. 8

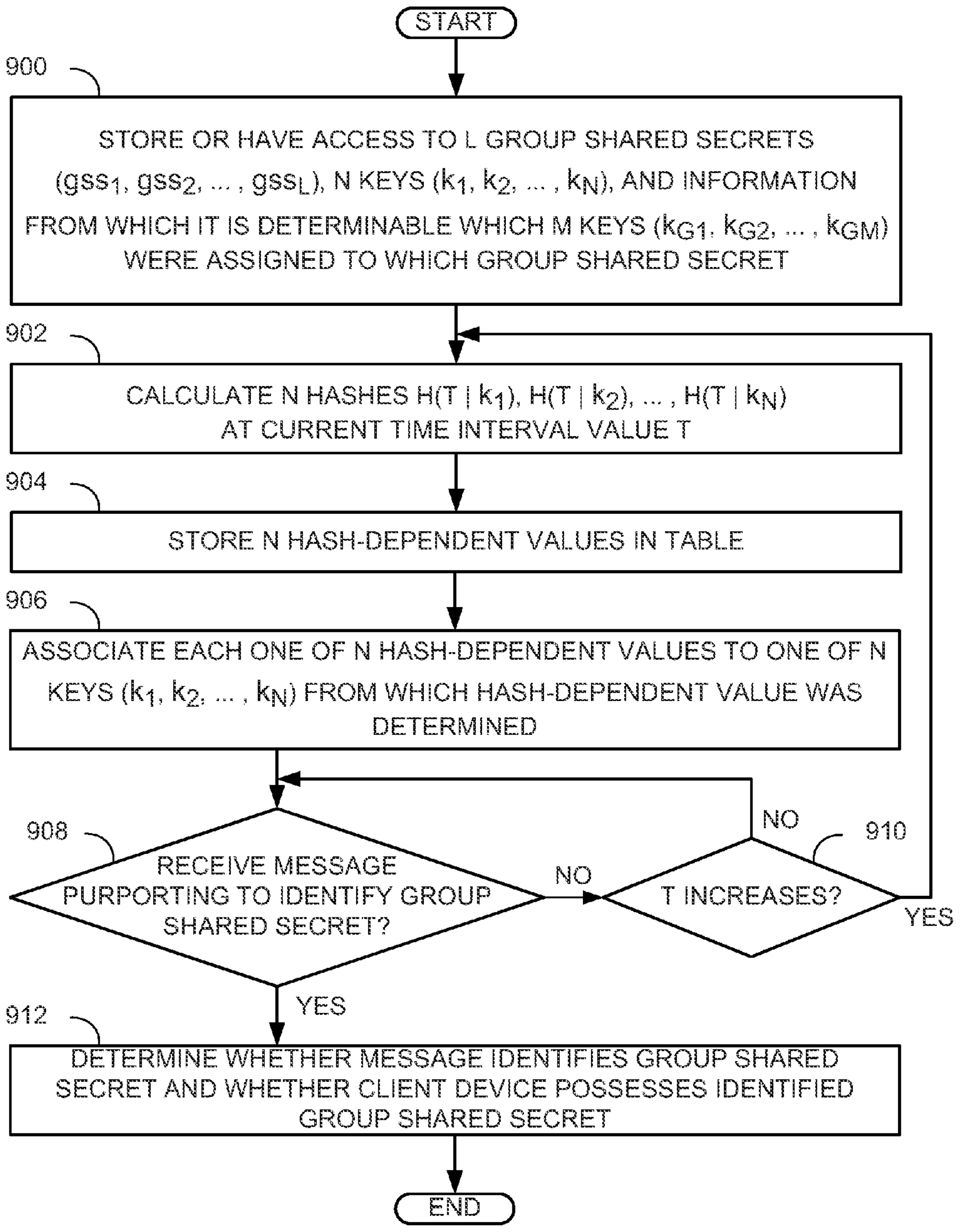

START
900
STORE OR HAVE ACCESS TO L GROUP SHARED SECRETS (gss_1, gss_2, ... , gss_L), N KEYS (k_1, k_2, ... , k_N), AND INFORMATION FROM WHICH IT IS DETERMINABLE WHICH M KEYS (k_{G1}, k_{G2}, ... , k_{GM}) WERE ASSIGNED TO WHICH GROUP SHARED SECRET
902
CALCULATE N HASHES H(T | k_1), H(T | k_2), ... , H(T | k_N) AT CURRENT TIME INTERVAL VALUE T
904
STORE N HASH-DEPENDENT VALUES IN TABLE
906
ASSOCIATE EACH ONE OF N HASH-DEPENDENT VALUES TO ONE OF N KEYS (k_1, k_2, ... , k_N) FROM WHICH HASH-DEPENDENT VALUE WAS DETERMINED
908
RECEIVE MESSAGE PURPORTING TO IDENTIFY GROUP SHARED SECRET?
NO
910
T INCREASES?
NO
YES
YES
912
DETERMINE WHETHER MESSAGE IDENTIFIES GROUP SHARED SECRET AND WHETHER CLIENT DEVICE POSSESSES IDENTIFIED GROUP SHARED SECRET
END

FIG. 9-1

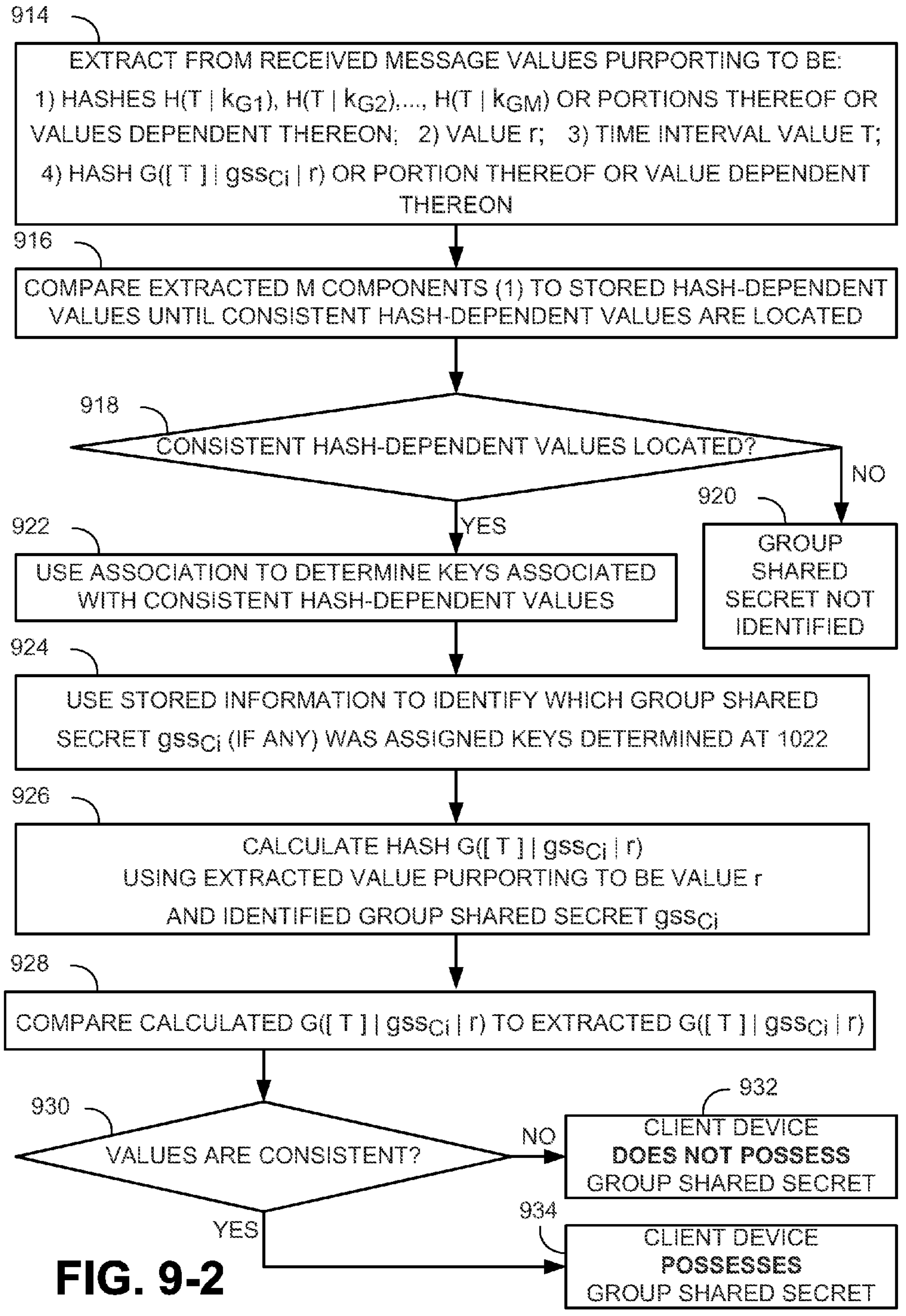

914
EXTRACT FROM RECEIVED MESSAGE VALUES PURPORTING TO BE: 1) HASHES $H(T | k_{G1})$, $H(T | k_{G2})$,..., $H(T | k_{GM})$ OR PORTIONS THEREOF OR VALUES DEPENDENT THEREON; 2) VALUE r; 3) TIME INTERVAL VALUE T; 4) HASH $G([T] | gss_{Ci} | r)$ OR PORTION THEREOF OR VALUE DEPENDENT THEREON
916
COMPARE EXTRACTED M COMPONENTS (1) TO STORED HASH-DEPENDENT VALUES UNTIL CONSISTENT HASH-DEPENDENT VALUES ARE LOCATED
918
CONSISTENT HASH-DEPENDENT VALUES LOCATED?
NO
920
GROUP SHARED SECRET NOT IDENTIFIED
YES
922
USE ASSOCIATION TO DETERMINE KEYS ASSOCIATED WITH CONSISTENT HASH-DEPENDENT VALUES
924
USE STORED INFORMATION TO IDENTIFY WHICH GROUP SHARED SECRET gss_{Ci} (IF ANY) WAS ASSIGNED KEYS DETERMINED AT 1022
926
CALCULATE HASH $G([T] | gss_{Ci} | r)$ USING EXTRACTED VALUE PURPORTING TO BE VALUE r AND IDENTIFIED GROUP SHARED SECRET gss_{Ci}
928
COMPARE CALCULATED $G([T] | gss_{Ci} | r)$ TO EXTRACTED $G([T] | gss_{Ci} | r)$
930
VALUES ARE CONSISTENT?
NO
932
CLIENT DEVICE **DOES NOT POSSESS** GROUP SHARED SECRET
YES
934
CLIENT DEVICE **POSSESSES** GROUP SHARED SECRET

FIG. 9-2

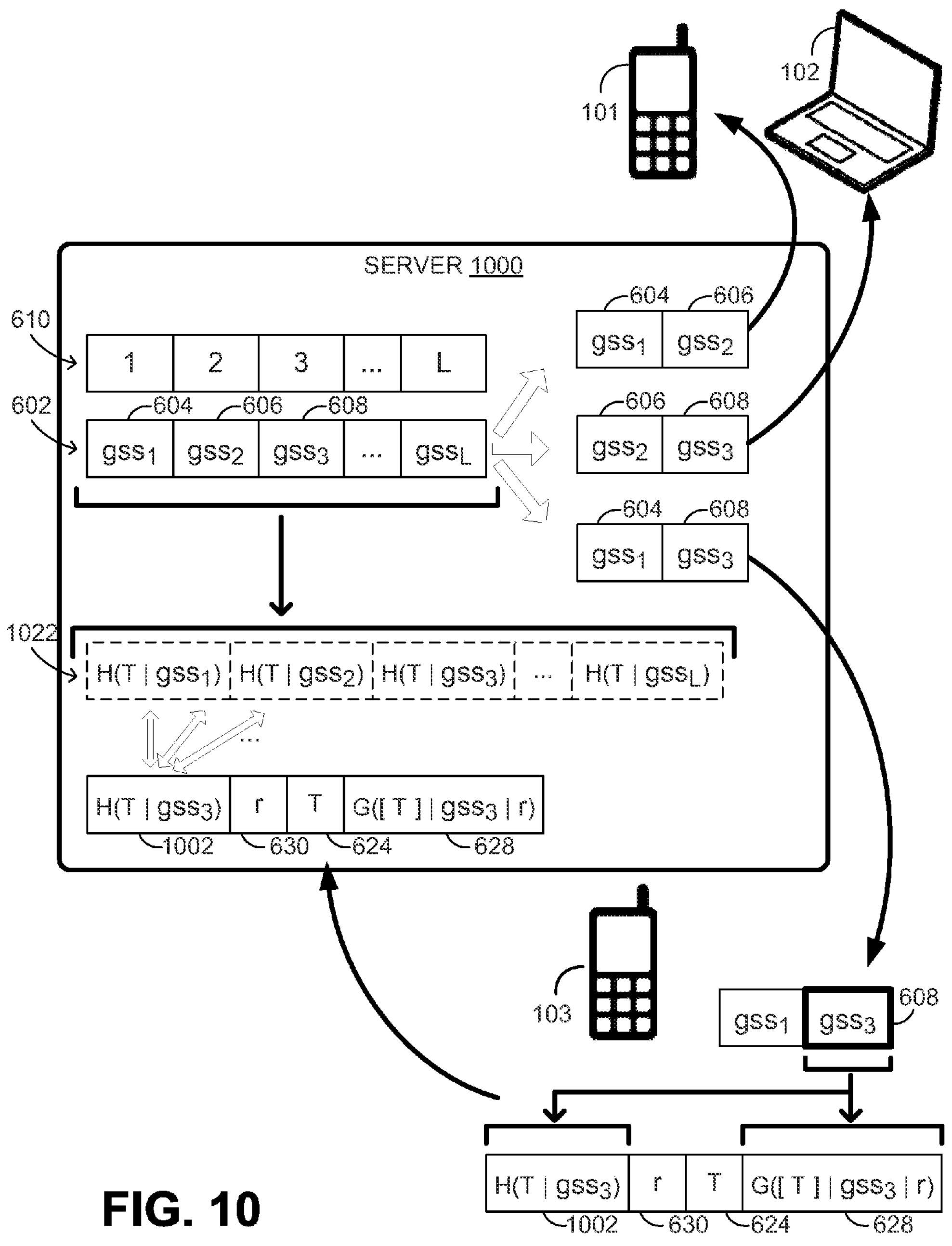

101
102
103
SERVER 1000
610
602
1022
1
2
3
...
L
gss_1
gss_2
gss_3
gss_L
604
606
608
$H(T \mid gss_1)$
$H(T \mid gss_2)$
$H(T \mid gss_3)$
$H(T \mid gss_L)$
$H(T \mid gss_3)$
r
T
$G([T] \mid gss_3 \mid r)$
1002
630
624
628

FIG. 10

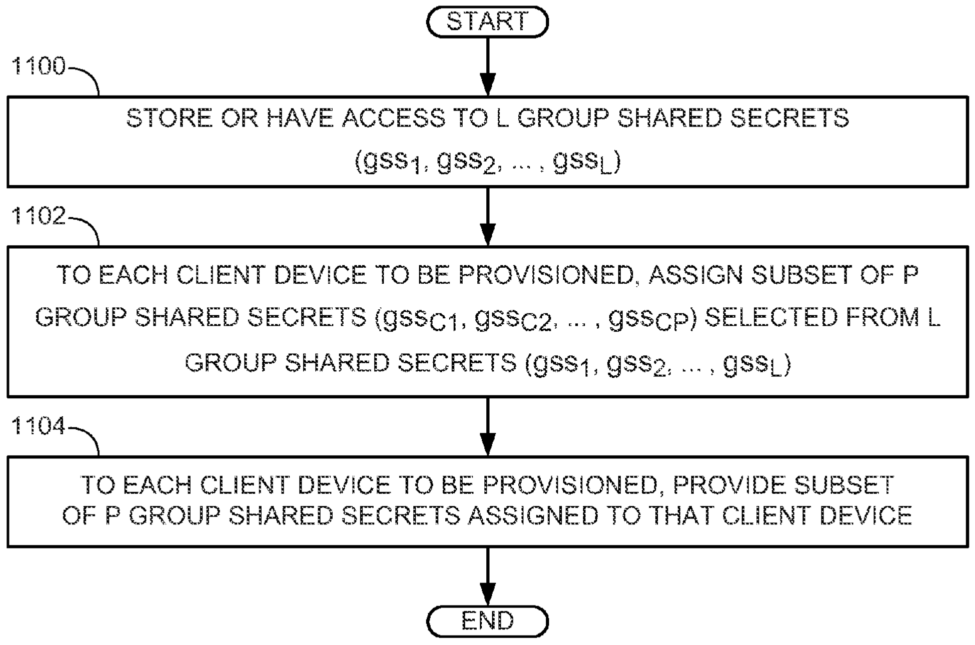

START
1100
STORE OR HAVE ACCESS TO L GROUP SHARED SECRETS (gss_1, gss_2, ... , gss_L)
1102
TO EACH CLIENT DEVICE TO BE PROVISIONED, ASSIGN SUBSET OF P GROUP SHARED SECRETS (gss_{C1}, gss_{C2}, ... , gss_{CP}) SELECTED FROM L GROUP SHARED SECRETS (gss_1, gss_2, ... , gss_L)
1104
TO EACH CLIENT DEVICE TO BE PROVISIONED, PROVIDE SUBSET OF P GROUP SHARED SECRETS ASSIGNED TO THAT CLIENT DEVICE
END

FIG. 11

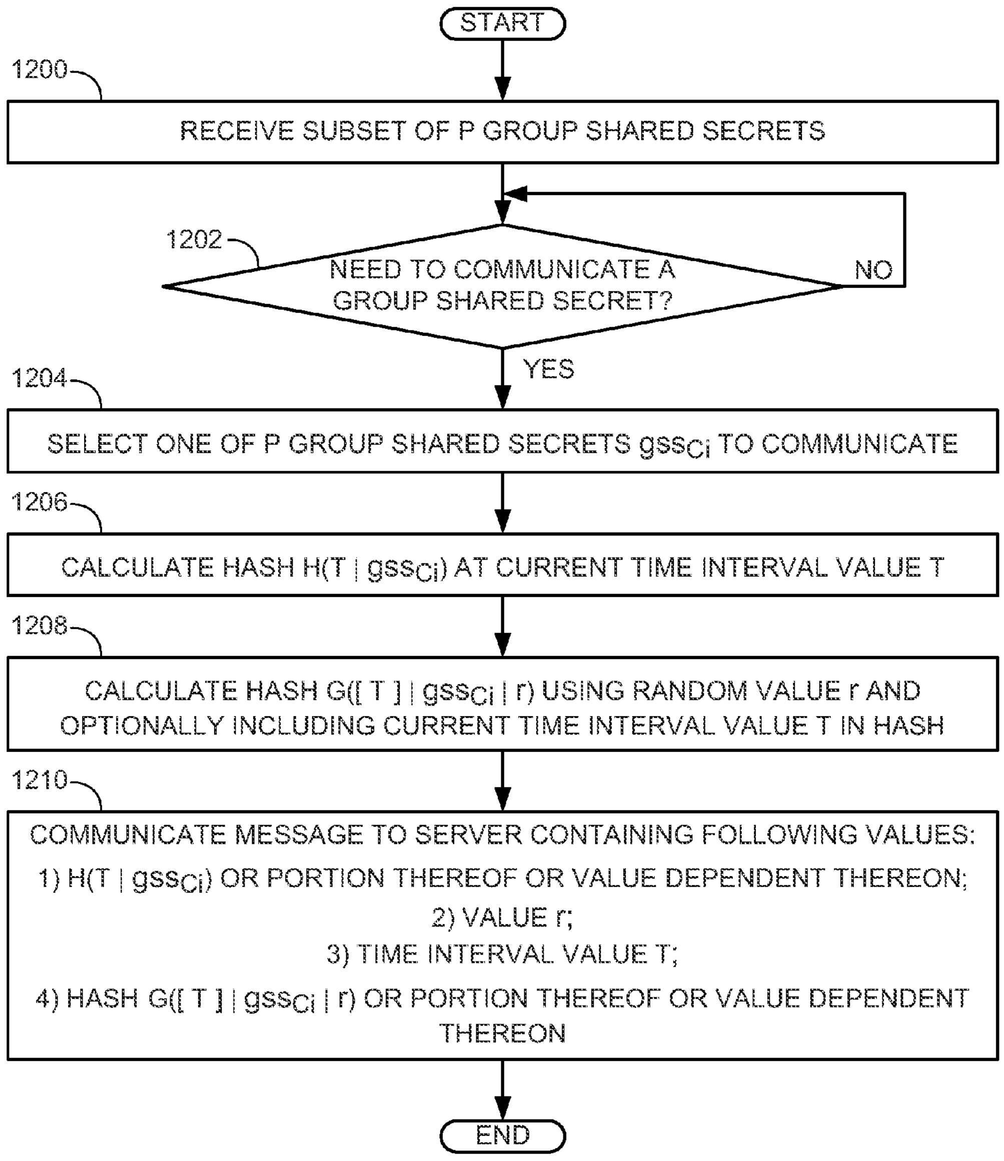

START
1200
RECEIVE SUBSET OF P GROUP SHARED SECRETS
1202
NEED TO COMMUNICATE A GROUP SHARED SECRET?
NO
YES
1204
SELECT ONE OF P GROUP SHARED SECRETS gss_{Ci} TO COMMUNICATE
1206
CALCULATE HASH $H(T \mid gss_{Ci})$ AT CURRENT TIME INTERVAL VALUE T
1208
CALCULATE HASH $G([\ T\ ] \mid gss_{Ci} \mid r)$ USING RANDOM VALUE r AND OPTIONALLY INCLUDING CURRENT TIME INTERVAL VALUE T IN HASH
1210
COMMUNICATE MESSAGE TO SERVER CONTAINING FOLLOWING VALUES:
1) $H(T \mid gss_{Ci})$ OR PORTION THEREOF OR VALUE DEPENDENT THEREON;
2) VALUE r;
3) TIME INTERVAL VALUE T;
4) HASH $G([\ T\ ] \mid gss_{Ci} \mid r)$ OR PORTION THEREOF OR VALUE DEPENDENT THEREON
END

FIG. 12

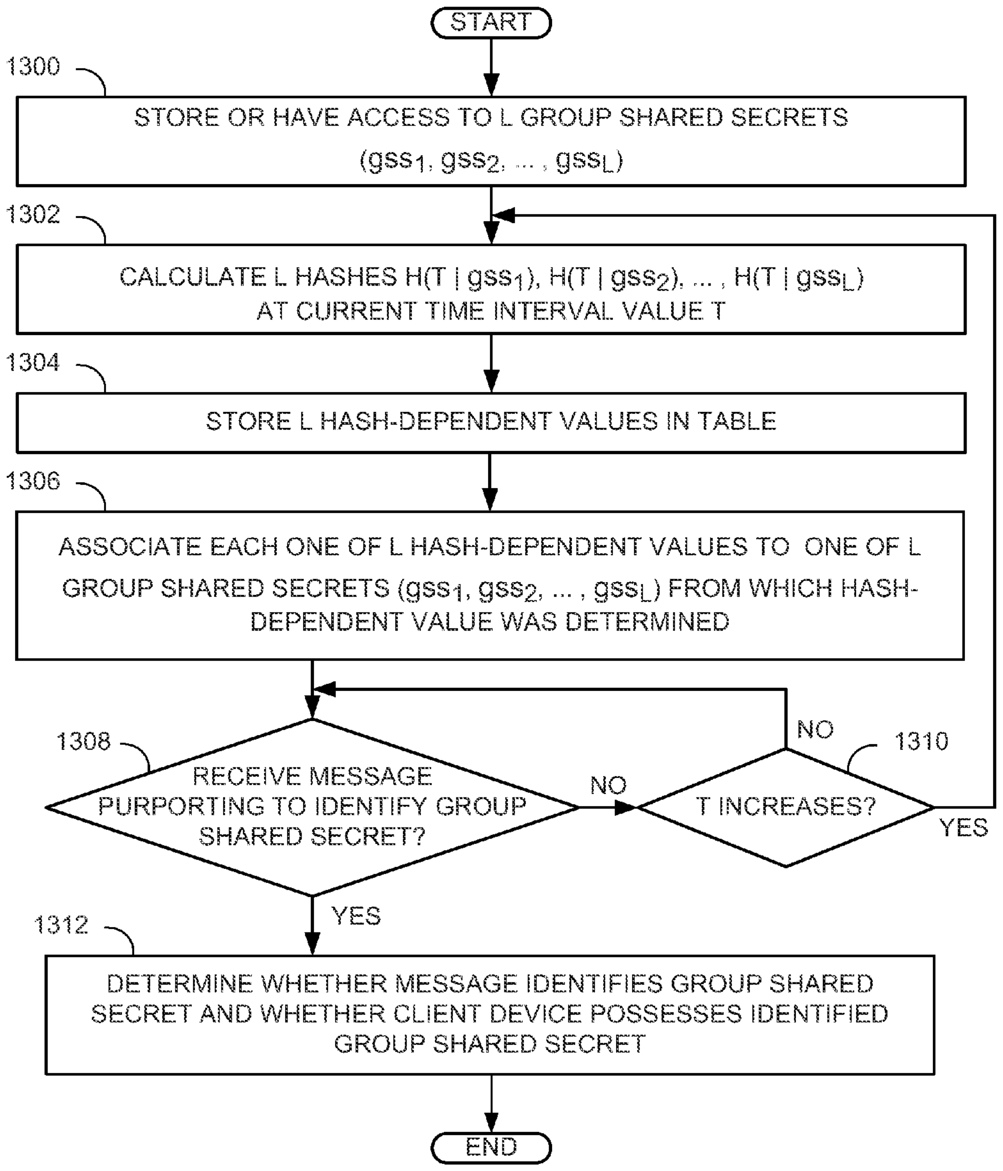

START
1300
STORE OR HAVE ACCESS TO L GROUP SHARED SECRETS (gss_1, gss_2, ... , gss_L)
1302
CALCULATE L HASHES H(T | gss_1), H(T | gss_2), ... , H(T | gss_L) AT CURRENT TIME INTERVAL VALUE T
1304
STORE L HASH-DEPENDENT VALUES IN TABLE
1306
ASSOCIATE EACH ONE OF L HASH-DEPENDENT VALUES TO ONE OF L GROUP SHARED SECRETS (gss_1, gss_2, ... , gss_L) FROM WHICH HASH-DEPENDENT VALUE WAS DETERMINED
1308
RECEIVE MESSAGE PURPORTING TO IDENTIFY GROUP SHARED SECRET?
NO
1310
T INCREASES?
NO
YES
YES
1312
DETERMINE WHETHER MESSAGE IDENTIFIES GROUP SHARED SECRET AND WHETHER CLIENT DEVICE POSSESSES IDENTIFIED GROUP SHARED SECRET
END

FIG. 13-1

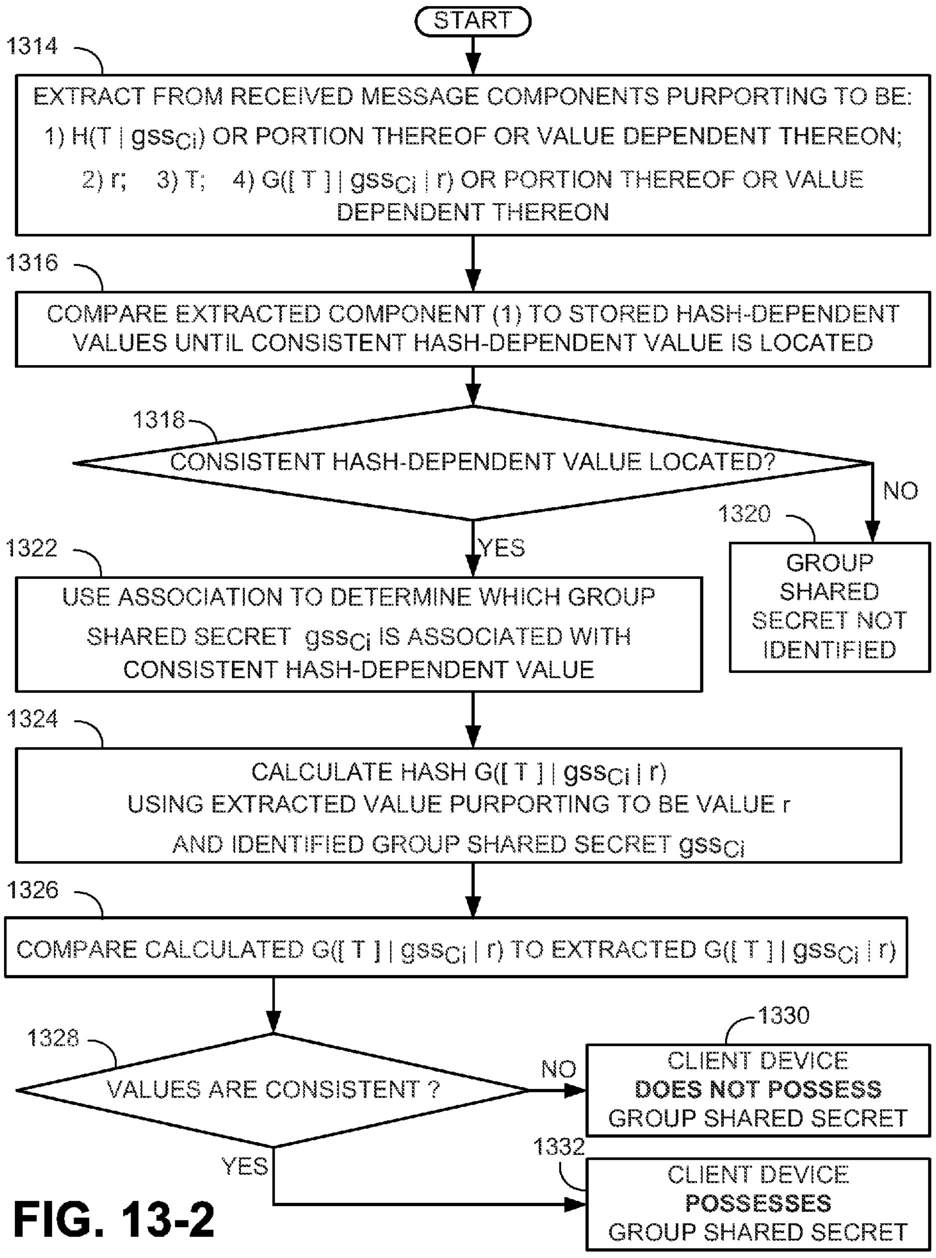

START
1314
EXTRACT FROM RECEIVED MESSAGE COMPONENTS PURPORTING TO BE:
1) H(T | gss_{Ci}) OR PORTION THEREOF OR VALUE DEPENDENT THEREON;
2) r; 3) T; 4) G([T] | gss_{Ci} | r) OR PORTION THEREOF OR VALUE DEPENDENT THEREON
1316
COMPARE EXTRACTED COMPONENT (1) TO STORED HASH-DEPENDENT VALUES UNTIL CONSISTENT HASH-DEPENDENT VALUE IS LOCATED
1318
CONSISTENT HASH-DEPENDENT VALUE LOCATED?
NO
1320
GROUP SHARED SECRET NOT IDENTIFIED
YES
1322
USE ASSOCIATION TO DETERMINE WHICH GROUP SHARED SECRET gss_{Ci} IS ASSOCIATED WITH CONSISTENT HASH-DEPENDENT VALUE
1324
CALCULATE HASH G([T] | gss_{Ci} | r) USING EXTRACTED VALUE PURPORTING TO BE VALUE r AND IDENTIFIED GROUP SHARED SECRET gss_{Ci}
1326
COMPARE CALCULATED G([T] | gss_{Ci} | r) TO EXTRACTED G([T] | gss_{Ci} | r)
1328
VALUES ARE CONSISTENT ?
NO
1330
CLIENT DEVICE **DOES NOT POSSESS** GROUP SHARED SECRET
YES
1332
CLIENT DEVICE **POSSESSES** GROUP SHARED SECRET

FIG. 13-2

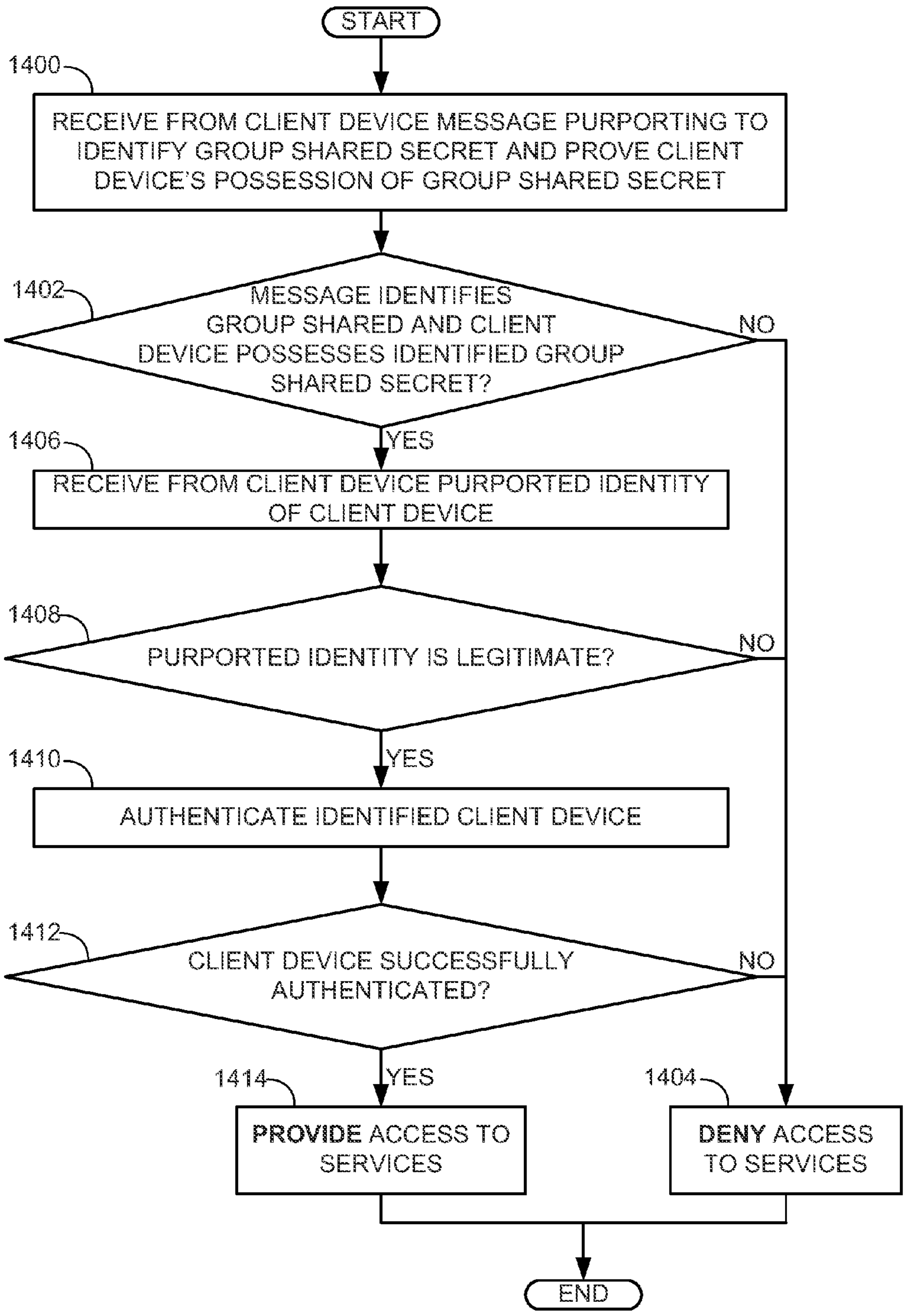

START
1400
RECEIVE FROM CLIENT DEVICE MESSAGE PURPORTING TO IDENTIFY GROUP SHARED SECRET AND PROVE CLIENT DEVICE'S POSSESSION OF GROUP SHARED SECRET
1402
MESSAGE IDENTIFIES GROUP SHARED AND CLIENT DEVICE POSSESSES IDENTIFIED GROUP SHARED SECRET?
NO
YES
1406
RECEIVE FROM CLIENT DEVICE PURPORTED IDENTITY OF CLIENT DEVICE
1408
PURPORTED IDENTITY IS LEGITIMATE?
NO
YES
1410
AUTHENTICATE IDENTIFIED CLIENT DEVICE
1412
CLIENT DEVICE SUCCESSFULLY AUTHENTICATED?
NO
YES
1414
PROVIDE ACCESS TO SERVICES
1404
DENY ACCESS TO SERVICES
END

FIG. 14

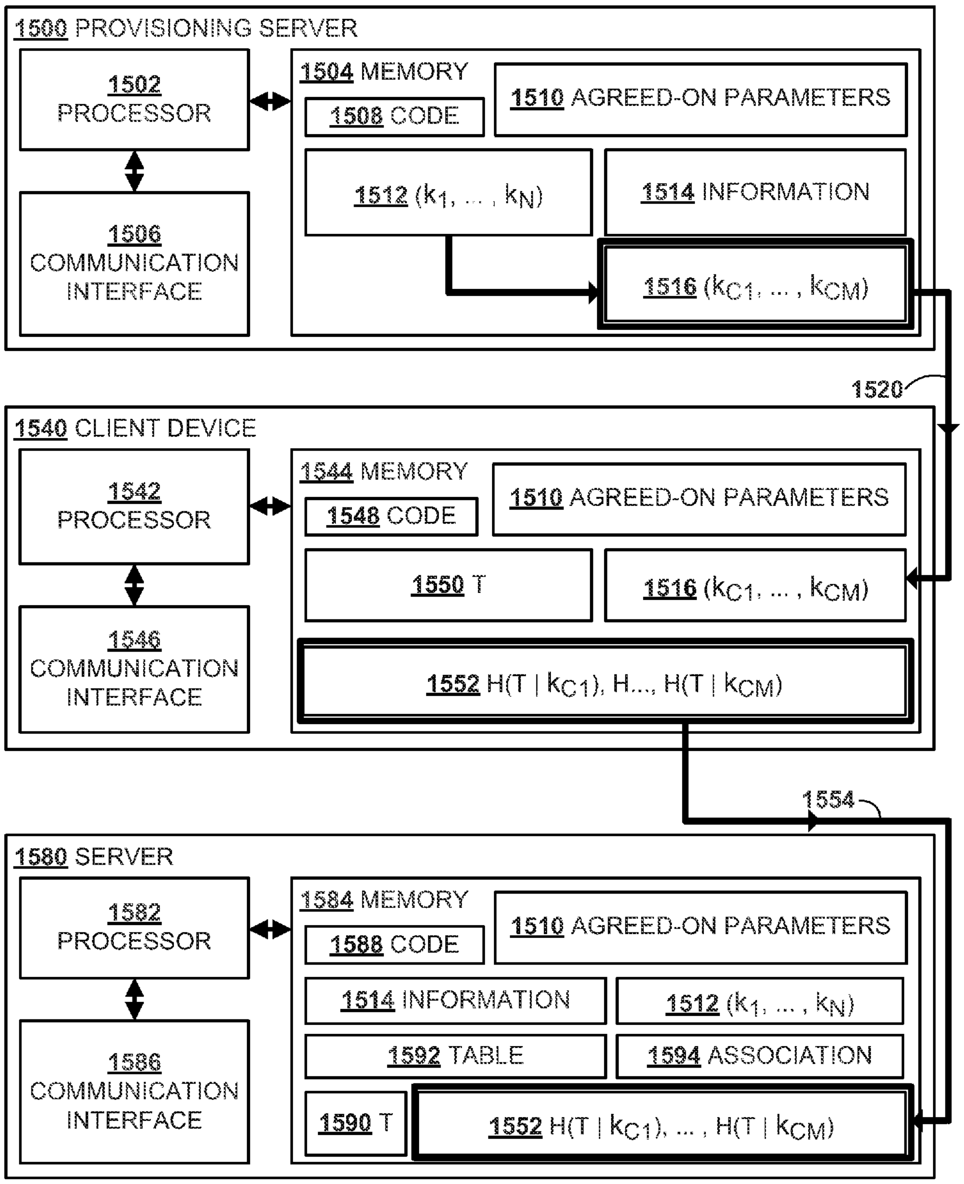

1500 PROVISIONING SERVER
1502 PROCESSOR
1506 COMMUNICATION INTERFACE
1504 MEMORY
1508 CODE
1510 AGREED-ON PARAMETERS
1512 (k_1, ... , k_N)
1514 INFORMATION
1516 (k_{C1}, ... , k_{CM})
1520
1540 CLIENT DEVICE
1542 PROCESSOR
1546 COMMUNICATION INTERFACE
1544 MEMORY
1548 CODE
1510 AGREED-ON PARAMETERS
1550 T
1516 (k_{C1}, ... , k_{CM})
1552 H(T | k_{C1}), H..., H(T | k_{CM})
1554
1580 SERVER
1582 PROCESSOR
1586 COMMUNICATION INTERFACE
1584 MEMORY
1588 CODE
1510 AGREED-ON PARAMETERS
1514 INFORMATION
1512 (k_1, ... , k_N)
1592 TABLE
1594 ASSOCIATION
1590 T
1552 H(T | k_{C1}), ... , H(T | k_{CM})

FIG. 15

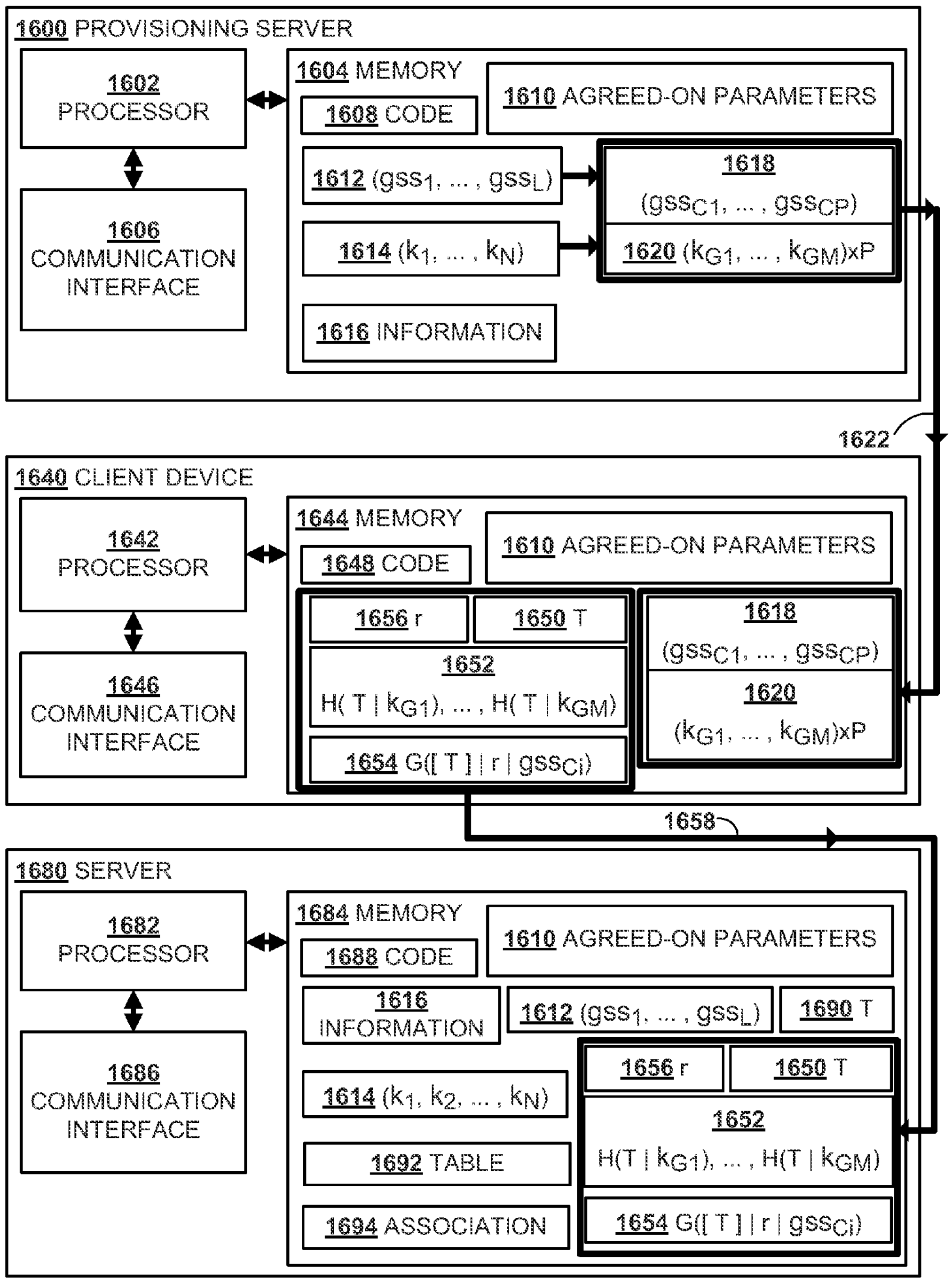

1600 PROVISIONING SERVER
1602 PROCESSOR
1606 COMMUNICATION INTERFACE
1604 MEMORY
1608 CODE
1610 AGREED-ON PARAMETERS
1612 (gss1, ... , gssL)
1614 (k1, ... , kN)
1616 INFORMATION
1618 (gssC1, ... , gssCP)
1620 (kG1, ... , kGM)xP
1622
1640 CLIENT DEVICE
1642 PROCESSOR
1646 COMMUNICATION INTERFACE
1644 MEMORY
1648 CODE
1610 AGREED-ON PARAMETERS
1656 r
1650 T
1652 H(T | kG1), ... , H(T | kGM)
1654 G([T] | r | gssCi)
1618 (gssC1, ... , gssCP)
1620 (kG1, ... , kGM)xP
1658
1680 SERVER
1682 PROCESSOR
1686 COMMUNICATION INTERFACE
1684 MEMORY
1688 CODE
1610 AGREED-ON PARAMETERS
1616 INFORMATION
1612 (gss1, ... , gssL)
1690 T
1614 (k1, k2, ... , kN)
1692 TABLE
1694 ASSOCIATION
1656 r
1650 T
1652 H(T | kG1), ... , H(T | kGM)
1654 G([T] | r | gssCi)

FIG. 16

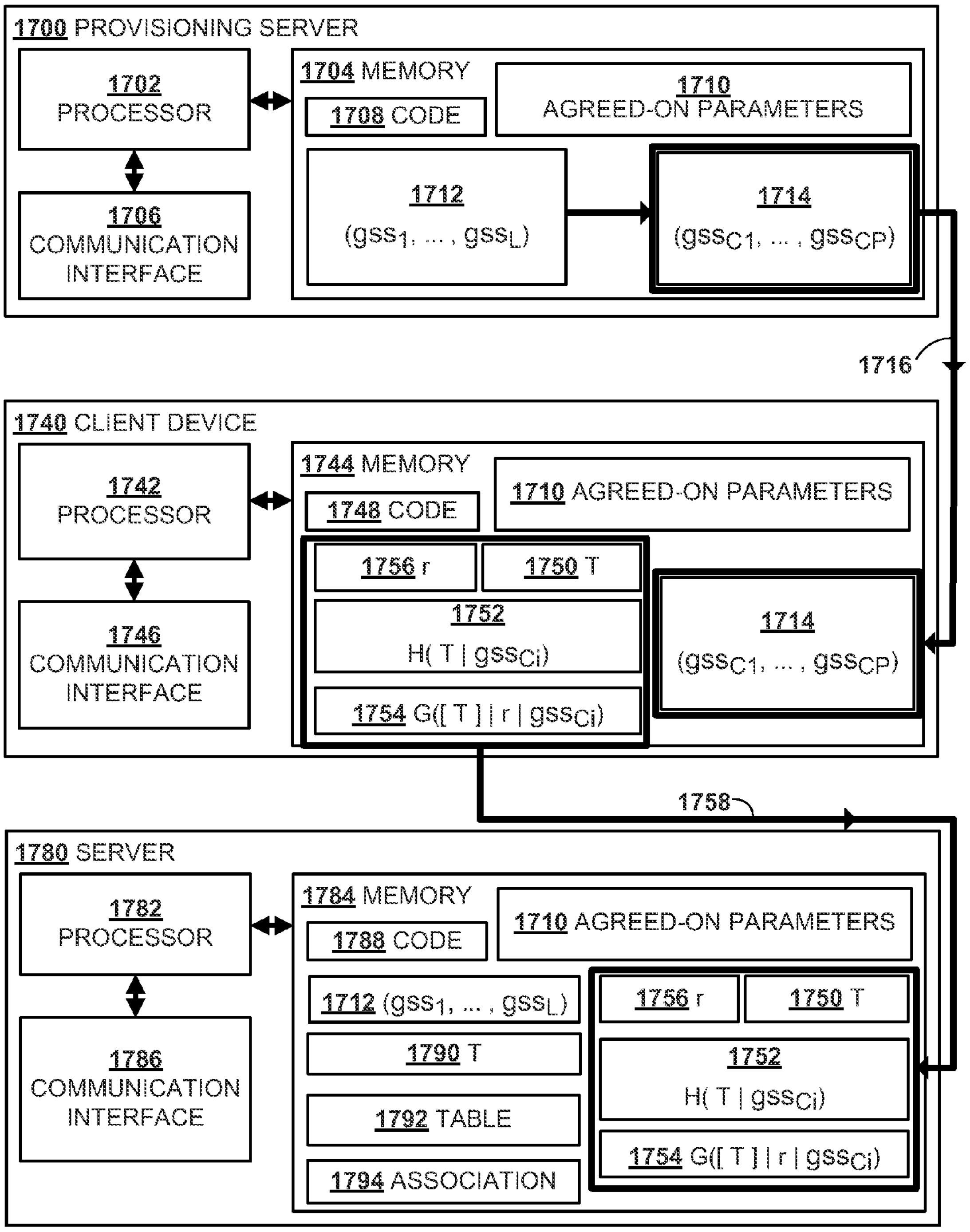

1700 PROVISIONING SERVER
1702 PROCESSOR
1706 COMMUNICATION INTERFACE
1704 MEMORY
1708 CODE
1710 AGREED-ON PARAMETERS
1712 $(gss_1, \ldots, gss_L)$
1714 $(gss_{C1}, \ldots, gss_{CP})$
1716
1740 CLIENT DEVICE
1742 PROCESSOR
1746 COMMUNICATION INTERFACE
1744 MEMORY
1748 CODE
1710 AGREED-ON PARAMETERS
1756 r
1750 T
1752 $H(T \mid gss_{Ci})$
1754 $G([T] \mid r \mid gss_{Ci})$
1714 $(gss_{C1}, \ldots, gss_{CP})$
1758
1780 SERVER
1782 PROCESSOR
1786 COMMUNICATION INTERFACE
1784 MEMORY
1788 CODE
1710 AGREED-ON PARAMETERS
1712 $(gss_1, \ldots, gss_L)$
1790 T
1792 TABLE
1794 ASSOCIATION
1756 r
1750 T
1752 $H(T \mid gss_{Ci})$
1754 $G([T] \mid r \mid gss_{Ci})$

FIG. 17

COMMUNICATING AN IDENTITY OF A GROUP SHARED SECRET TO A SERVER

TECHNICAL FIELD

The technology described herein relates generally to identity protection.

BACKGROUND

A client device may seek to communicate an identity to a server. For example, prior to permitting a client device to gain access to one or more services in a network, a server of the network may require authentication of the client device as proof that the client device is a legitimate client of the network server. In order to authenticate itself to the server, the client device may be required to communicate an identity to the server.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram illustrating a first technique for the provisioning of client-identifying keys by a server to a plurality of client devices, and the communication of one client device's provisioned client-identifying key to the server;

FIG. **2** is a schematic diagram illustrating a second technique for the provisioning of client-identifying keys by a server to a plurality of client devices, and the communication of one client device's provisioned client-identifying keys to the server;

FIG. **3** is a flowchart illustrating an example method to be performed by a provisioning server for provisioning client-identifying keys to client devices;

FIG. **4** is a flowchart illustrating an example method to be performed by a provisioned client device for communicating its provisioned client-identifying keys to a receiving server;

FIGS. **5-1** and **5-2** are flowcharts illustrating an example method to be performed by a receiving server for determining whether a received message could have been communicated by a client device that was provisioned with one or more client-identifying keys;

FIG. **6** is a schematic diagram illustrating a first example technique for the provisioning of group shared secrets by a server to a plurality of client devices, and the communicating of one client device's provisioned group shared secret to the server;

FIG. **7** is a flowchart illustrating a first example method to be performed by a provisioning server for provisioning group shared secret identifying keys to client devices;

FIG. **8** is a flowchart illustrating a first example method to be performed by a provisioned client device for communicating one of its provisioned group shared secrets to a receiving server;

FIGS. **9-1** and **9-2** are flowcharts illustrating a first example method to be performed by a receiving server for determining whether a received message from a client device identifies a group shared secret and whether the client device possesses the identified group shared secret;

FIG. **10** is a schematic diagram illustrating a second example technique for the provisioning of group shared secrets by a server to a plurality of client devices, and the communicating of one client device's provisioned group shared secret to the server;

FIG. **11** is a flowchart illustrating a second example method to be performed by a provisioning server for provisioning group shared secret identifying keys to client devices;

FIG. **12** is a flowchart illustrating a second example method to be performed by a provisioned client device for communicating one of its provisioned group shared secrets to a receiving server;

FIGS. **13-1** and **13-2** are flowcharts illustrating a second example method to be performed by a receiving server for determining whether a received message from a client device identifies a group shared secret and whether the client device possesses the identified group shared secret;

FIG. **14** is a flowchart illustrating an example method to be performed by a server for identification and authentication of a client device;

FIG. **15** is a block diagram of an example provisioning server, an example client device, and an example server configured to perform the technique illustrated in FIG. **2**;

FIG. **16** is a block diagram of an example provisioning server, an example client device, and an example server configured to perform the technique illustrated in FIG. **6**; and

FIG. **17** is a block diagram of an example provisioning server, an example client device, and an example server configured to perform the technique illustrated in FIG. **10**.

DETAILED DESCRIPTION

The examples described herein are illustrated primarily in relation to one or more servers and one or more client devices. Each server may comprise one or more servers, databases, computing devices, communication devices, or other computing equipment adapted to communicate over a network (either fixed or wireless) with client devices. Client devices may comprise servers, personal computers, or other data processing or communication devices, such as wireless communication devices, communicating over fixed and wireless networks and public networks.

It will be appreciated by those skilled in the art, however, that this description is not intended to limit the scope of the described examples to implementation on these particular systems or devices. For example, the methods and systems described herein may be applied to any appropriate communication device or data processing device adapted to communicate with another communication or data processing device over a fixed or wireless connection, whether portable or wirelessly enabled or not, whether provided with voice communication capabilities or not, and additionally or alternatively adapted to process data and carry out operations on data in response to user commands for any number of purposes, including productivity and entertainment.

Thus, the examples described herein may be implemented on computing devices adapted for communication or messaging, including without limitation cellular phones, smartphones, wireless organizers, personal digital assistants, desktop computers, terminals, laptops, tablets, handheld wireless communication devices, notebook computers, entertainment devices such as MP3 or video players, and the like. Unless expressly stated, a client, computing or communication device may include any such device, and a server may include similar types of devices, configured to provide some or all of the processes described herein. The configuration and operation of all such devices generally will be known to those skilled in the art. The devices described herein may be configured to manage cryptographic keys. For example, any of the devices described herein may comprise or be configured to operate in conjunction with one or more key management components, including, for example, a Subscriber Identity Module (SIM) card, a smart card, a trusted platform module (TPM), or a hardware security module (HSM).

A client device may seek to provide an identity, and optionally some proof of the identity to a network server. This may happen, for example, as part of the process of the client device authenticating itself to the network server. As another example, in the case that the client device is a satellite telephone with limited coverage, it may provide the identity to a server as part of a check-in process to determine if it has any pending text messages for download. In yet another example, in the case that the client device is a cellular telephone, it may provide the identity to a server when periodically announcing its presence in an area. The identity being provided by the client device may be, for example, an identity of the client device, an identity of a SIM card, an identity of a group to which the client device belongs, or an identity of a group shared secret held by the client device. It may be of interest to ensure that the identity is communicated by the client device to the server in such a way that the identity cannot be understood by an eavesdropper. It may also be of interest to ensure that the client device cannot be tracked by an eavesdropper as a result of communicating the identity. It may be possible for a client device to obscure the identity it is communicating to the server by using traditional cryptographic techniques, such as asymmetric cryptography, or by using database lookups, such that each time the client device and the server communicate in secret, they agree on a new random identifier to be used during the next communication. However, these techniques may be computationally expensive when a Denial of Service (DoS) attack or a similar increase in computational load is being experienced. From the point of view of the server, part of the DoS risk is related to the fact that the server is not privy to an identity of the purported client device with which the server is communicating. Without being privy to this identity, the server may be unable to screen out a purported client device which is behaving maliciously.

A technique is herein proposed whereby a client device that has previously been provisioned with one or more cryptographic keys by a provisioning server is able to communicate an identity to a server, herein described as a "receiving" server. The provisioned keys have been selected from a plurality of cryptographic keys and embedded in the client device at the time of manufacture, or provisioned at a later date, for example, via a storage module like a SIM or over a secure channel. The receiving server may have access to the set of cryptographic keys or to data dependent on the cryptographic keys, as well as access to information from which it is determinable which of the cryptographic keys were provisioned to the client device. The client device is able to use one or more of its provisioned keys to communicate an identity to the receiving server. Examples of possible identities that may be communicated by the client device include an identity of the client device itself, an identity of a SIM card associated with the client device, an identity of a group to which the client device belongs, an identity of a group shared secret held by the client device, or any other identity.

The basic principles of an example technique for communicating an identity from a client device to a server are described with respect to FIG. **1**, which illustrates a server **104** and a plurality of client devices **100**, including a client device **101**, a client device **102** and a client device **103**. The client devices **100** are illustrated as wireless communication devices, however, any of the client devices **100** may alternatively or additionally communicate via one or more fixed connections. Properties of the client devices **100** and the

server **104** will be discussed later, with respect to FIGS. **15-17**. In this simple example, the server **104** may store or have access to a plurality of cryptographic keys **106**, which will herein be referred to as client-identifying keys **106** for reasons that will become apparent later. The client-identifying keys **106**, which include key k_1 **108**, key k_2 **110** and key k_3 **112**, may be identified by indices **114**, namely, index 1, index 2, and index 3, as shown in FIG. **1**. In another example (not shown), the client-identifying keys **106** may be identified by arbitrary identifiers. In yet another example (not shown), the client identifying keys may effectively identify themselves.

Each one of the client-identifying keys **106** is a distinct value. In one example, each of the client-identifying keys **106** is an effectively random value, such that it cannot be generated again on another occasion, except by chance. In this case, the client-identifying keys **106** would be stored by the server **104** for future reference, for example, in a lookup table. In another example, each of the client-identifying keys **106** is a quasi-random or pseudo-random value generated using any suitable generation algorithm, such that the same client-identifying key **106** can be reliably generated on another occasion in a repeatable manner. For example, a particular client-identifying key k_i could be calculated as a hash of a concatenation of a random seed value s and an index i, that is $k_i=h(s|i)$, where h is any suitable hash algorithm, such as SHA-1, SHA-2, or MD5. In this case, the client-identifying keys **106** may not be stored by the server **104**, provided that the server **104** maintains a record of the conditions under which the client-identifying keys **106** were generated, including, for example, the hash algorithm h and the random seed value s. Each one of the client-identifying keys **106** may be of a sufficient length and complexity that it cannot be easily predicted or guessed by an attacker.

The server **104** assigns and provisions the client-identifying keys k_1 **108**, k_2 **110** and k_3 **112** to the client devices **101**, **102** and **103**, respectively. The client-identifying keys k_1 **108**, k_2 **110** and k_3 **112** may be embedded in the client devices **101**, **102** and **103**, respectively, at the time of manufacture, or provisioned at a later date, for example, via a storage module such as a SIM, or via a transmission over a secure channel.

The assignment of the client-identifying keys **106** to client devices may be carried out in a random, pseudo-random or quasi-random fashion or may be carried out in an arbitrary fashion, and the server **104** may maintain a record (not shown) of which of the client-identifying keys **106** was assigned to which client device, for example, in the form of a mapping function or a lookup table. Alternatively, the assignment of the client-identifying keys **106** to client devices may be carried out according to an algorithm. In either case, the server **104** may store information (not shown) from which it is determinable which of the client-identifying keys **106** was provisioned to which client device. Thus, the information may comprise the relevant mapping function, lookup table, algorithm or inverse thereof, or any other information by which the server **104** can determine which of the client-identifying keys **106** was provisioned to which client device, or can determine to which client device the subset of client-identifying keys **106** were assigned.

Alternatively, even if, at the time of assigning the client-identifying keys **106** to the client devices, the server **104** does not maintain any information from which it is determinable which of the client-identifying keys **106** was provisioned to which client device, it may still be possible for the server **104** to subsequently obtain such information. For example, after being provisioned with their respective client-identifying keys, the client devices could subsequently inform a central infrastructure of which of the client-identifying keys they possess, thereby permitting the server **104** to reconstruct a mapping function. For example, client devices that were provisioned client-identifying keys during manufacture could subsequently register themselves with a central infrastructure when first activated, and simultaneously provide indications of the client-identifying keys with which they were provisioned. In this case, it will be apparent to those of ordinary skill in the art that it may be of interest to communicate such indications over a secure channel.

Returning to FIG. **1**, the server **104** may possess a modulating value T that changes from time to time and is agreed on by the server **104** and any provisioned client devices. For example, the modulating value T may be a time interval value T and may be defined as the whole number of fixed-length intervals (or variable-length intervals) since some arbitrary point in time. For ease of understanding, the modulating value T is described herein as the time interval value T. However, it will be appreciated that the value T may refer to any modulating value that changes from time to time.

The time interval value T may be updated by the server **104** and any provisioned client devices according to one or more clocks, which may be synchronized. Alternatively or additionally, the server **104** may broadcast a current time interval value T to any provisioned client devices. The provisioned client devices may check that a current time interval value T has not been previously used.

It is possible that the time interval value T may be based on a spatial location. For example, in the case of wireless hotspots in coffee shops, each coffee shop may have its own server, and each server might have its own time interval value T.

It is also possible that the time interval value T may be determined according to a combination of a time on a clock and a spatial location. For example, the time interval value T may determined by "output concatenation/Cartesian product".

At any given moment in time, a legitimate client device may possess a current time interval value T that differs from a current time interval value T possessed by the server **104**. The current time interval value T of the legitimate client device may differ from that of the server **104**, for example, due to clock disagreement or latency associated with broadcasting or synchronization.

For each new time interval value T and for each of the client-identifying keys **106**, the server **104** may apply a function H to a combination of the time interval value T and the client-identifying key. Such a combination of two or more values, for example value X and value Y, is denoted herein as (X|Y) and refers to a concatenation or to any other combination of the values. The function H may be a function that is difficult to reverse, such as a hash algorithm. For example, the function H may be any of SHA-1, SHA-2, or MD5. In one example, the function H is a SHA-2 algorithm no smaller than SHA-256. It will be appreciated, however, that the function H may represent other operations. For example, the function H may correspond to a block cipher. It will also be appreciated that the definition of the function H may change from time to time, provided that the definition is agreed on by the entities involved, in this case, the server **104** and the client devices **101**, **102** and **103**. For example, the definition of the function H may change in accordance with a change in the current time interval value T. The server **104** may broadcast an indication of the function H that is currently in use. For simplicity, in the following discussion, the function H is referred to as a hash algorithm H, and any expression of the form H(X) is described as a hash.

It is noted that the length of time over which a particular time interval value T remains unchanged should generally be sufficient to allow the server **104** to calculate and store any required hashes for any time interval value T that is likely to be considered current by a provisioned client device, as will be discussed further below. For example, the shorter the length of the time interval, the more intervals the server **104** may need to consider active at any given time, depending on a maximum acceptable clock differential between the client devices and the server **104**. However, as will be discussed later, it is still of interest to keep the length of the time interval short enough to limit the window of opportunity for replay attacks, and to reduce the risk of being tracked by an eavesdropper. In one example, the length of any time interval is between five minutes and twenty minutes.

In the example of FIG. **1**, the server **104** uses the hash algorithm H to compute hashes $H(T|k_1)$ **118**, $H(T|k_2)$ **120** and $H(T|k_3)$ **122**. The server **104** may store each of the hashes $H(T|k_1)$ **118**, $H(T|k_2)$ **120** and $H(T|k_3)$ **122** in a table **116**. Alternatively, the server **104** may store only a portion of each of the hashes $H(T|k_1)$ **118**, $H(T|k_2)$ **120** and $H(T|k_3)$ **122** in the table **116**. In one example, the server **104** may only store enough of each one of the hashes $H(T|k_1)$ **118**, $H(T|k_2)$ **120**, and $H(T|k_3)$ **122** to distinguish the stored value from the rest of the values stored in the table **116**. For example, for a hash that is 256 bits in length, it may be sufficient to store only the first 128 bits or the last 128 bits or any predetermined 128 bits of the hash in order for the stored value to be distinguished from rest of the values stored in the table **116**. In another example, a prefix tree, also known as a trie, could be used to preserve some number of bits at the beginning of each hash, where the number of bits preserved is the smallest number which distinguishes that value from all other values in the trie. For example, if there are one million hashes, but only one of the hashes has a zero as its first bit, only a single bit of that hash would be preserved in the trie. In this case, the number of bits stored for each hash may vary from hash to hash. In another example, a variation of trie could be used in which a specific bit is compared at each step, such that different bits are preserved for different values. In yet another example, for each of the hashes $H(T|k_1)$ **118**, $H(T|k_2)$ **120** and $H(T|k_3)$ **122**, the server **104** may compute some other value dependent thereon, and store the hash-dependent values in the table **116**. For example, each hash-dependent value may be computed by applying a hash algorithm F to a combination of one of the hashes $H(T|k_i)$ and a small random seed value s, that is $F(H(T|k_i)|s)$, where the hash algorithm F may be the same or different from the hash algorithm H, where the seed value s is determined by trial and error such that the first N bits of each hash-dependent value $F(H(T|k_i)|s)$ are unique amongst all the hash-dependent values, and where N may be close to the theoretical limit on size (i.e., the minimum number of bits for which the new hashes can still be distinguished from each other).

Thus, while table **116** is illustrated as comprising each of the hashes $H(T|k_1)$ **118**, $H(T|k_2)$ **120** and $H(T|k_3)$ **122** in its entirety, the table **116** should be understood as alternatively comprising only a portion of each of the hashes $H(T|k_1)$ **118**, $H(T|k_2)$ **120** and $H(T|k_3)$ **122**, or, alternatively, values dependent thereon.

In addition, the combination of elements to which the hash algorithm H is applied may comprise additional elements (not shown) beyond a time interval value T and a particular client-identifying key k_i. For example, the combination may comprise the index i of the client-identifying key k_i, such that the hash corresponding to the particular client-identifying key k_i is expressed as $H(T|i|k_i)$. Including an index as salt in a hash calculation may make the hash value harder to attack.

In any case, since each of the values stored in the table **116** may be computed as a result of applying a hash algorithm H to a combination that includes at least the time interval value T and a particular client-identifying key k_i, for simplicity, these values will herein be referred to as hash-dependent values, and any table in which these values are stored will herein be referred to as a table of hash-dependent values. However, it will be appreciated that a table is only one way in which the hash-dependent values may be stored, and that other data structures are possible for storage of the hash-dependent values.

In order to account for client devices that possess adjacent time interval values T due, for example, to clock disagreement or latency as discussed previously, the server **104** may maintain one or more additional tables of hash-dependent values (not shown) determined from previous time interval values T or future time interval values T or both. Alternatively, the server **104** may maintain a single table that includes hash-dependent values determined from the present time interval value T and from previous time interval values T or future time interval values T or both. For example, if the time interval value T changes once per hour, the server **104** may store the hash-dependent values corresponding to the time interval value T for the current hour and either the previous hour or the next hour, or both.

For each table of hash-dependent values, the server **104** may associate each one of the hash-dependent values in the table with the respective one of the client-identifying key **106** from which the hash-dependent value was determined (or with the respective one of the indices **114** of the client-identifying key **106** from which the hash-dependent value was determined). The association may comprise, for example, a reverse map, a hash table, an index tree, an exhaustive linear search, or an ad-hoc function f.

In the case that the association comprises a hash table, some of the information about a hash-dependent value may be probabilistically preserved. For example, the position of a record in the hash table may depend on the hash-dependent value itself, but the position of the record may not be completely deterministic in isolation. For example, the location of other records in the hash table may force a particular record to be relocated. It is possible that one portion of a hash-dependent value could be used to determine storage location, while another portion could be used for comparison with a hash-dependent value received from a client device, as will be discussed later.

In the case that the association comprises an ad-hoc function f that associates a particular hash $H(T|k_i)$ to a particular client-identifying key k_i, the function might be defined as f: $H(T|k_i) \rightarrow k_i$ for valid time interval values T and valid client-identifying keys k_i. It will be appreciated that, for invalid time interval values T and/or invalid client-identifying keys k_i, the function f need not satisfy any particular requirements. In the example of FIG. **1**, the association (not shown) for the table **116** of hash-dependent values would associate the hashes $H(T|k_1)$ **118**, $H(T|k_2)$ **120**, and $H(T|k_3)$ **122** to the client-identifying keys k_1 **108**, k_2 **110** and k_3 **112**, respectively (or to index 1, index 2, and index 3, respectively).

At any time after being provisioned with its respective client-identifying key, any of the client devices **101**, **102** or **103** may seek to communicate an identity to the server **104**.

For example, a client device may be required to provide an identity as a prerequisite to authentication with the server **104**, or as part of a check-in process with the server **104**. In another example, the client device may seek to provide an identity when periodically announcing its presence to the server **104**.

In the example illustrated in FIG. **1**, the client device **103** seeks to communicate an identity to the server **104**. For simplicity, it may be assumed that the identity is an identity of the client device **103**, however, the identity could be some other identity, such as an identity of a SIM card of the client device **103**.

In the simplified example of FIG. **1**, the identity of the client device **103** may be communicated to the server **104** using the client-identifying key k_3 **112** that the client device **103** received from the server **104**. Rather than sending the client-identifying key k_3 **112** directly to the server **104**, the client device **103** may apply the hash algorithm H to a combination of at least the current time interval value T and the client-identifying key k_3 **112**, thereby obtaining a hash $H(T|k_3)$ **124**. The nature of the combination and the definition of the hash algorithm H are the same as that used by the server **104** to calculate the hashes $H(T|k_1)$ **118**, $H(T|k_2)$ **120** and $H(T|k_3)$ **122** as described previously. The client device **103** may communicate the hash $H(T|k_3)$ **124** to the server **104**, and the server **104** may proceed to compare the hash $H(T|k_3)$ **124** or a portion thereof or a value dependent thereon to the hash-dependent values in the table **116**. In addition, the server **104** may optionally compare the hash $H(T|k_3)$ **124** or a portion thereof or a value dependent thereon to hash-dependent values stored in one or more additional tables (not shown) corresponding to one or more adjacent time interval values T. This may be done until the server **104** locates a hash-dependent value that is consistent with the hash $H(T|k_3)$ **124** or a corresponding portion thereof or a value dependent thereon. For example, upon comparing the hash $H(T|k_3)$ **124** to the hash $H(T|k_1)$ **118**, the server **104** will determine that the hashes are not consistent. The server **104** may proceed to compare the hash $H(T|k_3)$ **124** to the hash $H(T|k_2)$ **120**. Upon determining that the hash $H(T|k_3)$ **124** is not consistent with the hash $H(T|k_2)$ **120**, the server **104** may then compare the hash $H(T|k_3)$ **124** to the hash $H(T|k_3)$ **122**. Upon determining that the hash $H(T|k_3)$ **124** is consistent with the hash $H(T|k_3)$ **122**, the server **104** may cease to do any more comparisons.

In another example, in the case that the table **116** stores hash-dependent values, such as $F(H(T|k_i)|s)$, as described previously, where s is a seed value determined by trial and error and F is a hash algorithm that is the same as or different than the hash algorithm H, upon receipt of the hash $H(T|k_3)$ **124** from the client device **103**, the server **104** may compute a corresponding hash-dependent value $F(H(T|k_3)|s)$ for comparison with the hash-dependent values $F(H(T|k_i)|s)$ stored in the table **116**. It will be appreciated that, in this case, there will be no direct comparison between any portion of the hashes $H(T|k_1)$ **118**, $H(T|k_2)$ **120**, and $H(T|k_3)$ **122** and any portion of the hash $H(T|k_3)$ **124**.

In the case that only a portion of the hash $H(T|k_3)$ **124** or a value dependent thereon is used by the server **104** for comparison to portions of hashes or hash-dependent values stored tables of hash-dependent values, the client device **103** may only communicate the relevant portion of the hash $H(T|k_3)$ **124** or the relevant hash-dependent value to the server **104**. In this case, the portion of a particular hash $H(T|k_i)$ that is needed for comparison or the manner by which the hash-dependent value is to be determined may be broadcasted or otherwise communicated to the client device

103 by the server **104**. However, given that bandwidth may be inexpensive, it may be unnecessary to strictly limit the size of the portion of a particular hash H(T|k_i) that is communicated to the server **104**. It is noted that, unlike the client devices **100**, the server **104** may store the hash-dependent values for all provisioned client devices, and may therefore be in a position to check for collisions and resolve them using a secondary strategy, such as a modestly-sized secondary table to distinguish between hash-dependent values.

Returning to FIG. **1**, once the server **104** locates one of the stored hash-dependent values that is consistent with the received hash H(T|k_3) **124** or portion thereof or value dependent thereon, the server **104** may use the association to determine which one of the client-identifying keys **106** (or the indices **114**) is associated with the consistent hash-dependent value. In this case, since the stored hash H(T|k_3) **122** is consistent with the received hash H(T|k_3) **124**, the server **104** may proceed to use the association to determine that the hash H(T|k_3) **122** is associated with the client-identifying key k_3 **112** (or with the index 3). Now the server **104** may use the stored information (not shown) from which it is determinable which of the client-identifying keys **106** was assigned to which client device in order to determine which client device, if any, was provisioned with the client-identifying key k_3 **112** (or with the key having the index 3). In this case, the server **104** determines that it was the client device **103** that was provisioned with the client-identifying key k_3 **112**.

In this example, no two client devices were provisioned with the same one of the client-identifying keys **106**, and thus the client-identifying key k_3 **112** is unique to the client device **103**. It follows that the client device **103** may use the client-identifying key k_3 **112** to uniquely identify itself to the server, and it may do so in a way that cannot be understood by an eavesdropper. Furthermore, since the client device **103** is communicating a value that changes with each new time interval value T, it is not possible for the client device **103** to be tracked by an eavesdropper from one time interval value T to the next. The eavesdropper cannot predict which hash-dependent value will be communicated by the client device **103** during a future time interval value T.

As mentioned previously, the client device **103** may be susceptible to tracking by an eavesdropper during the period when the time interval value T remains unchanged. For this reason, it may be of interest to use short-length time interval values or to provision each client device with multiple sets of client-identifying keys, or both.

As also mentioned previously, the proposed technique is not resistant to replay attacks during the period when the time interval value T remains unchanged. For example, an eavesdropper could overhear the hash H(T|k_3) **124** that the client device **103** communicates to the server **104**. Even though the eavesdropper does not know the client-identifying key k_3 **112** from which the hash H(T|k_3) **124** was calculated, if the eavesdropper repeats the hash H(T|k_3) **124** to the server **104** before the time interval value T has changed, the eavesdropper will effectively be communicating the identity of the client device **103** to the server **104**, even though it is not the client device **103**. The eavesdropper may not even be aware of which client device it is purporting to be. Thus, the server **104** can only use a received hash to determine if the hash could have been communicated by a client device that was provisioned with one of the client-identifying keys **106**. For example, if the server **104** receives a message comprising a value that is not consistent with any of the hash-dependent values in the table **116** or in any other table of hash-dependent values (not shown), the server **104** can determine with certainty that the message does not identify a client device that was provisioned with one of the client-identifying keys **106**. Similarly, even if the value is consistent with one of the hash-dependent values in the table **116** or in any other table of hash-dependent values (not shown), but the consistent hash-dependent value is associated with a client-identifying key that was not provisioned to any client device, the server **104** can also determine with certainty that the message does not identify a client device that was provisioned with one of the client-identifying keys **106**. However, if the server **104** receives a message comprising a value that is consistent with one of the hash-dependent values in the table **116** or in any other table of hash-dependent values (not shown), and the consistent hash-dependent value does correspond to one of the client-identifying keys **106** that was provisioned to a particular client device, the server **104** can only determine that the message identifies that particular client device, and therefore could have been communicated by that particular client device. In other words, for a received message that includes a hash or portion thereof or value dependent thereon, the server **104** can either determine an identity of a single client device which could have legitimately sent the message, or determine that no legitimate client device could have sent the message. It is noted that, while it is theoretically possible for a hash of one value to be the same as the hash of another different value, it is astronomically unlikely.

It is also noted that, in the case that an attacker repeatedly prompts a client device to disclose an identity, it is possible that the attacker could measure the exact moment that the time interval value T of the client device changes, thereby permitting the attacker to track the client device in the future based on any discrepancy in the client device's clock. For example, the attacker might be able to track a particular client device based on that client device's clock being 12.6 seconds fast. This risk may be mitigated by having the client devices obtain the current time interval value T from the server **104**, by having the client devices regularly synchronize their clocks with a central authority, or by introducing a small random element into the timing of each client device, such that clock discrepancies between client devices cannot be accurately measured by an attacker.

For a server with a very large number of client devices, the simplified technique illustrated in FIG. **1** may impose a large computational burden. For example, if the server had to communicate with one hundred million client devices, the server would have to store at least one hundred million client-identifying keys in order for each client device to be provisioned with a unique client-identifying key. The server would also have to compute one-hundred million hashes at every new time interval value T, which might be unfeasible. It might also be unfeasible for the server to compare a received hash or portion thereof with one hundred million hashes or portions thereof. Although a high-end server might be able to handle such a load given a modestly-optimized implementation, power usage, key security and latency would suffer significantly. Furthermore, with a minimum of 3200 MB of key material (based on 128-bit keys), key management would pose a significant challenge.

The computational burden on the server could be reduced by provisioning more than one client-identifying key to each client device. For example, if the server were to store N client-identifying keys, and to provision each client device with a unique subset of Y of the N client-identifying keys, according to the equation for the binomial coefficient C(N, Y) with the number N of client-identifying keys being much larger than the number Y of client-identifying keys in the subset, the server would be able to uniquely provision approximately $N^Y/Y!$ client devices, where "Y!" denotes the factorial of the number Y. In one example, if the server stores N=1,000,000 client-identifying keys, and each client device is provisioned with a unique subset of Y=4 of the 1,000,000 client-identifying keys, the server would be able to uniquely provision approximately 4.17×10^{22} client devices. Thus, by provisioning each client device with more than one client-identifying key, the technique described with respect to FIG. **1** may be scaled for use with a much larger number of client devices. The size of the subset of client-identifying keys provisioned may vary from one client device to another.

Accordingly, FIG. **2** is a schematic diagram illustrating a second example technique for the provisioning of client-identifying keys by a server **200** to a plurality of client devices **101**, **102** and **103**, and the communication of the client device **103**'s provisioned client-identifying keys to the server **200**. In contrast to the example technique illustrated in FIG. **1**, the example technique illustrated in FIG. **2** involves the provisioning of a plurality of client-identifying keys to each one of the client devices **101**, **102** and **103**.

The server **200** may store or have access to N client-identifying keys (k_1, k_2, k_3, . . . , k_N) **202**. The N client-identifying keys **202** may be identified by N corresponding indices (1, 2, 3, . . . , N) **204**, where N may take on any positive integer value. In another example (not shown), each of the N client-identifying keys **202** may be identified by an arbitrary identifier. In yet another example (not shown), each of the N client-identifying keys **202** may effectively identify itself. Typically, the number N of client-identifying keys **202** will be less than the number of client devices that may communicate with the server **200**. In one example, the number N of client-identifying keys **202** is N=1,000,000.

Each one of the client-identifying keys **202** is a distinct value. In one example, each of the client-identifying keys **202** is an effectively random value, such that it cannot be generated again on another occasion, except by chance. In this case, the client-identifying keys **202** would be stored by the server **200** for future reference, for example, in a lookup table. In another example, each of the client-identifying keys **202** is a quasi-random or pseudo-random value generated using any suitable generation algorithm, such that the same client-identifying key **202** can be reliably generated on another occasion in a repeatable manner. For example, a particular client-identifying key k_i could be calculated as a hash of a concatenation of a random seed value s and an index i, that is $k_i=h(s|i)$, where h is any suitable hash algorithm, such as SHA-1, SHA-2, or MD5. In this case, the client-identifying keys **202** may not be stored by the server **200**, provided that the server **200** maintains a record of the conditions under which the client-identifying keys **202** were generated, including, for example, the hash algorithm h and the random seed value s. Each one of the client-identifying keys **202** may be of a sufficient length and complexity that it cannot be easily predicted or guessed by an attacker.

In the example illustrated in FIG. **2**, the server **200** assigns and provisions a subset of four of the N client-identifying keys **202** to each of the client devices **101**, **102** and **103**. In particular, the server **200** assigns a subset **206** of client-identifying keys (k_8, k_{13}, k_{24}, k_{62}) to the client device **101**, a subset **208** of client-identifying keys (k_1, k_{24}, k_{30}, k_{57}) to the client device **102**, and a subset **210** of client-identifying keys (k_3, k_{17}, k_{43}, k_{60}) to the client device **103**.

The subsets **206**, **208** and **210** of client-identifying keys may be embedded in the client devices **101**, **102** and **103**, respectively, at the time of manufacture, or provisioned at a later date, for example, via a storage module such as a SIM, or via transmission over a secure channel.

The assignment of a subset of the client-identifying keys **202** to each client device may be carried out in a random, pseudo-random or quasi-random fashion or may be carried out in an arbitrary fashion, and the server **200** may maintain a record (not shown) of which of the client-identifying keys **202** were provisioned to which client device, for example, in the form of a mapping function or a lookup table. Alternatively, the assignment of a subset of the client-identifying keys **202** to each client device may be carried out according to an algorithm. In either case, the server **200** may store information (not shown) from which it is determinable which of the client-identifying keys **202** were provisioned to which client device. Thus, the information may comprise the relevant mapping function, lookup table, algorithm or inverse thereof, or any other information by which the server **200** can determine which of the client-identifying keys **202** were provisioned to which client device, or can determine to which client device the subset of client-identifying keys **202** were assigned.

Alternatively, even if, at the time of assigning the client-identifying keys **202** to the client devices, the server **200** does not maintain any information from which it is determinable which of the client-identifying keys **202** were provisioned to which client device, it may still be possible for the server **200** to subsequently obtain such information, for example during registration of the provisioned client devices with a central infrastructure, as described previously with respect to FIG. **1**.

Since there are likely more client devices than client-identifying keys **202**, some client devices may share one or more of the same client-identifying keys. For example, in FIG. **2**, the client devices **101** and **102** have each been provisioned with the client-identifying key k_{24}. It is also possible that some of the client-identifying keys **202** may not yet be provisioned to any client device at all, or else that they may be provisioned to client devices that are not illustrated in FIG. **2**. In this example, it is assumed that no two client devices are provisioned with exactly the same subset of client-identifying keys **202**.

As described with respect to FIG. **1**, the server **200** may possess a time interval value T that changes from time to time and is agreed on by the server **200** and any provisioned client devices. For example, the server **200** might broadcast the current time interval value T. For each new time interval value T and for each of the client-identifying keys **202**, the server **200** may calculate a hash of a combination of at least the time interval value T and the client-identifying key using a hash algorithm H, as described with respect to FIG. **1**. In the example illustrated in FIG. **2**, the server **200** uses the hash algorithm H to compute hashes $H(T|k_1)$, $H(T|k_2)$, $H(T|k_3)$, . . . , $H(T|k_N)$. As described with respect to FIG. **1**, the server **200** may store each of the hashes $H(T|k_1)$, $H(T|k_2)$, $H(T|k_3)$, . . . , $H(T|k_N)$ in a table **212** or some other suitable data structure (not shown). Alternatively, the server **200** may store only portions of the hashes, or some other values dependent thereon.

As described with respect to FIG. **1**, in order to account for client devices that possess adjacent time interval values T, the server **200** may maintain one or more additional tables of hash-dependent values (not shown) determined from previous time interval values T or future time interval values T or both. Alternatively, the server **200** may maintain a single table that includes hash-dependent values determined from the present time interval value T and from previous time interval values T or future time interval values T or both.

For each table of hash-dependent values, the server **200** may associate each one of the hash-dependent values in the table with the respective one of the client-identifying keys **202** from which the hash-dependent value was determined (or with the respective one of the indices **204** of the client-identifying key **202** from which the hash-dependent value was determined). The association may be implemented as described previously with respect to FIG. **1**. In the example of FIG. **2**, the association (not shown) for the table **212** of hash-dependent values would associate each one of the hash-dependent values in the table **212** with a corresponding one of the client-identifying keys **202** (or with a corresponding one of the indices **204**).

The client device **103** may seek to communicate an identity to the server **200**, where the identity is an identity of the client device **103** or some other identity, such as an identity of a SIM card of the client device **103**. In the example of FIG. **2**, this may be done using the client-identifying keys (k_3, k_{17}, k_{43}, k_{60}) **210** with which the client device **103** was provisioned by the server **200**. For each of client-identifying keys (k_3, k_{17}, k_{43}, k_{60}) **210**, the client device **103** may calculate a hash by applying the hash algorithm H to a combination of at least the current time interval value T and the client-identifying key. The nature of the combination and the definition of the hash algorithm H are the same as that used by the server **200** to calculate the hashes $H(T|k_1)$, $H(T|k_2)$, $H(T|k_3)$, . . . , $H(T|k_N)$ as described previously. From these hash calculations, the client device **103** may obtain four hashes **214**: $H(T|k_3)$, $H(T|k_{17})$, $H(T|k_{43})$, and $H(T|k_{60})$. The client device **103** may communicate the hashes **214** to the server **200**, and, for each one of the hashes **214**, the server **200** may proceed to compare the hash or a portion thereof or a value dependent thereon to the hash-dependent values $H(T|k_1)$, $H(T|k_2)$, $H(T|k_3)$, . . . , $H(T|k_N)$ stored in the table **212**. In addition, for each one of the hashes **214**, the server **200** may optionally compare the hash or a portion thereof or a value dependent thereon to hash-dependent values stored in one or more additional tables (not shown) corresponding to one or more adjacent time interval values T. This may be done until the server **200** locates hash-dependent values that are consistent with each of the received hashes **214** or corresponding portions thereof or values dependent thereon.

In the case that the table **212** stores hash-dependent values, such as $F(H(T|k_i)|s)$, as described previously with respect to FIG. **1**, upon receipt of the hashes **214** $H(T|k_3)$, $H(T|k_{17})$, $H(T|k_{43})$, and $H(T|k_{60})$ from the client device **103**, the server **200** may compute corresponding hash-dependent values $F(H(T|k_3)|s)$, $F(H(T|k_{17})|s)$, $F(H(T|k_{43})|s)$, and $F(H(T|k_{60})|s)$ for comparison with the hash-dependent values $F(H(T|k_i)|s)$ stored in the table **212**.

In the case that only a portion of each of the hashes **214** $H(T|k_3)$, $H(T|k_{17})$, $H(T|k_{43})$, and $H(T|k_{60})$ or values dependent thereon are used by the server **200** for comparison to portions of hashes or hash-dependent values stored tables of hash-dependent values, the client device **103** may only communicate the relevant portions of the hashes **214** or the relevant hash-dependent values to the server **200**. In this case, the portion of each hash that is needed for comparison or the manner by which each hash-dependent value is to be determined may be broadcasted or otherwise communicated to the client device **103** by the server **200**.

Returning to FIG. **2**, once the server **200** locates stored hash-dependent values that are consistent with the received

hashes **214** or portions thereof or values dependent thereon, the server **200** may use the association to determine which of the client-identifying keys **202** (or the indices **204**) are associated with the consistent hash-dependent values. In this case, the server **200** may use the association to determine that the hash-dependent values that are consistent with the received hashes **214** or portions thereof or values dependent thereon are associated with the client-identifying keys k_3, k_{17}, k_{43}, k_{60} (or with the indices 3, 17, 43 and 60). Now the server **200** may use the stored information (not shown) from which it is determinable which of the client-identifying keys **202** were provisioned to which client device in order to determine which client device, if any, was provisioned with the client-identifying keys k_3, k_{17}, k_{43}, k_{60} (or with the keys having the indices 3, 17, 43 and 60). In this case, the server **200** determines that it was the client device **103** that was provisioned with the subset **210** of client-identifying keys (k_3, k_{17}, k_{43}, k_{60}).

In this example, no two client devices were provisioned with exactly the same subset of the client-identifying keys **202**, and thus the subset **210** of client-identifying keys (k_3, k_{17}, k_{43}, k_{60}) is unique to the client device **103**. It follows that the client device **103** may use the client-identifying keys (k_3, k_{17}, k_{43}, k_{60}) to uniquely identify itself to the server **200**, and it may do so in a way that cannot be understood or tracked by an eavesdropper from one time interval value to the next. It will be apparent to those of ordinary skill in the art that, if care is taken in provisioning, it may be possible for a client device to uniquely identify itself using only some of the client-identifying keys with which the client device was provisioned. For example, in this simple case, it will be apparent that the client device **103** could uniquely identify itself to the server **200** using any one of its subset **210** of client-identifying keys because none of the four client-identifying keys in the subset **210** was provisioned to any of the other client devices (i.e., client devices **101** and **102**).

Similarly to the technique described with respect to FIG. **1**, this technique is not resistant to replay attacks during the period when the time interval value T remains unchanged. For example, an eavesdropper could overhear the hashes **214** that the client device **103** communicates to the server **200**. Even though the eavesdropper does not know the client-identifying keys **210** to which the hashes **214** correspond, or the current time interval value T, if the eavesdropper repeats the hashes **214** to the server **200** before the time interval value T has changed, the eavesdropper will effectively be communicating the identity of the client device **103** to the server **200**, even though it is not the client device **103**. The eavesdropper may not even be aware of which client device it is purporting to be. Thus, the server **200** can only use received hash-dependent values to determine if the hash-dependent values could have been communicated by a client device that was provisioned with the subset **210** of client-identifying keys **202**. For example, if the server **200** receives a message comprising values that are not consistent with any subset of the stored hash-dependent values in the table **212** or in any other table of hash-dependent values (not shown), the server **200** can determine with certainty that the message does not identify a client device that was provisioned with a subset of the client-identifying keys **202**. Similarly, even if the server **200** receives a message comprising values that are consistent with a subset of the stored hash-dependent values stored in the table **212** or in another other table of hash-dependent values (not shown), but the consistent hash-dependent values are not associated with any subset of the client-identifying keys **202** that was provisioned to a client device, the server **200** can determine with certainty that the message does not identify a client device that was provisioned with a subset of the client-identifying keys **202**. However, if the server **200** receives a message comprising values that are consistent with a subset of the hash-dependent values stored in the table **212** or in any other table of hash-dependent values (not shown), and the consistent hash-dependent values correspond to a subset of the client-identifying keys **202** that was provisioned to a particular client device, the server **200** can only determine that the message identifies that particular client device, and therefore could have been communicated by that particular client device. In other words, for a received message that includes a subset of hashes or portions thereof or values dependent thereon, the server **200** can either determine an identity of a single client device which could have legitimately sent the message, or determine that no legitimate client device could have sent the message.

It will be apparent that, in the case that a particular client device can be uniquely identified using only some of the client-identifying keys with which it was provisioned, as discussed above, the server **200** could make this determination when the hash-dependent values received in the message are consistent with stored hash-dependent values that are associated with only some of the client-identifying keys of the subset provisioned to the particular client device.

While the servers **104** and **200** are each illustrated as a single device, it is contemplated that each of the servers **104** and **200** may comprise multiple devices. For example, each of the servers **104** and **200** may comprise one or more provisioning servers, each of which is configured to provision one or more client-identifying keys to one or more client devices. Each of the servers **104** and **200** may also comprise one or more receiving servers, each of which is able to receive a message purporting to be from a provisioned client device and determine whether the message could have been communicated by a provisioned client device. The calculation of the hashes and the determination of the hash-dependent values to be stored for a particular time interval value T may be performed by the one or more provisioning servers or by the one or more receiving servers or by some combination thereof. For example, the one or more provisioning servers may share information with the one or more receiving servers, such as any of the client-identifying keys and the information from which it is determinable which client-identifying keys were provisioned to which client device. In one example, the shared information is stored on one or more databases accessible by the one or more provisioning servers and the one or more receiving servers. In another example, in the case of more than one receiving server, each receiving server may only be able to identify a subset of the client devices that were provisioned by a provisioning server. For example, the receiving server may not have access to all of the client-identifying keys or to the information from which it is determinable which client-identifying keys were provisioned to which client device.

In a variation on this system, a given receiving server may not be permitted or able to identify all client devices that were provisioned by a provisioning server. For example, the receiving server may not have access to all of the client-identifying keys or hashes.

FIG. **3** is a flowchart illustrating an example method to be performed by a provisioning server for provisioning client-identifying keys to client devices.

The method begins at **300** by having the provisioning server store or have access to a plurality of N client-identifying keys ($k_1, k_2, \ldots, k_N$). The N client-identifying

keys may be identified by indices (1, 2, . . . , N), where N may take on any positive integer value. Alternatively, each of the client-identifying keys ($k_1, k_2, \ldots, k_N$) may be identified by an arbitrary identifier or may effectively identify itself. As described with respect to FIG. **2**, each one of the client-identifying keys ($k_1, k_2, \ldots, k_N$) is a distinct value, such as an effectively random value, a quasi-random or a pseudo-random value, or a value that can be reliably generated on another occasion in a repeatable manner. In the latter case, it will be appreciated that the server may not explicitly store the client-identifying keys ($k_1, k_2, \ldots, k_N$), provided that the server maintains a record of the conditions under which the client-identifying keys were generated. Each one of the client-identifying keys ($k_1, k_2, \ldots, k_N$) may be of a sufficient length and complexity that it cannot be easily predicted or guessed by an attacker.

At **302**, the provisioning server assigns to each client device j to be provisioned a unique subset of M_j client-identifying keys ($k_{C1}, k_{C2}, \ldots, k_{CMj}$) selected from the N client-identifying keys ($k_1, k_2, \ldots, k_N$), where M_j is a positive integer less than N. In the example illustrated in FIG. **1**, the number M_j of client-identifying keys in the subset for all client devices {j} is $M_j=1$, whereas, in the example illustrated in FIG. **2**, the number M_j of client-identifying keys in the subset for all client devices {j} is $M_j=4$. In other examples, some of the client devices {j} may have more client-identifying keys provisioned thereto than others of the client devices {j}. In the present example, all client devices {j} are provisioned with a subset of $M_j=M$ client-identifying keys. The assignment of the subsets of client-identifying keys to the client devices {j} may be carried out in a random, pseudo-random or quasi-random fashion or may be carried out in an arbitrary fashion, and the server may maintain a record of which of the N client-identifying keys ($k_1, k_2, \ldots, k_N$) were assigned to which client device j, for example, in the form of a mapping function or a lookup table. Alternatively, the assignment of the subsets of client-identifying keys to the client devices {j} may be carried out according to an algorithm. As noted previously, two or more client devices may be assigned one or more of the same client-identifying keys, provided that no two client devices are assigned the exact same subset of client-identifying keys ($k_{C1}, k_{C2}, \ldots, k_{CM}$). It is also possible that some of the client-identifying keys ($k_1, k_2, \ldots, k_N$) may not yet be assigned to any client device at all.

At **304**, the provisioning server may store information from which it is determinable which M client-identifying keys were assigned to which client device. The information may comprise the relevant mapping function, lookup table, algorithm or inverse thereof, or any other information by which the server can determine which of the client-identifying keys were provisioned to which client device. The provisioning server may store the information in a memory of the provisioning server or in one or more databases that are accessible by both the provisioning server and a receiving server. Alternatively, as described previously, the provisioning server may reconstruct a mapping function based on information subsequently obtained from provisioned client devices.

At **306**, the provisioning server provides to each client device to be provisioned the subset of M client-identifying keys ($k_{C1}, k_{C2}, \ldots, k_{CM}$) assigned to that client device. Each subset of M assigned keys ($k_{C1}, k_{C2}, \ldots, k_{CM}$) may be embedded in a client device at the time of manufacture, or provisioned at a later date, for example, via a storage module such as a SIM, or via a transmission over a secure channel.

In the case that the provisioning server reconstructs a mapping function based on information subsequently obtained from provisioned client devices, it will be appreciated that the provisioning of the client devices at **306** may precede the storing of the information at **304**.

FIG. **4** is a flowchart illustrating an example method to be performed by a provisioned client device for communicating its provisioned client-identifying keys to a receiving server.

At **400**, the client device receives a unique subset of M client-identifying keys (k_{C1}, k_{C2}, . . . , k_{CM}) from a provisioning server. As described above, the subset of M client-identifying keys may be embedded in the client device at the time of manufacture, or may be received at a later date.

At some point after being provisioned with its unique subset of M client-identifying keys (k_{C1}, k_{C2}, . . . , k_{CM}), the client device may determine at **402** that it has a need to communicate an identity to a server. For example, it may seek to request services from a web server which requires identification of the client device as a prerequisite to authentication of the client device.

Once the client device determines at **402** that it has a need to communicate an identity to the server, for each of the M client-identifying keys received at **400**, the client device may proceed at **404** to calculate a hash by applying a hash algorithm H to a combination of at least the current time interval value T and the client-identifying key, thereby obtaining M hashes: $H(T|k_{C1})$, $H(T|k_{C2})$, . . . , $H(T|k_{CM})$. Although not explicitly shown, the client device may receive one or more of the current time interval value T, an indication of the hash algorithm H, and an indication of the nature of the combination via a broadcast from the provisioning server or a receiving server.

At **406**, the client device communicates a message to the server comprising each of the M hashes $H(T|k_{C1})$, $H(T|k_{C2})$, . . . , $H(T|k_{CM})$ calculated at **404**. Alternatively, for each of the M hashes $H(T|k_{C1})$, $H(T|k_{C2})$, . . . , $H(T|k_{CM})$ calculated at **404**, the client device may communicate a message to the server comprising a portion of each hash or a value dependent thereon.

The methods described herein are based on the assumption that each client device is provisioned with the same number M of client-identifying keys. However, it will be apparent to a person of ordinary skill in the art that different client devices may be provisioned with different numbers of client-identifying keys, provided that no client device is provisioned with a subset of another client device's client-identifying keys. In one example, a client device may indicate in the message communicated at **406** the number of client-identifying keys to which the message pertains.

FIGS. **5-1** and **5-2** are flowcharts illustrating an example method to be performed by a receiving server for determining whether a received message identifies a provisioned client device and therefore could have been communicated by a client device that was provisioned with one or more client-identifying keys. The receiving server may be the same server as the provisioning server that is configured to perform the method illustrated in FIG. **3**. Alternatively, the receiving server may be a separate server from the provisioning server, but may share information with the provisioning server, including, for example, the plurality of client-identifying keys (k_1, k_2, . . . , k_N) and the information from which it is determinable which M_j client-identifying keys were assigned to which client device j. In one example, the shared information is stored on one or more databases accessible by both the provisioning server and the receiving server.

The example method illustrated in FIG. **5-1** begins at **500** by having the server store or have access to the N client-identifying keys (k_1, k_2, . . . , k_N). The server also stores or has access to the information from which it is determinable which M_j client-identifying keys (k_{C1}, k_{C2}, . . . , k_{CMj}) were assigned to which provisioned client device j. In this example, all client devices {j} have been provisioned with a subset of M_j=M client-identifying keys.

At **502**, the server calculates for each of the N client-identifying keys a hash of a combination of at least the current time interval value T and the client-identifying key, thereby obtaining N hashes: $H(T|k_1)$, $H(T|k_2)$, . . . , $H(T|k_N)$. The nature of the combination and hash algorithm H are the same as that used by the client device to calculate hashes at **404**.

At **504**, the server may store each of the N calculated hashes or portions thereof or values dependent thereon as hash-dependent values in a table or some other suitable data structure. Although not shown, the server may store one or more additional tables of hash-dependent values determined from previous time interval values T or future time interval values T or both. Alternatively, the server may maintain a single table that includes hash-dependent values determined from the present time interval value T and from previous time interval values T or future time interval values T or both.

At **506**, for each table of hash-dependent values, the server associates each one of the N hash-dependent values in the table with the respective one of the client-identifying keys from which the hash-dependent value was determined (or with the respective index of the one of the N client-identifying keys (k_1, k_2, . . . , k_N) from which the hash-dependent value was determined).

At **508**, the server checks whether it has received a message purporting to identify a provisioned client device. If the server does not receive any such message, and if the server determines at **510** that the time interval value T has increased, the server proceeds to repeat the calculation of the N hashes $H(T|k_1)$, $H(T|k_2)$, . . . , $H(T|k_N)$ at **502** using the new time interval value T. The server may then store new hash-dependent values at **504**, and, at **506**, associate each one of the new hash-dependent values with the respective one of the N client-identifying keys from which the new hash-dependent value was determined (or with the respective index of the one of the N client-identifying keys from which the hash-dependent value was determined). As noted above, since the server may store additional hash-dependent values determined from previous time interval values T or future time interval values T or both, the new hash-dependent values may or may not overwrite previously stored hash-dependent values. Several tables of hash-dependent values and associations, such as reverse maps, may be maintained at any one time.

Once the server determines at **508** that it has received a message purporting to identify a provisioned client device, the server may proceed to determine at **512** whether the message identifies a provisioned client device.

The determination made at **512** is described in more detail by the actions illustrated in FIG. **5-2**.

Since, in this example, all legitimate client devices were provisioned with a subset of M client-identifying keys, the server expects to receive M components in any message purporting to identify a provisioned client device. Thus, at **514**, the server extracts from the received message M components purporting to be the hashes $H(T|k_{C1})$, $H(T|k_{C2})$, . . . , $H(T|k_{CM})$ or portions thereof or values dependent thereon. Although not explicitly shown, the server may extract from the received message the M components purporting to be the hashes $H(T|k_{C1})$, $H(T|k_{C2})$, . . . , $H(T|k_{CM})$ or portions thereof, and the server may subsequently calculate values dependent thereon. Extraction of the M components may occur separately for each individual component. Alternatively, in the case that the components have been combined, for example, using a Bloom filter, extraction of the M components may be understood as referring to the extraction of the combination.

At **516**, the server compares each extracted component, or relevant portion thereof or value dependent thereon, to each value in the table of hash-dependent values stored at **504**, or optionally to hash-dependent values stored in one or more additional tables. This may be done until the server locates hash-dependent values that are consistent with each of the M components extracted at **512**.

At **518**, the server checks whether there are stored hash-dependent values that are consistent with each of the M extracted components or relevant portions thereof or values dependent thereon. If the server determines at **518** that one or more of the M components or a relevant portion thereof or value dependent thereon is not consistent with any stored hash-dependent value, the server can determine with certainty at **520** that the received message does not identify any provisioned client device.

If the server determines at **518** that each of the M components or relevant portions thereof or values dependent thereon is consistent with a stored hash-dependent value, the server may proceed to use the association at **522** to determine the client-identifying key (or the index of the client-identifying key) that is associated with each consistent hash-dependent value. At **524**, the server may then proceed to use the information stored at **500** (i.e., the information from which it is determinable which M client-identifying keys were assigned to which client device) to determine if the client-identifying keys determined at **522** were provisioned to a particular client device.

The server checks at **526** whether the client-identifying keys determined at **522** correspond to a subset that was provisioned to a particular client device. If the server determines at **526** that the subset of client-identifying keys determined at **522** was not provisioned to any particular client device, the server can proceed to determine with certainty at **520** that the message does not identify any provisioned client device. This may occur even if each of the M extracted components corresponds to a client-identifying key that was provisioned to a client device, but there is no single client device that has been provisioned with each of the client-identifying keys corresponding to the M extracted components. For example, with reference to FIG. **2**, if an eavesdropping device overhears two of the hashes communicated by the client device **101** to the server **200**, such as the hashes $H(T|k_8)$ and $H(T|k_{13})$, and the eavesdropping device also overhears two of the hashes communicated by the client device **102** to the server **200**, such as the hashes $H(T|k_{30})$ and $H(T|k_{57})$, the eavesdropping device may attempt to identify itself to the server **200** using a combination of the eavesdropped hashes: $H(T|k_8)$, $H(T|k_{13})$, $H(T|k_{30})$, $H(T|k_{57})$. While the server **200** would determine at **518** that each of the four components is consistent with a stored hash value, after using the association at **522** and the stored information at **524**, the server **200** would determine at **526** that the particular subset of client-identifying keys corresponding to the extracted components was not provisioned to any single client device. Thus, the server **200** would determine with certainty at **520** that the message did not identify any provisioned client device. However, it is possible that the combination of the eavesdropped hashes $H(T|k_8)$, $H(T|k_{13})$, $H(T|k_{30})$, $H(T|k_{57})$ could identify another client device not shown in FIG. **2**. The larger the number N of client-identifying keys, the less likely it is that that a combination of eavesdropped hashes or hash-dependent values from several client devices would allow an eavesdropper to communicate an identity of another client device.

If the server determines **526** that the subset of client-identifying keys determined at **522** was provisioned to a particular client device, the server may proceed to determine at **528** that the message identifies that particular provisioned client device. The server is only able to determine at **528** that the message could have been communicated by the particular client device that the message purports to identify. The sender of the message is communicating a purported identity to the server, but is not yet proving to the server that it legitimately possesses that identity. A client device may prove that it possess the identity it purports to possess as part of an authentication process. This is described in more detail with respect to FIG. **14**.

The proposed technique does not require the use of asymmetric cryptography or the use of symmetric cryptography. The proposed technique permits a client device's identity to be communicated in a way that cannot be understood by eavesdroppers, provided that the hash algorithm used is irreversible. While an eavesdropper may overhear the hash-dependent values communicated by a particular client device, the eavesdropper cannot determine the client-identifying keys from which the hash-dependent values were calculated, and therefore cannot infer the identity of the client device. Furthermore, since the hash-dependent values communicated by each client device change with each new time interval value T, it is not possible for a client device to be tracked by the eavesdropper from one time interval value T to the next. The eavesdropper cannot predict which hash-dependent values will be communicated by the client device during a future time interval value T.

An analysis of the performance of the proposed technique is presented herein using example parameters. In one example, the number N of client-identifying keys is N=1,000,000, and each one of the client-identifying keys is 160 bits in length. The hash algorithm H is SHA-1, which uses 512-bit blocks. This totals 64 MB of material to be hashed. According to the crypto++ 5.6.0 benchmarks page (www.cryptopp.com/benchmarks.html), an Intel® Core 2 at 1.83 GHz running a single core in 32-bit mode can compute a SHA-1 hash at a rate of 153 MB/s. This system should be able to complete the required 1,000,000 hash calculations in about two to three seconds, even with its modest CPU.

The server may build a table of hashes consisting of 2,000,000 32-bit buckets. The server may use the first 21 bits of a hash as an index into the table of hashes, and then store the next 12 bits of the hash and a 20-bit client-identifying key in the first free bucket. Very occasionally, the server will be required to test more than one possible consistent client-identifying key. The required storage space for such a table of hashes is approximately 8 MB. The server may be required to store two such tables of hashes, as the server will have to pre-compute the table of hashes for the next time interval value T before the current time interval ends. Thus, the server will need 16 MB of RAM to store the hash values and corresponding reverse index. Determining a subset of indices from a subset of hash values received in a message may take nearly constant time, and may take less time than that required for a single hash calculation. However, this time does not include the time required to perform a database lookup if random assignment of client-identifying keys were used.

The proposed technique may be used to communicate any identity without disclosing it to eavesdroppers. In one example, the concept may be applied to the communication of an identity of a group shared secret.

A server may authenticate a client device, for example, using a secret shared between the client device and the server, or a certificate signed by the server. In the case of the shared secret, the server has to spend time locating the secret in a database in order to authenticate the client device. In the case of the certificate, the server has to spend time performing computations in order to authenticate the client device.

When a server is bombarded with authentication requests by illegitimate client devices, the server's resources may become exhausted and the server may be unable to authenticate legitimate client devices. This is known as a Denial of Service (DOS) attack. To address this issue, U.S. patent application Ser. No. 13/083,981 to Suffling, herein incorporated by reference in its entirety, discloses a method whereby, prior to authentication, a client device may be pre-authenticated by proving its possession of a group shared secret that was previously provisioned to one or more legitimate client devices of the network server. Only those client devices that are in possession of the group shared secret may be successfully pre-authenticated and permitted to proceed to the more expensive step of authentication.

In one example, a provisioning server stores L group shared secrets. An authenticating server also maintains the set of L group shared secrets. The provisioning server provisions each client device j with a subset of P_j of the L group shared secrets. When one of the client devices seeks to authenticate itself to the authenticating server, it transmits a "pre-authentication" request to the authenticating server based on a selected one of the P_j group shared secrets with which it was provisioned. The pre-authentication request comprises some proof of knowledge of the selected group shared secret, such as a time-dependent hash of the group shared secret, together with an index or identifying number that identifies the selected group shared secret in the store of L group shared secrets. The authenticating server uses the received index value to locate the corresponding one of the L group shared secrets in its memory, and then calculates the hash of this group shared secret to determine if it matches the hashed value received from the client device. If there is a match, then the client device is pre-authenticated.

Because some client devices may share one or more of the same group shared secrets and the client device is only selecting one of its group shared secrets to communicate to the authenticating server, it is not uniquely identifying itself in its identification message. However, by including in the message the index of the group shared secret that it purports to possess, it is still communicating the identity of the selected group shared secret. This information could be used by an eavesdropper to track the client device. For example, an eavesdropper could overhear a particular client device communicating a message purporting to identify the group shared secret having index i. The next time the eavesdropper overhears a message purporting to identify the group shared secret having index i, the eavesdropper may be reasonably confident that the message originated at the particular client device. Using the index of the group shared secret selected by the particular client device, the eavesdropper may track the client device. To avoid this problem, the index of the group shared secret selected by the client device may be

communicated to the server without disclosing it to eavesdroppers by applying the proposed technique.

In the examples described with respect to FIGS. **6-13**, communication takes place over a public network (such as the Internet or a similar network), adapted to implement the Internet Protocol Suite (TCP/IP) as defined in RFC 1122 as published by the Internet Engineering Task Force, and optionally its predecessor, successor, and accompanying or complementary standards. Reference to a TCP/IP-based communication system is made due to its prevalence; again, however, the person skilled in the art will appreciate that the examples described herein may be applied in environments and on networks implementing different communication protocols. For example, other protocols such as the user datagram protocol (UDP), which may also be provided over IP, can be implemented as well.

FIG. **6** is a schematic diagram illustrating a first example technique for the provisioning of group shared secrets by a server **600** to a plurality of client devices **101**, **102** and **103**, and the communicating of the identity of the client device **103**'s provisioned group shared secret to the server **600**.

The server **600** may store or have access to L group shared secrets **602**, including group shared secrets gss_1 **604**, gss_2 **606** and gss_3 **608**. The L group shared secrets may be identified by L corresponding indices **610**, where L may take on any positive integer value. In another example (not shown), each of the L group shared secrets **602** may be identified by an arbitrary identifier. In yet another example (not shown), each of the L group shared secrets **602** may effectively identify itself Typically, the number L of group shared secrets **602** will be less than the number of client devices that may communicate with the server **600**. In one example, the number L of group shared secrets **602** is L=1,000,000. Each one of the group shared secrets **602** is a distinct value. In one example, each of the group shared secrets **602** is an effectively random value, such that it cannot be generated again on another occasion, except by chance. In this case, the group shared secrets **602** would be stored by the server **600** for future reference, for example, in a lookup table. In another example, each of the group shared secrets **602** is a quasi-random or pseudo-random value generated using any suitable generation algorithm, such that the same group shared secret **602** can be reliably generated on another occasion in a repeatable manner. For example, a particular group shared secret gss_i could be calculated as a hash of a concatenation of a random seed value s and an index i, that is $k_i=h(s|i)$, where h is any suitable hash algorithm, such as SHA-1, SHA-2, or MD5. In this case, the group shared secrets **602** may not be stored by the server **600**, provided that the server **600** maintains a record of the conditions under which the group shared secrets **602** were generated, including, for example, the hash algorithm h and the random seed value s. Each one of the group shared secrets **602** may be of a sufficient length that it cannot be easily predicted or guessed by an attacker.

The server **600** also stores N group shared secret identifying keys (k_1, k_2, k_3, k_4, k_5, . . . , k_N) **612**. The N group shared secret identifying keys may be identified by N corresponding indices (1, 2, 3, 4, 5, . . . , N) **614**, where N may take on any positive integer value. In another example (not shown), each of the N group shared secret identifying keys **612** may be identified by an arbitrary identifier. In yet another example (not shown), each of the N group shared secret identifying keys **612** may effectively identify itself. Typically, the number N of group shared secret identifying keys **612** will be less than the number of group shared secrets.

Each one of the group shared secret identifying keys **612** is a distinct value. In one example, each of the group shared secret identifying keys **612** is an effectively random value, such that it cannot be generated again on another occasion, except by chance. In this case, the group shared secret identifying keys **612** would be stored by the server **600** for future reference, for example, in a lookup table. In another example, each of the group shared secret identifying keys **612** is a quasi-random or pseudo-random value generated using any suitable generation algorithm, such that the same group shared secret identifying key **612** can be reliably generated on another occasion in a repeatable manner. For example, a particular group shared secret identifying key k_i could be calculated as a hash of a concatenation of a random seed value s and an index i, that is $k_i = h(s|i)$, where h is any suitable hash algorithm, such as SHA-1, SHA-2, or MD5. In this case, the group shared secret identifying keys **612** may not be stored by the server **600**, provided that the server **600** maintains a record of the conditions under which the group shared secret identifying keys **612** were generated, including, for example, the hash algorithm h and the random seed value s. Each one of the group shared secret identifying keys **612** may be of a sufficient length and complexity that it cannot be easily predicted or guessed by an attacker.

In the example illustrated in FIG. **6**, the server **600** assigns a subset of three of the N group shared secret identifying keys **612** to each one of the group shared secrets **602**. In particular, the server **600** assigns a subset **616** of group shared secret identifying keys (k_1, k_2, k_3) to the group shared secret gss_1 **604**, a subset **618** of group shared secret identifying keys (k_2, k_3, k_5) to the group shared secret gss_2 **606**, and a subset **620** of group shared secret identifying keys (k_2, k_4, k_5) to the group shared secret gss_3 **608**. The assignment of a subset of the group shared secret identifying keys **612** to each one of the group shared secrets **602** may be carried out in a random, pseudo-random or quasi-random fashion or may be carried out in an arbitrary fashion, and the server **600** may maintain a record (not shown) of which of the group shared secret identifying keys **612** were provisioned to which group shared secret, for example, in the form of a mapping function or a lookup table. Alternatively, the assignment of a subset of the group shared secret identifying keys **612** to each one of the group shared secrets **602** may be carried out according to an algorithm. In either case, the server **600** may store information (not shown) from which it is determinable which of the group shared secret identifying keys **612** were provisioned to which group shared secret. Thus, the information may comprise the relevant mapping function, lookup table, algorithm or inverse thereof, or any other information by which the server **600** can determine which of the group shared secret identifying keys **612** were provisioned to which group shared secret, or can determine to which group shared secret the subset of group shared secret identifying keys **612** were assigned.

Some of the group shared secrets **602** may share one or more of the same group shared secret identifying keys **612**. For example, in FIG. **6**, the group shared secrets gss_1 **604** and gss_3 **608** have each been assigned the group shared secret identifying key k_2. It is also possible that some of the group shared secret identifying keys **612** may not yet be assigned to any group shared secret at all, or else that they may be assigned to group shared secrets that are not illustrated in FIG. **6**. In this example, it is assumed that no two of the group shared secrets **602** are assigned exactly the same subset of the group shared secret identifying keys **612**.

In the example illustrated in FIG. **6**, the server **600** assigns and provisions to each of the client devices **101**, **102** and **103** a subset of two of the group shared secrets **602**. In particular, the server **600** provisions the group shared secrets gss_1 **604** and gss_2 **606** to the client device **101**, the group shared secrets gss_2 **606** and gss_3 **608** to the client device **102**, and the group shared secrets gss_1 **604** and gss_3 **608** to the client device **103**. In addition, for each group shared secret provisioned to a client device, the client device also receives the subset of group shared secret identifying keys assigned to that group shared secret. For example, the client device **103** receives the subset **616** of group shared secret identifying keys (k_1, k_2, k_3) for the group shared secret gss_1 **604** and the subset **620** of group shared secret identifying keys (k_2, k_4, k_5) for the group shared secret gss_3 **608**.

The subset of the group shared secrets **602** assigned to each client device, and the subset of group shared secret identifying keys **612** assigned to each group shared secret, may be embedded in the client device at the time of manufacture, or provisioned at a later date.

The assignment of a subset of the group shared secrets **602** to each client device may be carried out in a random, pseudo-random or quasi-random fashion or may be carried out in an arbitrary fashion. Alternatively, the assignment of a subset of the group shared secrets **602** to each client device may be carried out according to an algorithm.

As described with respect to FIG. **1** and FIG. **2**, the server **600** may possess a time interval value T that changes from time to time and is agreed on by the server **600** and any provisioned client devices. For example, the server **600** might broadcast the current time interval value T. For each new time interval value T, the server **600** may calculate for each of the group shared secret identifying keys **612** a hash of a combination of at least the time interval value T and the group shared secret identifying key using a hash algorithm H, as described previously. In the example of FIG. **6**, the server **600** uses the hash algorithm H to compute hashes $H(T|k_1)$, $H(T|k_2)$, $H(T|k_3)$, $H(T|k_4)$, $H(T|k_5)$, . . . , $H(T|k_N)$, which the server **600** may store in a table **622** or some other suitable data structure (not shown). Alternatively, the server **600** may store only portions of the hashes, or some other values dependent thereon. In order to account for client devices that possess adjacent time interval values T, the server **600** may maintain one or more additional tables of hash-dependent values (not shown) determined from previous time interval values T or future time interval values T or both. Alternatively, the server **600** may maintain a single table that includes hash-dependent values determined from the present time interval value T and from previous time interval values T or future time interval values T or both. Although this description indicates that the same hash algorithm H is used to compute the hashes for all group shared secret identifying keys, different hash algorithms could be used to compute the hashes for different ones of the group shared secret identifying keys. That is, a hash algorithm Ha could be used to compute the hash $Ha(T|k_1)$ and a different hash algorithm Hb could be used to compute the hash $Hb(T|k_2)$, provided that the provisioned client device also knows to use the hash algorithm Ha for computing $Ha(T|k_1)$ and the hash algorithm Hb for computing $Hb(T|k_2)$.

For each table of hash-dependent values, the server **600** may associate each one of the hash-dependent values with the respective one of the group shared secret identifying keys **612** from which the hash-dependent value was determined (or with the respective index of the group shared secret identifying key **612** from which the hash-dependent value was calculated). The association be implemented as described previously with respect to FIG. **1**. In the example of FIG. **6**, the association (not shown) for the table **622** of hash-dependent values would associate each one of the hash-dependent values in the table **622** with a corresponding one of the group shared secret identifying keys **612** (or with a corresponding one of the indices **614**).

The client device **103** may seek to communicate a group shared secret to the server **600**. In the example of FIG. **6**, the client device **103** selects the group shared secret gss$_3$ **608** to communicate to the server **600**. Thus, for each of the group shared secret identifying keys **620** corresponding to the group shared secret gss$_3$ **608**, the client device **103** may calculate a hash by applying the hash algorithm H to a combination of at least the current time interval value T **624** and the group shared secret identifying key. The nature of the combination and the definition of the hash algorithm H are the same as that used by the server **600** to calculate the hashes $H(T|k_1)$, $H(T|k_2)$, $H(T|k_3)$, $H(T|k_4)$, $H(T|k_5)$, . . . , $H(T|k_N)$ as described previously. From these hash calculations, the client device **103** may obtain three hashes **626**: $H(T|k_2)$, $H(T|k_4)$, and $H(T|k_5)$. In the same manner that the hashes **214** were used by the server **200** to arrive at the identity of the client device **103**, the server **600** may use the hashes **626** to arrive at the identity of the group shared secret gss$_3$ **608** selected by the client device **103**.

In addition to communicating an identity of a group shared secret, the client device may seek to prove to the server that it possesses the group shared secret that it has identified. This may be done by communicating an additional hash value to the server. In this example, the client device **103** calculates an additional hash by applying a hash algorithm G to a combination of at least the current time interval value T **624** (optionally), the selected group shared secret gss$_3$ **608**, and a value r **630**. From this hash calculation, the client device **103** may obtain a hash $G([T]|gss_3|r)$ **628**, where square brackets are used to indicate that the current time interval value T is optional. Alternatively, a different time interval value could be used in place of the time interval value T. The hash algorithm G used to obtain the hash **628** may be the same as or different than the hash algorithm H used to obtain the hash **626**. In one example, the value r is a pseudo-random value chosen by the client device, and is determined by applying a hash algorithm to a combination of the current time interval value T and a secret constant C_{CLIENT} specific to the client device.

The client device **103** communicates to the server **600** a message comprising the hashes **626**, the value r **630**, the current time interval value T **624**, and the hash **628**. The hashes **626** are included so that the client device **103** can communicate the identity of the group shared secret gss$_3$ **608** that it purports to possess. The hash **628** and the value r **630** are included so that the client device **103** may prove to the server **600** that it possesses the group shared secret gss$_3$ **608**. The value r may be used to detect replay attacks. For example, if the server **600** receives a message comprising a value r that is the same as the value r that was communicated in a previously received message, the server **600** may determine that the current message is a replay attack. In the case that the value r **630** is related in some way to the time interval value T **624**, a client device may be prevented from communicating multiple identification messages is rapid succession. Since the server **600** may be unable to keep a record of every value r ever used, using the time interval value T **624** in the calculation of the value r **630** may assure the server **600** that the value r **630** is not some old value that is being replayed. The current time interval value T **624** may also be included in the message so that the server **600** is privy to which value of the time interval value T was used

to calculate the hashes **626**, and optionally the hash **628**, and so that the server **600** may confirm that client device **103** possesses the correct time interval value T.

To determine the identity of the group shared secret that the client device **103** purports to possess, the server **600** proceeds to compare each one of the hashes **626** to the hashes in the table **622** stored on the server **600**. As described previously with respect to FIG. **1** and FIG. **2**, it will be appreciated that, in the case that the server **600** stores only portions of hashes or some other values dependent thereon in the table **622**, the server **600** may use corresponding portions of the hashes **626** or values dependent thereon for the comparison. Once the server **600** locates stored hash-dependent values that are consistent with the received hashes **626** or portions thereof or values dependent thereon, the server **600** may use the association to determine which of the group shared secret identifying keys **612** (or the indices **614**) are associated with the consistent hash-dependent values. In this case, the server **600** may use the association to determine that the hash-dependent values that are consistent with the received hashes **626** or portions thereof or values dependent thereon are associated with the group shared secret identifying keys k_2, k_4, k_5 (or with the indices 2, 4 and 5). Now the server **600** may use the stored information (not shown) from which it is determinable which of the group shared secret identifying keys **612** were assigned to which group shared secret in order to determine which one of the group shared secrets **702**, if any, was assigned the group shared secret identifying keys k_2, k_4, and k_5 (or with the keys having the indices 2, 4 and 5). In this case, the server **600** determines that it was the group shared secret gss$_3$ **608** that was assigned the subset **620** of group shared secret identifying keys (k_2, k_4, k_5).

In this example, no two group shared secrets were assigned exactly the same subset of the group shared secret identifying keys **612**, and thus the subset **620** of group shared secret identifying keys (k_2, k_4, k_5) is unique to the group shared secret gss$_3$ **608**. It follows that the client device **103** may use the group shared secret identifying keys (k_2, k_4, k_5) to uniquely identify its choice of group shared secret to the server **600**, and it may do so in a way that cannot be understood or tracked by an eavesdropper from one time interval value T to the next. It will be apparent to those of ordinary skill in the art that, if care is taken in provisioning, it may be possible for a client device to uniquely identify its choice of group shared secret using only some of the group shared secret identifying keys that were assigned to the group shared secret. For example, in this simple case, it will be apparent that the group shared secret gss$_3$ **608** could be uniquely identified to the server **200** using only the group shared secret identifying key k_4 because this key was not assigned to either of the other group shared secrets gss$_1$ or gss$_2$).

At this point, the client device **103** has only communicated to the server **600** the identity of the group shared secret that it purports to possess. It has not yet proven that it actually possesses the identified group shared secret. For example, an eavesdropping device overhearing the hashes **626** could repeat them to the server **600** during the same time interval value T **624**, and would also be purporting to possess the group shared secret gss$_3$ **608**. The eavesdropping device may not even be aware of which group shared secret it is purporting to possess.

In order to verify that the client device **103** actually possesses the group shared secret gss$_3$ **608** that it has identified, the server **600** may calculate an additional hash (not shown) by applying the hash algorithm G to a combination of at least the current time interval value T (optionally), the group shared secret gss_3 **608**, and the value r **630** that it received from the client device **103**. From this hash calculation, the server **600** may obtain a calculated hash $G([T]|gss_3|r)$ (not shown). The nature of the combination and definition of the hash algorithm G are the same as that used by the client device **103** to obtain the hash **628**. The server **600** may then compare the calculated hash (not shown) to the hash **628** received from the client device **103**. Alternatively, the server **600** may only compare corresponding portions of the calculated hash and the hash **628**, or values dependent thereon. If the hash-dependent values are consistent, the server **600** may determine that the client device **103** possesses the group shared secret key gss_3 **608** that it has identified.

While the server **600** is illustrated as a single device, it is contemplated that the server **600** may comprise multiple devices. For example, the server **600** may comprise one or more provisioning servers, each of which is configured to provision one or more of the group shared secrets **702** and the group shared secret identifying keys **612** to one or more client devices. The server **600** may also comprise one or more receiving servers, each of which is able to receive a message purporting to identify a group shared secret and prove the sender's possession of the identified group shared secret. The calculation of the hashes $H(T|k_1)$, $H(T|k_2)$, $H(T|k_3)$, $H(T|k_4)$, $H(T|k_5)$, . . . , $H(T|k_N)$ and the determination of the hash-dependent values to be stored in the table **622** for a particular time interval value T may be performed by the one or more provisioning servers or by the one or more receiving servers or by some combination thereof. For example, the one or more provisioning servers may share information with the one or more receiving servers, such as any of the group shared secrets **702**, any of the group shared secret identifying keys **612** and the information from which it is determinable which group shared secret identifying keys were assigned to which group shared secret. In one example, the shared information is stored on one or more databases accessible by the one or more provisioning servers and the one or more receiving servers. In another example, in the case of more than one receiving server, each receiving server may only be able to identify a subset of the group shared secrets. For example, the receiving server may not have access to all of the group shared secret identifying keys or to the information from which it is determinable which group shared secret identifying keys were provisioned to which group shared secret.

FIG. **7** is a flowchart illustrating a first example method to be performed by a provisioning server for provisioning group shared secrets to client devices.

The method begins at **700** by having the provisioning server store or have access to a plurality of L group shared secrets (gss_1, gss_2, . . . , gss_L), also denoted as group shared secrets $\{gss_q\}$. The L group shared secrets may be identified by indices (1, 2, . . . , L), where L may take on any positive integer value. Alternatively, each of the group shared secrets $\{gss_q\}$ may be identified by an arbitrary identifier or may effectively identify itself. The provisioning server also stores or has access to a plurality of N group shared secret identifying keys (k_1, k_2, . . . , k_N). The N group shared secret identifying keys may be identified by indices (1, 2, . . . , N). Alternatively, each of the group shared secret identifying keys (k_1, k_2, . . . , k_N) may be identified by an arbitrary identifier or may effectively identify itself.

Each one of the group shared secrets $\{gss_q\}$ and the group shared secret identifying keys (k_1, k_2, . . . , k_N) is a distinct value, such as an effectively random value, a quasi-random or a pseudo-random value, or a value that can be reliably generated on another occasion in a repeatable manner. In the latter case, it will be appreciated that the server may not explicitly store the group shared secrets $\{gss_q\}$ and/or the group shared secret identifying keys (k_1, k_2, . . . , k_N), provided that the server maintains a record of the conditions under which the group shared secrets and/or the group shared secret identifying keys were generated. Each one of the group shared secrets $\{gss_q\}$ and the group shared secret identifying keys (k_1, k_2, . . . , k_N) may be of a sufficient length and complexity that it cannot be easily predicted or guessed by an attacker

At **702**, the provisioning server assigns to each group shared secret gss_q a unique subset of M_q group shared secret identifying keys (k_{G1}, k_{G2}, . . . , k_{GMq}) selected from the N group shared secret identifying keys (k_1, k_2, . . . , k_N), where M_q is a positive integer less than N. In the example illustrated in FIG. **6**, the number M_q of group shared secret identifying keys in the subset for all group shared secrets $\{gss_q\}$ is $M_q=3$. In other examples, some of the group shared secrets $\{gss_q\}$ may have more group shared secret identifying keys provisioned thereto than others of the group shared secrets $\{gss_q\}$. In the present example, all group shared secrets $\{gss_q\}$ are provisioned with a subset of $M_q=M$ group shared secret identifying keys. The assignment of the subsets of group shared secret identifying keys to the group shared secrets $\{gss_q\}$ may be carried out in a random, pseudo-random or quasi-random fashion or may be carried out in an arbitrary fashion, and the server may maintain a record of which of the N group shared secret identifying keys (k_1, k_2, . . . , k_N) were assigned to which group shared secret gss_q, for example, in the form of a mapping function or a lookup table. Alternatively, the assignment of the subsets of group shared secret identifying keys to the group shared secrets $\{gss_q\}$ may be carried out according to an algorithm. As noted previously, two or more group shared secrets may be assigned one or more of the same group shared secret identifying keys, provided that no two group shared secrets are assigned the exact same subset (km, k_{G2}, . . . , k_{GM}) of the group shared secret identifying keys (k_1, k_2, . . . , k_N). It is also possible that some of the group shared secret identifying keys (k_1, k_2, . . . , k_N) may not be assigned to any group shared secret at all.

At **704**, the provisioning server may store information from which it is determinable which M group shared secret identifying keys were assigned to which group shared secret. The information may comprise the relevant mapping function, lookup table, algorithm or inverse thereof, or any other information by which the server can determine which of the group shared secret identifying keys were assigned to which group shared secret.

At **706**, the provisioning server assigns to each client device j to be provisioned a subset of P_j group shared secrets (gss_{C1}, gss_{C2}, . . . , gss_{CPj}) selected from the L group shared secrets (gss_j, gss_2, . . . , gss_L), where P_j is a positive integer less than L. In the example illustrated in FIG. **6**, the number P_j of group shared secrets in the subset for all client devices $\{j\}$ is $P_j=2$. In other examples, some of the client devices $\{j\}$ may have more group shared secrets provisioned thereto than others of the client devices $\{j\}$. In the present example, all client devices $\{j\}$ are provisioned with a subset of $P_j=P$ group shared secret identifying keys. The assignment of the subsets of group shared secrets to the client devices $\{j\}$ may be carried out in a random, pseudo-random or quasi-random fashion or may be carried out in an arbitrary fashion. Alternatively, the assignment of the subsets of group shared secrets to the client devices $\{j\}$ may be carried out according to an algorithm. Two or more client devices may be assigned one or more of the same group shared secrets. It is also possible that some of the group shared secrets $\{gss_q\}$ may not yet be assigned to any client device at all.

It should be noted that if two client devices are provisioned with an identical subset of P of the L group shared secrets, and all of those P group shared secrets are compromised, both of the client devices will be compromised as a result. To avoid this, each client device may be provisioned with a unique subset of P group shared secrets. Thus, if a client device happens to select from its subset a group shared secret that is compromised, it may still proceed to attempt to identify another one of its P group shared secrets.

At **708**, the provisioning server provides to each client device to be provisioned its respective assigned subset of P group shared secrets (gss_{C1}, gss_{C2}, . . . , gss_{CP}). In addition, for each one of the P group shared secrets (gss_{C1}, gss_{C2}, . . . , gss_{CP}), the provisioning server provides to the client device the unique subset of M group shared secret identifying keys (k_{G1}, k_{G2}, . . . , k_{GM}) assigned to that group shared secret. The subset of P group shared secrets (gss_{C1}, gss_{C2}, . . . , gss_{CP}) assigned to each client device, and the unique subset of M group shared secret identifying keys (k_{G1}, k_{G2}, . . . , k_{GM}) assigned to each group shared secret, may be embedded in a client device at the time of manufacture, or provisioned at a later date, for example, via a storage module such as a SIM, or via a transmission over a secure channel.

FIG. **8** is a flowchart illustrating a first example method to be performed by a provisioned client device for communicating one of its provisioned group shared secrets to a receiving server.

At **800**, the client device receives from a provisioning server a subset of P group shared secrets (gss_{C1}, gss_{C2}, . . . , gss_{CP}) and, for each one of the P group shared secrets, the client device receives a unique subset of M group shared secret identifying keys (k_{G1}, k_{G2}, . . . , k_{GM}). As described above, the subset of P group shared secrets (gss_{C1}, gss_{C2}, . . . , gss_{CP}), and the unique subset of M group shared secret identifying keys (k_{G1}, k_{G2}, . . . , k_{GM}) assigned to each group shared secret, may be embedded in the client device at the time of manufacture, or received at a later date.

At some point after being provisioned with its subset of group shared secrets (gss_{C1}, gss_{C2}, . . . , gss_{CP}) and the unique subsets of group shared secret identifying keys (k_{G1}, k_{G2}, . . . , k_{GM}) corresponding to each group shared secret, the client device may determine at **802** that it has a need to communicate a group shared secret to a server. For example, it may seek to pre-authenticate itself to a web server.

Once the client device determines at **802** that it has a need to communicate a group shared secret to the server, the client device may proceed at **804** to select one of its P group shared secrets (gss_{C1}, gss_{C2}, . . . , gss_{CP}) to communicate to the server. The selected group shared secret is denoted gss_{C1}.

At **806**, the client device may proceed to calculate, for each of the M group shared secret identifying keys assigned to the selected group shared secret gss_{Ci}, a hash by applying a hash algorithm H to a combination of at least the current time interval value T and the group shared secret identifying key, thereby obtaining M hashes: $H(T|k_{G1})$, $H(T|k_{G2})$, $H(T|k_{GM})$. Although not explicitly shown, the client device may receive one or more of the current time interval value T, an indication of the hash algorithm H, and an indication of the nature of the combination via a broadcast from the provisioning server or a receiving server.

At **808**, the client device calculates another hash by application a hash algorithm G to a combination of the current time interval value T (optionally), the selected group shared secret gss_{Ci}, and a value r, thereby obtaining a hash $G([T]|gss_{Ci}|r)$, where the value r is used to detect replay attacks as described previously.

At **810**, the client device communicates a message to the server comprising each one of the M hashes $H(T|k_{G1})$, $H(T|k_{G2})$, . . . , $H(T|k_{GM})$ calculated at **806**, the value r, the current time interval value T, and the hash $G([T]|gss_{Ci}|r)$ calculated at **808**. Alternatively to including each of the M hashes $H(T|k_{G1})$, $H(T|k_{G2})$, . . . , $H(T|k_{GM})$ in its entirety in the message, the client device may include only portions of the M hashes or values dependent thereon. Similarly, the client device may include a portion of the hash $G([T]|gss_{Ci}|r)$ or a value dependent thereon. The order of the values in the message may be agreed on by the server and the provisioned client devices.

The methods described herein are based on the assumption that each group shared secret is assigned the same number M of group shared secret identifying keys. However, it will be apparent to a person of ordinary skill in the art that different group shared secrets may be assigned different numbers of group shared secret identifying keys, provided that no group shared secret is assigned a subset of another group shared secret's group shared secret identifying keys. In one example, a client device may indicate in the message communicated at **810** the number of group shared secret identifying keys to which the message pertains.

FIGS. **9-1** and **9-2** are flowcharts illustrating a first example method to be performed by a receiving server for determining whether a received message from a client device identifies a group shared secret and whether the client device possesses the identified group shared secret. The receiving server may be the same server as the provisioning server that is configured to perform the method illustrated in FIG. **7**. Alternatively, the receiving server may be a separate server from the provisioning server, but may share information with the provisioning server, including, for example, the group shared secrets (gss_1, gss_2, . . . , gss_L), the group shared secret identifying keys (k_1, k_2, . . . , k_N) and the information from which it is determinable which M_q group shared secret identifying keys were assigned to which group shared secret gss_q. In one example, the shared information is stored on one or more databases accessible by the provisioning server and the receiving server.

The method illustrated in FIG. **9-1** begins at **900** by having the server store or have access to the L of group shared secrets (gss_1, gss_2, . . . , gss_L), as well as the N group shared secret identifying keys (k_1, k_2, . . . , k_N). The server also stores or has access to the information from which it is determinable which M_q group shared secret identifying keys (k_{G1}, k_{G2}, . . . , k_{GM}) were assigned to which group shared secret gss_q. In this example, all group shared secrets $\{gss_q\}$ have been assigned a subset M_q=M group shared secret identifying keys.

At **902**, the server calculates for each of the N group shared secret identifying keys a hash of a combination of at least the current time interval value T and the group shared secret identifying key, thereby obtaining N hashes: $H(T|k_1)$, $H(T|k_2)$, . . . , $H(T|k_N)$. The nature of the combination and the hash algorithm H are the same as that used by the client device to calculate hashes at **808**.

In another example, not shown in FIGS. **8** and **9-1**, the client device and the server may include the index of the group shared secret identifying key in each of the hash calculations performed at **806** and **902**, respectively. Thus, instead of calculating M hashes $H(T|k_{G1})$, $H(T|k_{G2})$, . . . , $H(T|k_{GM})$, the client device may calculate M hashes $H(T|G1|k_{G1})$, $H(T|G2|k_{G2})$, . . . , $H(T|GM|k_{GM})$. Similarly, instead of calculating N hashes $H(T|k_1)$, $H(T|k_2)$, . . . , $H(T|k_N)$, the server may calculate N hashes $H(T|1|k_1)$, $H(T|2|k_2)$, . . . , $H(T|N|k_N)$.

At **904**, the server may store each of the N calculated hashes or portions thereof or values dependent thereon as hash-dependent values in a table or some other suitable data structure. Although not shown, the server may store one or more additional tables of hash-dependent values determined from previous time interval values T or future time interval values T or both. Alternatively, the server may maintain a single table that includes hash-dependent values determined from the present time interval value T and from previous time interval values T or future time interval values T or both.

At **906**, for each table of hash-dependent values, the server associates each one of the N hash-dependent values in the table with the respective one of the N group shared secret identifying keys from which the hash-dependent value was determined (or with the respective index of the one of the N group shared secret identifying keys (k_1, k_2, . . . , k_N) from which the hash-dependent value was determined).

At **908**, the server checks whether it has received a message purporting to identify a group shared secret. If the server does not receive any such message, and if the server determines at **910** that the time interval value T has increased, the server proceeds to repeat the calculation of the N hashes $H(T|k_1)$, $H(T|k_2)$, . . . , $H(T|k_N)$ at **902** using the new time interval value T. The server may then store new hash-dependent values at **904**, and generate at **906** the association of each one of the new hash-dependent values with the respective one of the N group shared secret identifying keys from which the new hash-dependent value was determined (or with the respective index of the one of the N group shared secret identifying keys from which the hash-dependent value was determined). As noted above, since the server may store additional hash-dependent values determined from previous time interval values T or future time interval values T or both, the new hash-dependent values may or may not overwrite previously stored hash-dependent values. Several tables of hash-dependent values and associations may be maintained at any one time.

Once the server determines at **908** that it has received a message purporting to identify a group shared secret, the server may proceed to determine at **912** whether the message identifies a group shared secret and whether the client device from which the message was received possesses the identified group shared secret.

The determination made at **912** is described in more detail by the actions illustrated in FIG. **9-2**.

At **914**, the server extracts from the received message values purporting to be: the hashes $H(T|k_{G1})$, $H(T|k_{G2})$, . . . , $H(T|k_{GM})$ or portions thereof or values dependent thereon, as well as the value r, the current time interval value T, and the hash $G([T]|gss_{Ci}|r)$ or a portion thereof or value dependent thereon. Extraction of the components may occur separately for each individual component. Alternatively, in the case that the components have been combined, for example, using a Bloom filter, extraction of the components may be understood as referring to the extraction of the combination.

At **916**, the server compares each one of the M extracted hashes $H(T|k_{G1})$, $H(T|k_{G2})$, . . . , $H(T|k_{GM})$ or relevant portions thereof or values dependent thereon to each value in the table of hash-dependent values stored at **904**, or optionally to hash-dependent values stored in one or more additional tables. This may be done until the server locates

hash-dependent values that are consistent with each of the M extracted values in the received message.

At **918**, the server checks whether there are stored hash-dependent values that are consistent with each of the M extracted hashes $H(T|k_{G1})$, $H(T|k_{G2})$, . . . , $H(T|k_{GM})$ or relevant portions thereof or values dependent thereon. If the server determines at **918** that one or more of the M extracted hashes or relevant portions thereof or values dependent thereon are not consistent with any stored hash-dependent value, the server can determine with certainty at **920** that the client device is not identifying a group shared secret.

If the server determines at **918** that each of the M extracted hashes $H(T|k_{G1})$, $H(T|k_{G2})$, . . . , $H(T|k_{GM})$ or portions thereof or values dependent thereon is consistent with a stored hash-dependent value, the server may proceed to use the association at **922** to determine the group shared secret identifying key (or the index of the group shared secret identifying key) that is associated with each consistent hash-dependent value. At **924**, the server may use the information stored at **900** (i.e., the information from which it is determinable which M group shared secret identifying keys were assigned to which group shared secret) to determine which group shared secret gss_{Ci}, if any, was assigned the group shared secret identifying keys determined at **922**. Although not explicitly shown, if the server determines at **924** that there is no group shared secret that was assigned the group shared secret identifying keys determined at **922**, the server may determine that the client device is not identifying a group shared secret and the method may end.

In order to verify that the client device from which the message is received actually possesses the identified group shared secret gss_{Ci}, the server may calculate at **926** an additional hash by applying the hash algorithm G to a combination of at least the current time interval value T (optionally), the identified group shared secret gss_{Ci} identified at **924**, and the value r that it extracted from the received message at **914**. From this hash calculation, the server may obtain a calculated hash $G([T]|gss_{Ci}|r)$. The nature of the combination and definition of the hash algorithm G are the same as that used by the client device to obtain the hash at **808**. At **928**, the server may compare the calculated hash to the hash $G([T]|gss_{Ci}|r)$ that it extracted from the received message at **914**. Alternatively, the server may only compare corresponding portions of the calculated hash and the received hash, or values dependent thereon. The server checks at **930** whether the hashes are consistent. If the hashes are consistent, the server may determine at **934** that the client device possesses the group shared secret gss_{Ci} that it has identified. If the server determines at **930** that the hashes are not consistent, the server may determine at **932** that the client device does not possess the group shared secret gss_{Ci} that it has identified.

The proposed technique permits a client device to communicate its choice of group shared secret in a way that cannot be understood by eavesdroppers. While an eavesdropping device may overhear the hashes $H(T|k_{G1})$, $H(T|k_{G2})$, . . . , $H(T|k_{GM})$ or portions thereof or values dependent thereon communicated by a particular client device, the eavesdropping device cannot determine the group shared secret identifying keys from which the hash-dependent values were obtained, and therefore cannot infer the identity of the group shared secret. Furthermore, since the hash-dependent values communicated by each client device change with each new time interval value T, it is not possible for a client device to be tracked by the eavesdropping device from one time interval value T to the next.

Rather than identifying each group shared secret by a plurality of group shared secret identifying keys, it may be possible to simplify the technique by identifying each group shared secret by a single group shared secret identifying key. The technique may be further simplified if each group shared secret identifying key and the group shared secret that it identifies are in fact one and the same. This may be better understood with reference to FIGS. **10**-**13**.

FIG. **10** is a schematic diagram illustrating a second example technique for the provisioning of group shared secrets by a server **1000** to a plurality of client devices **101**, **102** and **103**, and the communicating of the identity of the client device **103**'s provisioned group shared secret to the server **1000**.

Similarly to the server **600** illustrated in FIG. **6**, the server **1000** may store or have access to L group shared secrets **702**, including group shared secrets gss_1**604**, gss_2 **606** and gss_3 **608**, and L corresponding indices **610**. Using this simplified technique, the server **1000** does not need to store a separate set of group shared secret identifying keys since the group shared secrets effectively identify themselves.

In the example illustrated in FIG. **10**, the server **1000** assigns and provisions to each of the client devices **101**, **102** and **103** a subset of two of the group shared secrets **702**. In particular, as described with respect to FIG. **6**, the server **600** provisions group shared secrets gss_1 **604** and gss_2 **606** to the client device **101**, a group shared secrets gss_2 **606** and gss_3 **608** to the client device **102**, and group shared secrets gss_1**604** and gss_3 **608** to the client device **103**.

As described with respect to FIG. **6**, for each new time interval value T, the server **1000** may calculate for each of the group shared secrets **702** a hash of a combination of at least the current time interval value T and the group shared secret. In the example of FIG. **10**, the server **1000** uses the hash algorithm H to compute hashes: $H(T|gss_1)$, $H(T|gss_2)$, $H(T|gss_3)$, . . . , $H(T|gss_L)$, which the server **1000** may store in a table **1022** or some other suitable data structure (not shown). Alternatively, the server **1000** may store only portions of the hashes, or some other values dependent thereon. The server **1000** may maintain one or more additional tables of hash-dependent values (not shown) determined from previous time interval values T or future time interval values T or both. Alternatively, the server **1000** may maintain a single table that includes hash-dependent values determined from the present time interval value T and from previous time interval values T or future time interval values T or both. For each table of hash-dependent values, the server **1000** may associate each one of the hash-dependent values with the respective one of the group shared secrets **702** from which the hash-dependent value was determine (or with the respective one of the indices **610**).

The client device **103** may seek to communicate a group shared secret to the server **1000**. In the example of FIG. **10**, the client device **103** selects the group shared secret gss_3 **608** to communicate to the server **1000**. Thus, the client device **103** may calculate a hash by applying the hash algorithm H to a combination of at least the current time interval value T **624** and the group shared secret gss_3 **608**. The nature of the combination and the definition of the hash algorithm H are the same as that used by the server **1000** to calculate the hashes $H(T|gss_1)$, $H(T|gss_2)$, $H(T|gss_3)$, . . . , $H(T|gss_L)$ as described previously. From this hash calculation, the client device **103** may obtain a hash $H(T|gss_3)$ **1002**. In contrast to the technique illustrated in FIG. **6**, instead of using the hashes $H(T|k_2)$, $H(T|k_4)$, and $H(T|k_5)$ **626** to communicate the identity of the group shared secret gss_3 **608** to the server, the client device **103** may use the single hash value $H(T|gss_3)$ **1002** to communicate the identity of the group shared secret gss_3 **608**.

As described with respect to FIG. **6**, the client device may also seek to prove to the server that it possesses the group shared secret that it has identified. As before, this may be done by having the client device **103** calculate the additional hash $G([T]|gss_3|r)$ **628**.

The client device **103** communicates to the server **1000** a message comprising the hash **1002**, the value r **630**, the current time interval value T **624**, and the hash **628**. The hash **1002** is included so that the client device **103** can communicate the identity of the group shared secret gss_3 **608** that it purports to possess. The hash **628** and the value r **630** are included so that the client device **103** may prove to the server **1000** that it possesses the group shared secret gss_3 **608**. The current time interval value T **624** may be included so that the server **1000** is privy to which value of the time interval value T was used to calculate the hash **1002**, and optionally the hash **628**, and so that the server **1000** may confirm that client device **103** possesses the correct time interval value T.

To determine the identity of the group shared secret that the client device **103** purports to possess, the server **1000** proceeds to compare the hash **1002** to the hashes in the table **1022** stored on the server **1000**. In the case that the server **1000** stores only portions of hashes or some other values dependent thereon in the table **1022**, the server **1000** may use a corresponding portion of the hash **1002** or a value dependent thereon for the comparison. Once the server **1000** locates a stored hash-dependent value that is consistent with the received hash **1002** or a portion thereof or value dependent thereon, the server **1000** may use the association to determine which of the group shared secrets **702** (or the indices **610**) is associated with the consistent hash-dependent value. In this case, the server **1000** may use the association to determine that the hash-dependent value that is consistent with the received hash **1002** or portion thereof or value dependent thereon is associated with the group shared secret gss_3 **608** (or with the index 3). By following the example technique illustrated in FIG. **10**, the client device **103** is effectively communicating an identity of its choice of group shared secret to the server **1000**, and is doing so in a way that cannot be understood or tracked by an eavesdropper from one time interval value T to the next.

At this point, the client device **103** has only communicated to the server **1000** the identity of the group shared secret that it purports to possess. It has not yet proven that it actually possesses the identified group shared secret. For example, an eavesdropping device overhearing the hash **1002** could repeat it to the server **1000** during the same time interval value T **624**, and would also be purporting to possess the group shared secret gss_3**608**. The eavesdropping device may not even be privy to which group shared secret is purporting to possess.

In order to verify that the client device **103** actually possesses the group shared secret gss_3**608** that it has identified, the server **1000** may calculate an additional hash (not shown) by applying the hash algorithm G to a combination of at least the current time interval value T (optionally), the group shared secret gss_3 **608**, and the value r **630** that it received from the client device **103**. From this hash calculation, the server **1000** may obtain a calculated hash $G([T]|gss_3|r)$ (not shown). The server **1000** may then compare the calculated hash (not shown) to the hash **628** received from the client device **103**. Alternatively, the server **1000** may only compare corresponding portions of the calculated hash and the hash **628**, or values dependent thereon. If the hash-dependent values are consistent, the server **1000** may determine that the client device **103** possesses the group shared secret key gss_3 **608** that it has identified.

While the server **1000** is illustrated as a single device, it is contemplated that the server **1000** may comprise multiple devices. For example, the server **1000** may comprise one or more provisioning servers, each of which is configured to provision one or more of the group shared secrets **702** to one or more client devices. The server **1000** may also comprise one or more receiving servers, each of which is able to receive a message purporting to identify a group shared secret and prove the sender's possession of the identified group shared secret. The calculation of the hashes **1022** and the determination of the hash-dependent values to be stored for a particular time interval value T may be performed by the one or more provisioning servers or by the one or more receiving servers or by some combination thereof. For example, the one or more provisioning servers may share information with the one or more receiving servers, such as any of the group shared secrets **702**. In one example, the shared information is stored on one or more databases accessible by the one or more provisioning servers and the one or more receiving servers. In another example, in the case of more than one receiving server, each receiving server may only be able to identify a subset of the group shared secrets. For example, the receiving server may not have access to all of the group shared secret identifying keys or to the information from which it is determinable which group shared secret identifying keys were provisioned to which group shared secret.

FIG. **11** is a flowchart illustrating a second example method to be performed by a provisioning server for provisioning group shared secrets to client devices.

The method begins at **1100** by having the provisioning server store or have access to a plurality of L group shared secrets (gss_1, gss_2, . . . , gss_L), also denoted as group shared secrets $\{gss_q\}$. The L group shared secrets may be identified by indices (1, 2, . . . , L), where L may take on any positive integer value. Alternatively, each of the group shared secrets $\{gss_q\}$ may be identified by an arbitrary identifier or may effectively identify itself. Each one of the group shared secrets $\{gss_q\}$ is a distinct value, such as an effectively random value, a quasi-random or a pseudo-random value, or a value that can be reliably generated on another occasion in a repeatable manner. In the latter case, it will be appreciated that the server may not explicitly store the group shared secrets $\{gss_q\}$, provided that the server maintains a record of the conditions under which the group shared secrets were generated. Each one of the group shared secrets $\{gss_q\}$ may be of a sufficient length and complexity that it cannot be easily predicted or guessed by an attacker

At **1102**, the provisioning server assigns to each client device j to be provisioned a subset of P_j group shared secrets (gss_{C1}, gss_{C2}, . . . , gss_{CPj}) selected from the L group shared secrets (gss_1, gss_2, . . . , gss_L), where P_j is a positive integer less than L. In the example illustrated in FIG. **10**, the number P_j of group shared secrets in the subset for all client devices $\{j\}$ is $P_j=2$. In other examples, some of the client devices $\{j\}$ may have more group shared secrets provisioned thereto than others of the client devices $\{j\}$. In the present example, all client devices $\{j\}$ are provisioned with a subset of $P_j=P$ group shared secret identifying keys. The assignment of the subsets of group shared secrets to the client devices $\{j\}$ may be carried out in a random, pseudo-random or quasi-random fashion or may be carried out in an arbitrary fashion. Alternatively, the assignment of the subsets of group shared secrets to the client devices $\{j\}$ may be carried out according to an algorithm. Two or more client devices may be assigned one or more of the same group shared secrets. It is also possible that some of the group shared secrets $\{gss_q\}$ may not yet be assigned to any client device at all.

At **1104**, the provisioning server provides to each client device to be provisioned its respective assigned subset of P group shared secrets (gss_{C1}, gss_{C2}, . . . , gss_{CP}). The subset of P group shared secrets (gss_{C1}, gss_{C2}, . . . , gss_{CP}) assigned to each client device may be embedded in a client device at the time of manufacture, or provisioned at a later date, for example, via a storage module such as a SIM, or via a transmission over a secure channel.

FIG. **12** is a flowchart illustrating a second example method to be performed by a provisioned client device for communicating one of its provisioned group shared secrets to a receiving server.

At **1200**, the client device receives from a provisioning server a subset of P group shared secrets (gss_{C1}, gss_{C2}, . . . , gss_{CP}). The P group shared secrets (gss_{C1}, gss_{C2}, . . . , gss_{CP}) may be embedded in the client device at the time of manufacture, or received at a later date.

At some point after being provisioned with its subset of group shared secrets (gss_{C1}, gss_{C2}, . . . , gss_{CP}), the client device may determine at **1202** that it has a need to communicate a group shared secret to a server.

Once the client device determines at **1202** that it has a need to communicate a group shared secret to the server, the client device may proceed at **1204** to select one of its P group shared secrets (gss_{C1}, gss_{C2}, . . . , gss_{CP}) to communicate to the server. The selected group shared secret is denoted gss_{Ci}.

At **1206**, the client device may proceed to calculate a hash by applying a hash algorithm H to a combination of at least the current time interval value T and the selected group shared secret gss_{Ci}, thereby obtaining a hash $H(T|gss_{Ci})$. Although not explicitly shown, the client device may receive one or more of the current time interval value T, an indication of the hash algorithm H, and an indication of the nature of the combination via a broadcast from the provisioning server or a receiving server.

At **1208**, the client device calculates another hash by application a hash algorithm G to a combination of the current time interval value T (optionally), the selected group shared secret gss_{Ci}, and a value r, thereby obtaining a hash $G([T]|gss_{Ci}|r)$, where the value r is used to detect replay attacks as described previously.

At **1210**, the client device communicates a message to the server comprising the hash $H(T|gss_{C1})$ calculated at **1206**, the value r, the current time interval value T, and the hash $G([T]|gss_{Ci}|r)$ calculated at **1208**. Alternatively to including the hash $H(T|gss_{C1})$ in its entirety in the message, the client device may include only a portion of the hash $H(T|gss_{C1})$ or a value dependent thereon. Similarly, the client device may include a portion of the hash $G([T]|gss_{Ci}|r)$ or a value dependent thereon. The order of the values in the message may be agreed on by the server and the provisioned client devices.

FIGS. **13-1** and **13-2** are flowcharts illustrating a second example method to be performed by a receiving server for determining whether a received message from a client device identifies a group shared secret and whether the client device possesses the identified group shared secret.

The receiving server may be the same server as the provisioning server that is configured to perform the method illustrated in FIG. **11**. Alternatively, the receiving server may be a separate server from the provisioning server, but may share information with the provisioning server, including, for example, the group shared secrets (gss_1, gss_2, . . . , gss_L). In one example, the shared information is stored on one or more databases accessible by both the provisioning server and the receiving server.

The method illustrated in FIG. **13-1** begins at **1300** by having the server store or have access to the L of group shared secrets (gss_1, gss_2, . . . , gss_L).

At **1302**, the server calculates for each of the L group shared secrets a hash of a combination of at least the current time interval value T and the group shared secret, thereby obtaining L hashes: $H(T|gss_1)$, $H(T|gss_2)$, . . . , $H(T|gss_L)$. The nature of the combination and the hash algorithm H are the same as that used by the client device to calculate hash at **1206**.

In another example, not shown in FIGS. **12** and **13-1**, the client device and the server may include the index of the group shared secret in the hash calculations performed at **1206** and **1302**, respectively. Thus, instead of calculating the hash $H(T|gss_{C1})$, the client device may calculate the hash $H(T|Ci|gss_{Ci})$. Similarly, instead of calculating L hashes $H(T|gss_1)$, $H(T|gss_2)$, . . . , $H(T|gss_L)$, the server may calculate L hashes $H(T|1|gss_i)$, $H(T|2|gss_2)$, . . . , $H(T|L|gss_L)$. As noted previously, including an index as salt in a hash calculation may make the hash value harder to attack.

At **1304**, the server may store each of the L calculated hashes or portions thereof or values dependent thereon as hash-dependent values in a table or some other suitable data structure. Although not shown, the server may store one or more additional tables of hash-dependent values determined from previous time interval values T or future time interval values T or both. Alternatively, the server may maintain a single table that includes hash-dependent values determined from the present time interval value T and from previous time interval values T or future time interval values T or both.

At **1306**, for each table of hash-dependent values, the server associates each one of the L hash-dependent values with the respective one of the L group shared secrets from which the hash-dependent value was determined (or with the respective index of the one of the L group shared secrets (gss_1, gss_2, . . . , gss_L) from which the hash-dependent value was determined).

At **1308**, the server checks whether it has received a message purporting to identify a group shared secret. If the server does not receive any such message, and if the server determines at **1310** that the time interval value T has increased, the server proceeds to repeat the calculation of the L hashes $H(T|gss_1)$, $H(T|gss_2)$, . . . , $H(T|gss_L)$ at **1302** using the new time interval value T. The server may then store new hash-dependent values at **1304**, and generate at **1306** the association that associates each one of the new hash-dependent values with the respective one of the L group shared secrets from which the new hash-dependent value was determined (or with the respective index of the one of the L group shared secrets from which the hash-dependent value was determined). As noted above, since the server may store additional hash-dependent values determined from previous time interval values T or future time interval values T or both, the new hash-dependent values may or may not overwrite previously stored hash-dependent values. Several tables of hash-dependent values and associations may be maintained at any one time.

Once the server determines at **1308** that it has received a message purporting to identify a group shared secret, the server may proceed to determine at **1312** whether the message identifies a group shared secret and whether the client device from which the message was received possesses the identified group shared secret.

The determination made at **1312** is described in more detail by the actions illustrated in FIG. **13-2**.

At **1314**, the server extracts from the received message values purporting to be: the hash $H(T|gss_{Ci})$ or a portion thereof or value dependent thereon, as well as the value r, the current time interval value T, and the hash $G([T]|gss_{Ci}|r)$ or a portion thereof or value dependent thereon. Extraction of the components may occur separately for each individual component. Alternatively, in the case that the components have been combined, for example, using a Bloom filter, extraction of the components may be understood as referring to the extraction of the combination.

At **1316**, the server compares the extracted hash $H(T|gss_{C1})$ or relevant portion thereof or value dependent thereon, to each value in the table of hash-dependent values stored at **1304**, or optionally to hash-dependent values stored in one or more additional tables. This may be done until the server locates a hash-dependent value that is consistent with the extracted value in the received message.

At **1318**, the server checks whether there is any stored hash-dependent value that is consistent with the extracted value $H(T|gss_{Ci})$ or relevant portion thereof or value dependent thereon. If the server determines at **1318** that the extracted hash $H(T|gss_{Ci})$ or relevant portion thereof or value dependent thereon is not consistent with any stored hash-dependent value, the server can determine with certainty at **1320** that the client device is not identifying a group shared secret.

If the server determines at **1318** that the extracted hash $H(T|gss_{Ci})$ or a portion thereof or value dependent thereon is consistent with a stored hash-dependent value, the server may proceed to use the association at **1322** to determine the group shared secret gss_{Ci} (or the index Ci of the group shared secret gss_{Ci}) that is associated with the consistent hash-dependent value.

In order to verify that the client device from which the message is received actually possesses the identified group shared secret gss_{Ci}, the server may calculate at **1324** an additional hash by applying the hash algorithm G to a combination of at least the current time interval value T (optionally), the group shared secret gss_{Ci} identified at **1322**, and the value r that it extracted from the received message at **1314**. From this hash calculation, the server may obtain a calculated hash value $G([T]|gss_{Ci}|r)$. The nature of the combination and definition of the hash algorithm G are the same as that used by the client device to obtain the hash **1208**. At **1326**, the server may compare the calculated hash to the hash $G([T]|gss_{Ci}|r)$ that it extracted from the received message at **1314**. Alternatively, the server may only compare corresponding portions of the calculated hash and the received hash, or values dependent thereon. The server checks at **1328** whether the hashes are consistent. If the hashes are consistent, the server may determine at **1332** that the client device possesses the group shared secret gss_{Ci} that it has identified. If the server determines at **1328** that the hashes are not consistent, the server may determine at **1330** that the client device does not possess the group shared secret gss_{Ci} that it has identified.

As described with respect to the technique and methods illustrated in FIGS. **6-9**, the technique and methods illustrated in FIGS. **10-13** allow a client device to communicate its choice of group shared secret in a way that cannot be understood by eavesdroppers. For example, while an eavesdropping device may overhear the hash $H(T|gss_{Ci})$ communicated by a particular client device, the eavesdropping device cannot determine the identity of the group shared secret from which the hash was obtained. Furthermore, since the hash communicated by each client device changes with each new time interval value T, it is not possible for a client device to be tracked by the eavesdropper from one time interval value T to the next.

FIG. **14** is a flowchart illustrating an example method to be performed by a server for identification and authentication of a client device.

At **1400**, the server receives from a client device a message purporting to identify a group shared secret and purporting to prove the client device's possession of the group shared secret that the message purports to identity.

At **1402**, the server determines whether the message identifies a group shared secret and whether the client device from which the message was received possesses the identified group shared secret. This determination may be made according to the method illustrated in FIGS. **9-1** and **9-2**, the method illustrated in FIGS. **13-1** and **13-2**, or any suitable variations thereof.

If the server determines at **1402** that the message does not identify a group shared secret or that the client device does not possess the group shared secret that the message identifies, the server may deny access to one or more services at **1404** and the method may end.

If the server determines at **1402** that the message does identify a group shared secret and that the client device possesses the identified group shared secret, the server may proceed to **1406**.

At **1406**, the server receives from the client device a purported identity of the client device. Then the server proceeds to determine at **1408** whether the purported identity of the client device is legitimate.
This determination may be made according to the method illustrated in FIGS. **5-1** and **5-2** or any suitable variation thereof.

The purported identity may be received in the same message received from the client device at **1400**, or in a different message. For example, the client device may communicate a message containing the M hashes $H(T|k_{C1})$, $H(T|k_{C2})$, . . . , $H(T|k_{CM})$ calculated at **504** or portions thereof or values dependent thereon, the M hashes $H(T|k_{G1})$, $H(T|k_{G2})$, . . . , $H(T|k_{GM})$ calculated at **806** or portions thereof or values dependent thereon, the value r, the current time interval value T, and the hash $G([T]|gss_{Ci}|r)$ calculated at **808** or a portion thereof or value dependent thereon. Alternatively, in place of the M hashes $H(T|k_{G1})$, $H(T|k_{G2})$, . . . , $H(T|k_{GM})$, the client device may include in the message the hash $H(T|gss_{Ci})$ calculated at **1206** or a portion thereof or value dependent thereon.

If the server determines at **1408** that the purported identity of the client device is not legitimate, the server may deny access to one or more services at **1404** and the method may end. If the server determines at **1408** that the purported identity of the client device is legitimate, the server may proceed to authenticate the client device at **1410**. There are numerous methods that may be used for authentication of the client device.

In one example, the client device may possess a unique key k_{CLIENT} that is known to the server. The client device may perform a hash of the unique key k_{CLIENT} and the current time interval value T and communicate the hash to the server. The server may then verify that the received hash is consistent with a corresponding hash of the server's copy of the unique key k_{CLIENT}. It should be noted, however, that this method of authentication would be vulnerable to replay attacks during the period that the time interval value T remains unchanged.

In another example, the client device may use public key cryptography to establish a secure link with the server. The client device may communicate a session key to the server using the server's public key signed by a private key of the client device.

In yet another example, the server may use symmetric cryptography to authenticate a client device. Once the server determines the purported identity of a client device, the server may locate a unique key k_{CLIENT}. The client may communicate a session key encrypted with the unique key k_{CLIENT}, and the server may use the copy of the unique key k_{CLIENT} that it has located in order to decrypt the session key. The session key may be used to establish a secure tunnel.

In yet another example, the client device may communicate to the server a session key encrypted with the server's public key, such that only the server is able to decrypt the session key.

Further details of possible authentication methods are beyond the scope of the present discussion.

It may be desirable to include one or more parameters necessary for authentication in a previous message communicated by the client device to the server. For example, an encrypted version of the unique key k_{CLIENT} may be included in the message that purports to include an identity of a group shared secret or an identity of a client device or both.

If the server determines at **1412** that the client device has not been successfully authenticated, the server may deny access to one or more services at **1404** and the method may end.

If the server determines at **1412** that the client device has been successfully authenticated, the server may provide to the client device access to one or more services at **1414**.

FIG. **15** is a block diagram of an example provisioning server **1500**, an example client device **1540**, and an example server **1580** configured to perform the example technique illustrated in FIG. **2**.

The provisioning server **1500** is an example of the server **200** when acting in a provisioning capacity. The provisioning server **1500** comprises a processor **1502** which is coupled to a memory **1504** and to a communication interface **1506** through which it is able to communicate with one or more client devices, such as the client device **1540**. The provisioning server **1500** may contain other elements which, for clarity, are not shown in FIG. **15**.

The client device **1540** is an example of any one of the client devices **100**. The client device **1540** comprises a processor **1542** which is coupled to a memory **1544** and to a communication interface **1546**. The client device **1540** may contain other elements which, for clarity, are not shown in FIG. **15**.

The server **1580** is an example of the server **200** when acting in a receiving capacity. The server **1580** comprises a processor **1582** which is coupled to a memory **1584** and to a communication interface **1586**. The server **1580** may contain other elements which, for clarity, are not shown in FIG. **15**.

The communication interfaces **1506**, **1546**, and **1586** may be wired communication interfaces or wireless communication interfaces. For example, the communication interfaces **1506**, **1546**, and **1586** may comprise any of Universal Serial Bus (USB) interfaces, Ethernet interfaces, Integrated Services Digital Network (ISDN) interfaces, Digital Subscriber Line (DSL) interfaces, Local Area Network (LAN) interfaces, High-Definition Multimedia (HDMI) interfaces, Digital Visual Interfaces (DVIs), or Institute of Electrical and Electronics Engineers (IEEE) 1394 interfaces such as i.LINK™, Lynx^{SM} or Firewire®. Alternatively, the communication interfaces **1606**, **1546**, and **1586** may be Wireless Local Area Network (WLAN) interfaces, short-range wireless communication interfaces such as Wireless Personal Area Network (WPAN) interfaces, Wireless Wide Area Network (WWAN) interfaces, or Wireless Metropolitan Area Network (WMAN) interfaces.

Each of the memories **1504**, **1544**, and **1584** is able to store agreed-on parameters **1510**. Any of the agreed-on parameters **1510** may be agreed on by two or more of the provisioning server **1500**, the client device **1540** and the server **1580**, depending on the particular parameter. For example, such parameters may include any hash algorithms to be used to for calculating hashes, such as the hash algorithms H and F, parameters indicative of the nature of any combination to which a hash algorithm is to be applied, parameters indicative of any additional operations to be performed on calculated hashes to obtain hash-dependent values, and parameters indicative of which portion of any hash or hash-dependent value is to be stored, communicated and/or compared. Although not explicitly shown, each of the memories **1504**, **1544**, and **1584** may comprise multiple memories or storage media. For example, cryptographic data may be stored in a different memory or storage medium than code.

The memory **1504** of the provisioning server **1500** is able to store code **1508** that, when executed by processor **1502**, results in the example method illustrated in FIG. **3**. Alternatively, the code **1508** may be stored in a different memory (not shown) than the memory **1504**. In another example, some portion of the example method illustrated in FIG. **3** may be performed by application-specific integrated circuits (ASICs) or other dedicated hardware, without involving execution of the code **1508** by the processor **1502**. The memory **1504** may also store applications (not shown) installed in the provisioning server **1500** to be executed by the processor **1502**.

In addition to the agreed-on parameters **1510**, the memory **1504** is also able to store a plurality of N client-identifying keys ($k_1, \ldots, k_N$) **1512**. Alternatively, the memory **1504** may store a record (not shown) of the conditions under which the client-identifying keys ($k_1, \ldots, k_N$) **1512** were generated. Although not explicitly shown, the memory **1504** may optionally store the N indices (1, . . . , N) by which the client-identifying keys ($k_1, \ldots, k_N$) **1512** are identified.

The provisioning server **1500**, being responsible for assigning to each client device to be provisioned a unique subset of the N client-identifying keys **1512**, may also store in the memory **1504** information **1514** from which it is determinable which of the N client-identifying keys **1512** were assigned to which client device. Alternatively, the information **1514** may be stored on one or more databases (not shown) that are accessible by the provisioning server **1500**.

As denoted by arrow **1520**, a subset of M client-identifying keys ($k_{C1}, \ldots, k_{CM}$) **1516** that were assigned by the provisioning server **1500** to the client device **1540** are able to be communicated, optionally with the corresponding indices (C1, . . . , CM) (not shown), by the provisioning server **1500** to the client device **1540**, where they may be stored in the memory **1544**. While not explicitly shown, the client-identifying keys ($k_{C1}, \ldots, k_{CM}$) **1516** may be communicated by the provisioning server **1500** via the communication interface **1506** and may be received by the client device **1540** via the communication interface **1546**, and optionally via one or more intermediate devices.

The memory **1544** of the client device **1540** is able to store code **1548** that, when executed by processor **1542**, results in the example method illustrated in FIG. **4**. Alternatively, the code **1548** may be stored in a different memory (not shown) than the memory **1544**. In another example, some portion of the example method illustrated in FIG. **4** may be performed by ASICs or other dedicated hardware, without involving execution of the code **1548** by the processor **1542**. The memory **1544** may also store applications (not shown) installed in the client device **1540** to be executed by the processor **1542**. Examples of such applications include data communication applications, voice communication applications, messaging applications, games, calculators, and the like.

The memory **1544** is able to store a current time interval value T **1550**, which may be used to calculate a hash of each of the client-identifying keys ($k_{C1}, \ldots, k_{CM}$) **1516** received from the server, thereby obtaining M hashes $H(T|k_{C1}), \ldots, H(T|k_{CM})$ **1552**. The memory **1544** may store each hash in its entirety, as shown in FIG. **15**, or alternatively may store only a portion of each hash or a value dependent thereon.

As denoted by arrow **1554**, a message comprising the hashes $H(T|k_{C1}), \ldots, H(T|k_{CM})$ **1552** or portions thereof or values dependent thereon is able to be communicated by the client device **1540** to the server **1580**. The server **1580** may extract the hashes **1552** or portions thereof or values dependent thereon from the message and store them in the memory **1584**. While not explicitly shown, the message comprising the hashes **1552** may be sent from the client device **1540** via the communication interface **1546** and may be received by the server **1580** via the communication interface **1586**, and optionally via one or more intermediate devices.

The memory **1584** of the server **1580** is able to store the N client-identifying keys ($k_1, \ldots, k_N$) **1512**, and optionally the corresponding N indices (1, . . . , N) (not shown). The memory **1584** is also able to store the information **1514** from which it is determinable which of the N client-identifying keys were assigned to which client device. The information may comprise a relevant mapping function, a lookup table, an algorithm or inverse thereof, or any other information by which the server **1580** can determine which of the client-identifying keys **1512** were provisioned to which client device. Alternatively, any of the client-identifying keys ($k_1, \ldots, k_N$) **1512** and the information **1514** may be stored on the one or more databases (not shown), which are accessible to the server **1580**.

The memory **1584** is able to store code **1588** that, when executed by the processor **1582**, results in the example method illustrated in FIGS. **5-1** and **5-2**. Alternatively, the code **1588** may be stored in a different memory (not shown) than the memory **1584**. In another example, some portions of the example methods illustrated in FIGS. **5-1** and **5-2** may be performed by ASICs or other dedicated hardware, without involving execution of the code **1588** by the processor **1582**. The memory **1584** may also store applications (not shown) installed in the server **1580** to be executed by the processor **1582**.

The memory **1584** is able to store a current time interval value T **1590**. The memory **1584** may optionally store one or more previous time interval values T or future time interval values T or both (not shown). The memory **1584** is able to store a table **1592** comprising hash-dependent values obtained from hash calculations performed on the client-identifying keys **1512** using the current time interval value T, as described previously. The memory **1584** is also able to store an association **1594** of each one of the hash-dependent values in the table **1592** with the one of the client-identifying keys **1512** from which it was calculated. The memory **1584** may optionally store one or more additional tables (not shown) of hash-dependent values and associations (not shown) determined from one or more previous time interval values T or future time interval values T or both.

FIG. **16** is a block diagram of an example provisioning server **1600**, an example client device **1640**, and an example server **1680** configured to perform the example technique illustrated in FIG. **6**.

The provisioning server **1600** is an example of the server **600** when acting in a provisioning capacity. The provisioning server **1600** comprises a processor **1602** which is coupled to a memory **1604** and to a communication interface **1606** through which it is able to communicate with one or more client devices, such as the client device **1640**. The provisioning server **1600** may contain other elements which, for clarity, are not shown in FIG. **16**.

The client device **1640** is an example of any one of the client devices **100**. The client device **1640** comprises a processor **1642** which is coupled to a memory **1644** and to a communication interface **1646**. The client device **1640** may contain other elements which, for clarity, are not shown in FIG. **16**.

The server **1680** is an example of the server **600** when acting in a receiving capacity. The server **1680** comprises a processor **1682** which is coupled to a memory **1684** and to a communication interface **1686**. The server **1680** may contain other elements which, for clarity, are not shown in FIG. **16**.

The communication interfaces **1606**, **1646**, and **1686** may be wired communication interfaces or wireless communication interfaces. For example, the communication interfaces **1606**, **1646**, and **1686** may comprise any of USB interfaces, Ethernet interfaces, ISDN interfaces, DSL interfaces, LAN interfaces, HDMI interfaces, DVIs, or IEEE 1394 interfaces such as i.LINK™, Lynx^{SM} or Firewire®. Alternatively, the communication interfaces **1606**, **1646**, and **1686** may be WLAN interfaces, short-range wireless communication interfaces such as WPAN interfaces, WWAN interfaces, or WMAN interfaces.

Each of the memories **1604**, **1644**, and **1684** is able to store agreed-on parameters **1610**. Any of the agreed-on parameters **1610** may be agreed on by two or more of the provisioning server **1600**, the client device **1640** and the server **1680**, depending on the particular parameter. For example, such parameters may include any hash algorithms to be used for calculating hashes, such as the hash algorithms H, G and F, parameters indicative of the nature of any combination to which a hash algorithm is to be applied, parameters indicative of any additional operations to be performed on calculated hashes to obtain hash-dependent values, and parameters indicative of which portion of any hash or hash-dependent value is to be stored, communicated and/or compared. Although not explicitly shown, each of the memories **1604**, **1644**, and **1684** may comprise multiple memories or storage media. For example, cryptographic data may be stored in a different memory or storage medium than code.

The memory **1604** of the provisioning server **1600** is able to store code **1608** that, when executed by processor **1602**, results in the example method illustrated in FIG. **7**. Alternatively, the code **1608** may be stored in a different memory (not shown) than the memory **1604**. In another example, some portion of the example method illustrated in FIG. **7** may be performed by ASICs or other dedicated hardware, without involving execution of the code **1608** by the processor **1602**. The memory **1604** may also store applications (not shown) installed in the provisioning server **1600** to be executed by the processor **1602**.

In addition to the agreed-on parameters **1610**, the memory **1604** is also able to store a plurality of L group shared secrets ($gss_1, \ldots, gss_L$) **1612**, as well as a plurality of N group shared secret identifying keys ($k_1, \ldots, k_N$) **1616**. Alternatively, the memory **1604** may store records (not shown) of the conditions under which the group shared secrets ($gss_1, \ldots, gss_L$) **1612** and/or the group shared secret identifying keys ($k_1, \ldots, k_N$) **1614** were generated. Although not explicitly shown, the memory **1604** may optionally store the L indices (1, . . . , L) by which the group shared secrets **1612** are identified and/or the N indices (1, . . . , N) by which the group shared secret identifying keys ($k_1, \ldots, k_N$) **1614** are identified.

The provisioning server **1600**, being responsible for assigning to each group shared secret a unique subset of the N group shared secret identifying keys, also stores in the memory **1604** information **1616** from which it is determinable which of the N group shared secret identifying keys were assigned to which of the group shared secrets **1612**.

Alternatively (not shown), any of the group shared secrets ($gss_1, \ldots, gss_L$) **1612**, the group shared secret identifying keys ($k_1, \ldots, k_N$) **1614**, and the information **1616** may be stored on one or more databases (not shown) that are accessible by the provisioning server **1600**.

As denoted by arrow **1622**, a subset of P group shared secrets ($gss_{C1}, \ldots, gss_{CP}$) **1618** that were assigned by the provisioning server **1600** to the client device **1640** are able to be communicated, optionally with the corresponding indices (C1, . . . , CP) (not shown), by the provisioning server **1600** to the client device **1640**. For each of the P group shared secrets **1618**, the provisioning server **1600** is also able to communicate the group shared secret identifying keys ($k_{G1}, \ldots, k_{GM}$) that were assigned to that group shared secret. This is denoted in FIG. **16** as the group shared secret identifying keys ($k_{G1}, \ldots, k_{GM}$)×P **1620**. While not explicitly shown, the group shared secrets ($gss_C1, \ldots, gss_{CP}$) **1618** and the group shared secret identifying keys ($k_{G1}, \ldots, k_{GM}$)×P **1620** may be communicated by the provisioning server **1600** via the communication interface **1606** and may be received by the client device **1640** via the communication interface **1646**, and optionally via one or more intermediate devices. The client device **1640** may store these received values in the memory **1644**.

The memory **1644** of the client device **1640** is able to store code **1648** that, when executed by processor **1642**, results in the example method illustrated in FIG. **8**. Alternatively, the code **1648** may be stored in a different memory (not shown) than the memory **1644**. In another example, some portion of the example method illustrated in FIG. **8** may be performed by ASICs or other dedicated hardware, without involving execution of the code **1648** by the processor **1642**. The memory **1644** may also store applications (not shown) installed in the client device **1640** to be executed by the processor **1642**.

The memory **1644** is able to store a current time interval value T **1650**, which it may use to calculate a hash of each of the group shared secret identifying keys ($k_{G1}, \ldots, k_{GM}$) **1652** that correspond to a group shared secret gss_{Ci} that it has selected from the received group shared secrets ($gss_{C1}, \ldots, gss_{CP}$) **1618** to communicate to the server **1680**. From these hash calculations, the client device **1640** is able to obtain M hashes $H(T|k_{G1}), \ldots, H(T|k_{GM})$ **1652**. The client device **1640** may store each hash in its entirety, as shown in FIG. **16**, or alternatively may store only a portion of each hash or a value dependent thereon.

The memory **1644** is also able to store a value r **1656**. The current time interval value T **1650** (optionally), the value r **1656** and the selected group shared secret gss_{Ci} are used to obtain the hash $G([T]|r|gss_{Ci})$ **1654**. The memory **1644** may store the hash in its entirety, as shown in FIG. **16**, or alternatively may store only a portion of the hash or a value dependent thereon.

As denoted by arrow **1658**, a message comprising the hashes **1652** or portions thereof or values dependent thereon, as well as the hash **1654** or portion thereof or value dependent thereon, and the value r **1656** and optionally the time interval value T **1650** is able to be communicated by the client device **1640** to the server **1680**. The server **1680** may extract the hashes **1652** or portions thereof or values dependent thereon, the hash **1654** or portion thereof or value dependent thereon, the value r **1656** and optionally the time interval value T **1650** from the message and store them in the memory **1684**. While not explicitly shown, the message may be sent from the client device **1640** via the communication interface **1646** and may be received by the server **1680** via the communication interface **1686**, and optionally via one or more intermediate devices.

The memory **1684** of the server **1680** is able to store the L group shared secrets $(gss_1, \ldots, gss_L)$ **1612** as well as the N group shared secret identifying keys $(k_1, \ldots, k_N)$ **1616**, and optionally the indices (1, . . . , L) and/or the indices (1, . . . , N). The memory **1684** is also able to store the information **1620** from which it is determinable which of the N group shared secret identifying keys were assigned to which of the group shared secrets **1612**. The information may comprise a relevant mapping function, a lookup table, an algorithm or inverse thereof, or any other information by which the server **1680** can determine which of the group shared secret identifying keys **1612** were assigned to which group shared secret. Alternatively, any of the group shared secrets $(gss_1, \ldots, gss_L)$ **1612**, the group shared secret identifying keys $(k_1, \ldots, k_N)$ **1614**, and the information **1620** may be stored on the one or more databases (not shown), which are accessible to the server **1680**.

The memory **1684** is able to store code **1688** that, when executed by the processor **1682**, results in the example method illustrated in FIGS. **9-1** and **9-2**. Alternatively, the code **1688** may be stored in a different memory (not shown) than the memory **1684**. In another example, some portions of the example methods illustrated in FIGS. **9-1** and **9-2** may be performed by ASICs or other dedicated hardware, without involving execution of the code **1688** by the processor **1682**. The memory **1684** may also store applications (not shown) installed in the server **1680** to be executed by the processor **1682**.

The memory **1684** is able to store a current time interval value T **1690**. The memory **1684** may optionally store one or more previous time interval values T or future time interval values T or both (not shown). The memory **1684** is able to store a table **1692** comprising hash-dependent values obtained from hash calculations performed on the group shared secret identifying keys **1616** using the current time interval value T, as described previously. The memory **1684** is also able to store an association **1694** of each one of the hash-dependent values in the table **1692** with the one of the group shared secret identifying keys **1614** from which it was calculated. The memory **1684** may optionally store one or more additional tables (not shown) of hash-dependent values and associations (not shown) determined from one or more previous time interval values T or future time interval values T or both.

FIG. **17** is a block diagram of an example provisioning server **1700**, an example client device **1740**, and an example server **1780** configured to perform the example technique illustrated in FIG. **10**.

The provisioning server **1700** is an example of the server **1000** when acting in a provisioning capacity. The provisioning server **1700** comprises a processor **1702** which is coupled to a memory **1704** and to a communication interface **1706** through which it is able to communicate with one or more client devices, such as the client device **1740**. The provisioning server **1700** may contain other elements which, for clarity, are not shown in FIG. **17**.

The client device **1740** is an example of any one of the client devices **100**. The client device **1740** comprises a processor **1742** which is coupled to a memory **1744** and to a communication interface **1746**. The client device **1740** may contain other elements which, for clarity, are not shown in FIG. **17**.

The server **1780** is an example of the server **1000** when acting in a receiving capacity. The server **1780** comprises a processor **1782** which is coupled to a memory **1784** and to a communication interface **1786**. The server **1780** may contain other elements which, for clarity, are not shown in FIG. **17**.

The communication interfaces **1706**, **1746**, and **1786** may be wired communication interfaces or wireless communication interfaces. For example, the communication interfaces **1706**, **1746**, and **1786** may comprise any of USB interfaces, Ethernet interfaces, ISDN interfaces, DSL interfaces, LAN interfaces, HDMI interfaces, DVIs, or IEEE 1394 interfaces such as i.LINK™, Lynx^{SM} or Firewire®. Alternatively, the communication interfaces **1706**, **1746**, and **1786** may be WLAN interfaces, short-range wireless communication interfaces such as WPAN interfaces, WWAN interfaces, or WMAN interfaces.

Each of the memories **1704**, **1744**, and **1784** is able to store agreed-on parameters **1710**. Any of the agreed-on parameters **1710** may be agreed on by two or more of the provisioning server **1700**, the client device **1740** and the server **1780**, depending on the particular parameter. For example such parameters may include any hash algorithms to be used for calculating hashes, such as the hash algorithms H, G and F, parameters indicative of the nature of any combination to which a hash algorithm is to be applied, parameters indicative of any additional operations to be performed on calculated hashes to obtain hash-dependent values, and parameters indicative of which portion of any hash or hash-dependent value is to be stored, communicated and/or compared. Although not explicitly shown, each of the memories **1704**, **1744**, and **1784** may comprise multiple memories or storage media. For example, cryptographic data may be stored in a different memory or storage medium than code.

The memory **1704** of the provisioning server **1700** is able to store code **1708** that, when executed by processor **1702**, results in the example method illustrated in FIG. **11**. Alternatively, the code **1708** may be stored in a different memory (not shown) than the memory **1704**. In another example, some portion of the example method illustrated in FIG. **11** may be performed by ASICs or other dedicated hardware, without involving execution of the code **1708** by the processor **1702**. The memory **1704** may also store applications (not shown) installed in the provisioning server **1700** to be executed by the processor **1702**.

In addition to the agreed-on parameters **1710**, the memory **1704** is also able to store a plurality of L group shared secrets ($gss_1, \ldots, gss_L$) **1712**. Alternatively (not shown), any of the group shared secrets ($gss_1, \ldots, gss_L$) **1712** may be stored on one or more databases (not shown) that are accessible by the provisioning server **1700**.

Alternatively, the memory **1704** may store records (not shown) of the conditions under which the group shared secrets ($gss_1, \ldots, gss_L$) **1712** were generated. Although not explicitly shown, the memory **1704** may optionally store the L indices (1, . . . , L) by which the group shared secrets **1712** are identified.

As denoted by arrow **1716**, a subset of P group shared secrets ($gss_{C1}, \ldots, gss_{CP}$) **1714** that were assigned by the provisioning server **1700** to the client device **1740** are able to communicated, optionally with the corresponding indices (C1, . . . , CP) (not shown), by the provisioning server **1700** to the client device **1740**. While not explicitly shown, the group shared secrets ($gss_{C1}, \ldots, gss_{CP}$) **1714** may be communicated by the provisioning server **1700** via the communication interface **1706** and may be received by the client device **1740** via the communication interface **1746**, and optionally via one or more intermediate devices. The client device may store these received values in the memory **1744**.

The memory **1744** of the client device **1740** is able to store code **1748** that, when executed by processor **1742**, results in the example method illustrated in FIG. **12**. Alternatively, the code **1748** may be stored in a different memory (not shown) than the memory **1744**. In another example, some portion of the example method illustrated in FIG. **12** may be performed by ASICs or other dedicated hardware, without involving execution of the code **1748** by the processor **1742**. The memory **1744** may also store applications (not shown) installed in the client device **1740** to be executed by the processor **1742**. Examples of such applications include data communication applications, voice communication applications, messaging applications, games, calculators, and the like.

The memory **1744** is able to store a current time interval value T **1750**, which it may use to calculate a hash of a group shared secret gss_{Ci} that it has selected from the received group shared secrets ($gss_{C1}, \ldots, gss_{CP}$) **1714**. From this calculation, the client device **1740** is able to obtain a hash $H(T|gss_{Ci})$ **1752**. The client device **1740** may store the hash in its entirety, as shown in FIG. **17**, or alternatively may store only a portion of the hash or a value dependent thereon.

The memory **1744** is also able to store a value r **1756**. The current time interval value T **1750** (optionally), the value r **1756** and the selected group shared secret gss_{Ci} are used to obtain the hash value $H([T]|r|gss_{Ci})$ **1754**. The memory **1744** may store the hash in its entirety, as shown in FIG. **17**, or alternatively may store only a portion of the hash or a value dependent thereon.

As denoted by arrow **1758**, a message comprising the hash **1752** or a portion thereof or value dependent thereon, as well as the hash **1754** or portion thereof or value dependent thereon, and the value r **1756** and optionally the time interval value T **1750** is able to be communicated by the client device **1740** to the server **1780**. The server **1780** may extract the hash **1752** or portion thereof or value dependent thereon, the hash **1754** or portion thereof or value dependent thereon, the value r **1756** and optionally the time interval value T **1750** from the message and store them in the memory **1784**. While not explicitly shown, the message may be sent from the client device **1740** via the communication interface **1746** and may be received by the server **1780** via the communication interface **1786**, and optionally via one or more intermediate devices.

The memory **1784** of the server **1780** is able to store the L group shared secrets ($gss_1, \ldots, gss_L$) **1712**, and optionally the indices (1, . . . , L).

The memory **1784** is able to store code **1788** that, when executed by the processor **1782**, results in the example method illustrated in FIGS. **13-1** and **13-2**. Alternatively, the code **1788** may be stored in a different memory (not shown) than the memory **1784**. In another example, some portions of the example methods illustrated in FIGS. **13-1** and **13-2** may be performed by ASICs or other dedicated hardware, without involving execution of the code **1788** by the processor **1782**. The memory **1784** may also store applications (not shown) installed in the server **1780** to be executed by the processor **1782**.

The memory **1784** is able to store a current time interval value T **1790**. The memory **1784** may optionally store one or more previous time interval values T or future time interval values T or both (not shown). The memory **1784** is able to store a table **1792** comprising hash-dependent values obtained from hash calculations performed on the group shared secrets **1714** using the current time interval value T, as described previously. The memory **1784** is also able to store an association **1794** of each one of the hash-dependent values in the table **1792** with the one of the group shared secret **1712** from which it was calculated. The memory **1784** may optionally store one or more additional tables (not shown) of hash-dependent values and associations (not shown) determined from one or more previous time interval values T or future time interval values T or both.

What is claimed is:

1. A method to be performed by a server, the method comprising:
- storing information from which it is determinable which unique subset of M_q of N group shared secret identifying keys was assigned to each of L group shared secrets $\{gss_q\}$, where L, N, and M_q are positive integers and M_q is less than N;
- when there is a change in a modulating value:
  - calculating for each of the N group shared secret identifying keys a hash of a combination comprising the group shared secret identifying key and the modulating value;
  - determining a hash-dependent value for each hash; and
  - associating each hash-dependent value with the group shared secret identifying key from which the corresponding hash was calculated or with an index of the group shared secret identifying key from which the corresponding hash was calculated;
- receiving a message purporting to identify one of the L group shared secrets $\{gss_q\}$; and
- determining whether the message identifies one of the L group shared secrets $\{gss_q\}$.

2. The method as claimed in claim **1**, wherein determining whether the message identifies one of the group shared secrets $\{gss_q\}$ comprises:
- extracting from the message M_q components, each of the M_q components purporting to be a hash-dependent value determined from a hash of a combination comprising one of the group shared secret identifying keys and a current instance of the modulating value;
- determining for each of the M_q components whether the component is consistent with any of the hash-dependent values;

where each of the M_q components is consistent with one of the hash-dependent values, using the association to determine the group shared secret identifying key that is associated with the consistent hash-dependent value;

using the stored information to determine whether the group shared secret identifying keys associated with the consistent hash-dependent values correspond to any of the unique subsets of group shared secret identifying keys that were assigned to the L group shared secrets $\{gss_q\}$; and

where the group shared secret identifying keys correspond to one of the unique subsets of client-identifying keys that was assigned to a particular one of the group shared secrets $\{gss_q\}$, determining that the message identifies the particular one of the group shared secrets $\{gss_q\}$.

3. The method as claimed in claim **2**, wherein determining whether the component is consistent with any of the hash-dependent values comprises determining whether a portion of the component is consistent with a corresponding portion of any of the hash-dependent values.

4. The method as claimed in claim **1**, further comprising:

determining whether the message was received from a client device that possesses the particular one of the group shared secrets $\{gss_q\}$.

5. The method as claimed in claim **4**, wherein determining whether the message was received from a client device that possesses the particular one of the group shared secrets $\{gss_q\}$ comprises:

extracting from the message a value purporting to be a value r and a value purporting to be a hash of a combination comprising the particular one of the group shared secrets $\{gss_q\}$ and the value r, wherein r is a positive integer;

calculating a hash of a combination comprising the particular one of the group shared secrets $\{gss_q\}$ and the extracted value purporting to be the value r;

comparing the calculated hash of the combination to the extracted value purporting to be the hash of the combination; and

where the values are consistent with one another, determining that the message was received from a client device that possesses the particular one of the group shared secrets $\{gss_q\}$.

6. A method to be performed by a server, the method comprising:

when there is a change in a modulating value:

calculating for each of L group shared secrets $\{gss_q\}$ a hash of a combination comprising the group shared secret gss_q and the modulating value, wherein L is a positive integer;

determining a hash-dependent value for each hash; and

associating each hash-dependent value with the group shared secret from which the corresponding hash was calculated or with an index of the group shared secret from which the corresponding hash was calculated;

receiving a message purporting to identify a particular one of the L group shared secrets $\{gss_q\}$; and

determining whether the message identifies the particular one of the group shared secrets $\{gss_q\}$.

7. The method as claimed in claim **6**, wherein determining whether the message identifies the particular one of the group shared secrets $\{gss_q\}$ comprises:

extracting from the message a value purporting to be a hash-dependent value determined from a hash of a

combination comprising the particular one of the group shared secrets $\{gss_q\}$ and a current instance of the modulating value;

determining whether the extracted value is consistent with any of the hash-dependent values;

where the extracted value is consistent with one of the hash-dependent values, using the association to determine the group shared secret that is associated with the consistent hash-dependent value.

8. A server comprising:

a communication interface through which the server is able to receive a message purporting to identify a particular group shared secret from L group shared secrets $\{gss_q\}$; and

a memory storing information from which it is determinable which unique subset of M_q of N group shared secret identifying keys was assigned to each of the L group shared secrets $\{gss_q\}$, wherein the server, when there is a change in a modulating value, is operative:

to calculate for each of the N group shared secret identifying keys a hash of a combination comprising the group shared secret identifying key and the modulating value;

to determine a hash-dependent value for each hash; and

to associate each hash-dependent value with the group shared secret identifying key from which the corresponding hash was calculated or an index of the group shared secret identifying key from which the corresponding hash was calculated;

wherein the server is further operative to determine whether the message identifies one of the L group shared secrets $\{gss_q\}$, and

wherein L, N, and M_q are positive integers and M_q is less than N.

9. The server as claimed in claim **8**, wherein determining whether the message identifies the particular one of the group shared secrets $\{gss_q\}$ comprises:

extracting from the message M_q components, each of the M_q components purporting to be a hash-dependent value determined from a hash of a combination comprising one of the group shared secret identifying keys and a current instance of the modulating value;

determining for each of the M_q components whether the component is consistent with any of the hash-dependent values;

where each of the M_q components is consistent with one of the hash-dependent values, using the association to determine the group shared secret identifying key that is associated with the consistent hash-dependent value;

using the information to determine whether the group shared secret identifying keys associated with the consistent hash-dependent values correspond to any of the unique subsets of group shared secret identifying keys that were assigned to the L group shared secrets $\{gss_q\}$; and

where the group shared secret identifying keys correspond to one of the unique subsets of client-identifying keys that was assigned to a particular one of the group shared secrets $\{gss_q\}$, determining that the message identifies the particular one of the group shared secrets $\{gss_q\}$.

10. The server as claimed in claim **9**, wherein determining whether the component is consistent with any of the hash-dependent values comprises determining whether a portion of the component is consistent with a corresponding portion of any of the hash-dependent values.

11. The server as claimed in claim **8**, wherein the server is further operative to determine whether the message was received from a client device that possesses the particular one of the group shared secrets $\{gss_q\}$.

12. The server as claimed in claim **11**, wherein determining whether the message was received from a client device that possesses the particular one of the group shared secrets $\{gss_q\}$ comprises:

extracting from the message a value purporting to be a value r and a value purporting to be a hash of a combination comprising the one of the particular group shared secrets $\{gss_q\}$ and the value r, wherein r is a positive integer;

calculating a hash of a combination comprising the particular one of the group shared secrets $\{gss_q\}$ and the extracted value purporting to be the value r;

comparing the calculated hash of the combination to the extracted value purporting to be the hash of the combination; and

where the values are consistent with one another, determining that the message was received from a client device that possesses the particular one of the group shared secrets $\{gss_q\}$.

13. A server comprising:

a communication interface through which the server is able to receive a message purporting to identify a particular one of L group shared secrets $\{gss_q\}$, wherein L is a positive integer;

wherein the server, when there is a change in a modulating value, is operative:

to calculate for each of the L group shared secrets $\{gss_q\}$ a hash of a combination comprising the group shared secret gss_q and the modulating value;

to determine a hash-dependent value for each hash; and

to associate each hash-dependent value with the group shared secret from which the corresponding hash was calculated or with an index of the group shared secret from which the corresponding hash was calculated;

wherein the server is further operative to determine whether the message identifies the particular one of the L group shared secrets $\{gss_q\}$.

14. The server as claimed in claim **13**, wherein determining whether the message identifies the particular one of the group shared secrets $\{gss_q\}$ comprises:

extracting from the message a value purporting to be a hash-dependent value determined from a hash of a combination comprising the particular one of the group shared secrets and a current instance of the modulating value;

determining whether the extracted value is consistent with any of the hash-dependent values;

where the extracted value is consistent with one of the hash-dependent values, using the association to determine the group shared secret that is associated with the consistent hash-dependent value.

15. A non-transitory computer-readable medium storing information from which it is determinable which unique subset of M_q of N group shared secret identifying keys was assigned to each of L group shared secrets $\{gss_q\}$, the computer-readable medium further storing code which, when executed by a processor of a server, causes the server, when there is a change in a modulating value:

to calculate for each of the N group shared secret identifying keys a hash of a combination comprising the group shared secret identifying key and the modulating value;

to determine a hash-dependent value for each hash; and

to associate each hash-dependent value with the group shared secret identifying key from which the corresponding hash was calculated or with an index of the group shared secret identifying key from which the corresponding hash was calculated,

wherein the code, when executed by the processor, further results in the server determining whether a message received through a communication interface of the server and purporting to identify a particular group shared secret from the L group shared secrets $\{gss_q\}$ identifies one of the L group shared secrets $\{gss_q\}$, and

wherein L, N, and M_q are positive integers and M_q is less than N.

16. A non-transitory computer-readable medium storing code which, when executed by a processor of a server, causes the server, when there is a change in a modulating value:

to calculate for each of L group shared secrets $\{gss_q\}$ a hash of a combination comprising the group shared secret gss_q and the modulating value, wherein L is a positive integer;

to determine a hash-dependent value for each hash; and

to associate each hash-dependent value with the group shared secret from which the corresponding hash was calculated or with an index of the group shared secret from which the corresponding hash was calculated,

wherein the code, when executed by the processor, further results in the server determining whether a message received through a communication interface of the server and purporting to identify a particular one of the L group shared secrets $\{gss_q\}$ identifies the particular one of the L group shared secrets $\{gss_q\}$.

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