US009628450B2

(12) **United States Patent**
Rohloff

(10) **Patent No.: US 9,628,450 B2**
(45) **Date of Patent: *Apr. 18, 2017**

(54) **SYSTEM AND METHOD FOR MERGING ENCRYPTION DATA WITHOUT SHARING A PRIVATE KEY**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 42 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/254,666**

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

(65) **Prior Publication Data**

US 2015/0304287 A1 Oct. 22, 2015

(51) **Int. Cl.**
H04L 29/06 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 63/0442*** (2013.01); ***H04L 63/0428*** (2013.01); ***H04L 63/061*** (2013.01)

(58) **Field of Classification Search**
CPC H04L 63/0442; H04L 63/061; H04L 63/0892; H04L 63/04; H04L 63/045; H04L 63/0471; H04L 63/0428
See application file for complete search history.

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(57) **ABSTRACT**

A method for data privacy in a distributed communication system including a plurality of client terminals merges encrypted streaming data using tree-like encryption key switching and without sharing any private keys in a distributed communication system. The merged data is then sent to client terminals to be further process by respective client terminals.

18 Claims, 9 Drawing Sheets

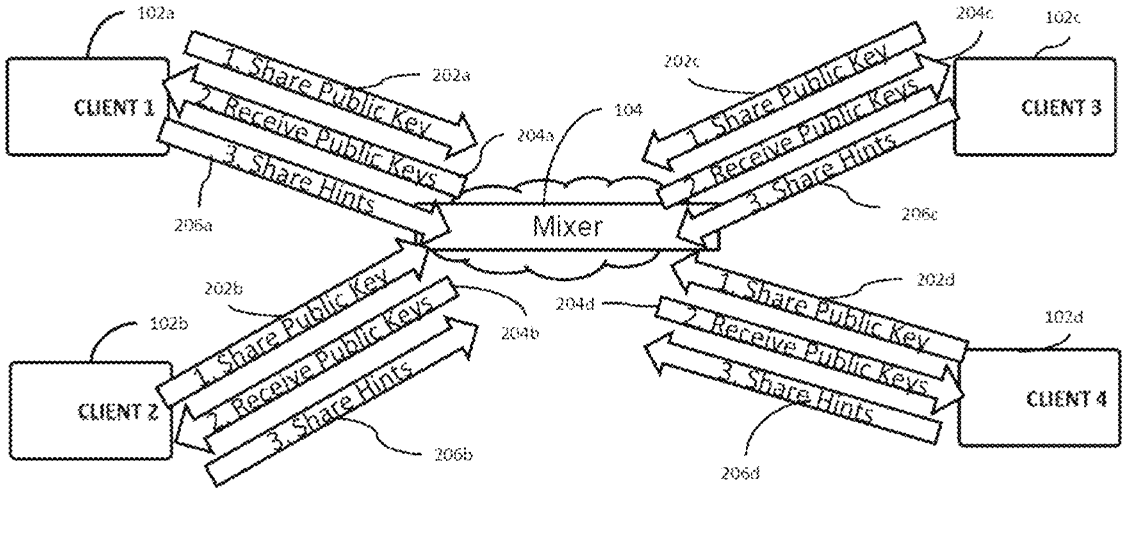

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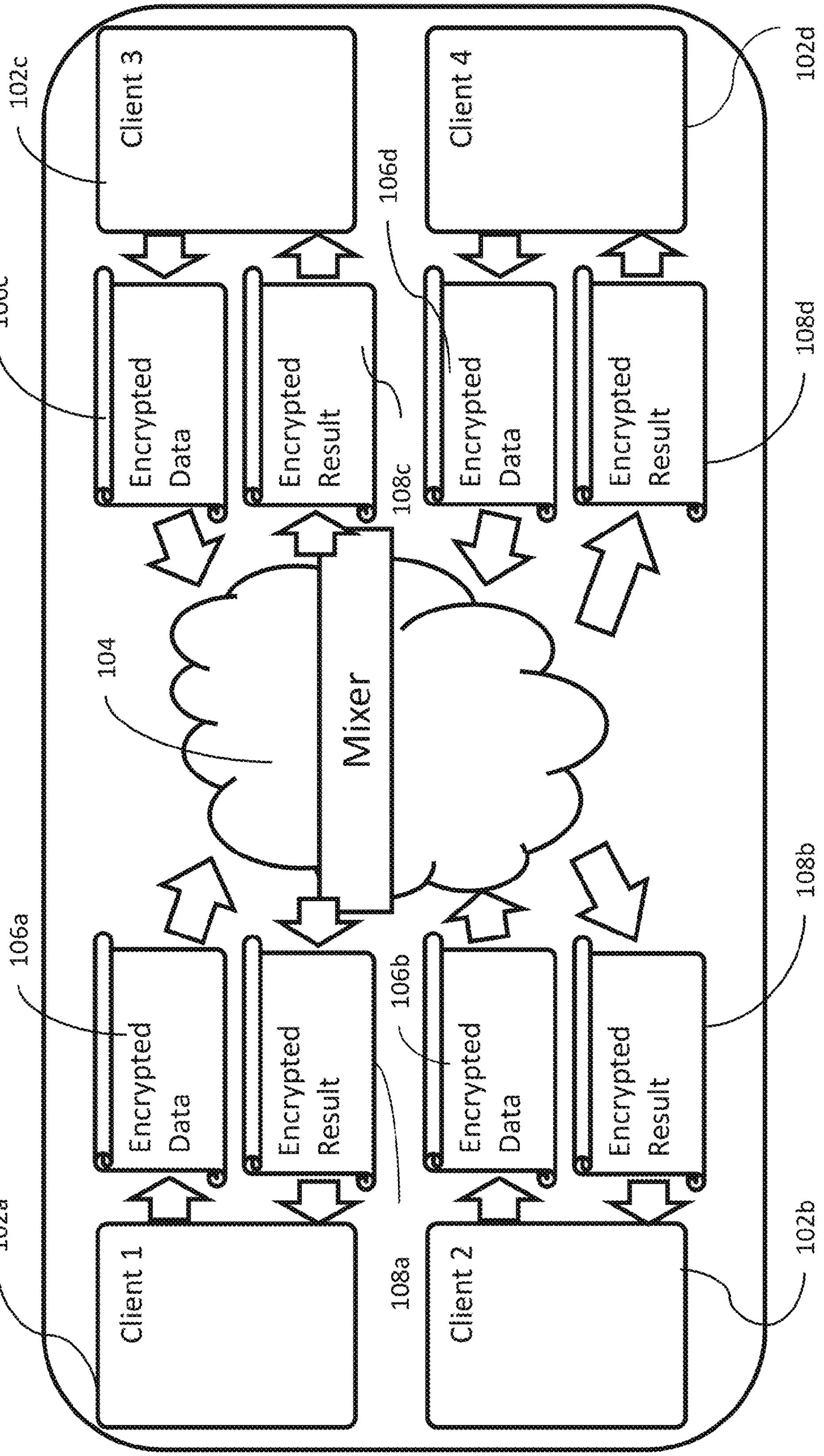
FIG. 1


102c
Client 3
102d
Client 4
106c
Encrypted Data
Encrypted Result
108c
106d
Encrypted Data
Encrypted Result
108d
104
Mixer
106a
Encrypted Data
Encrypted Result
106b
Encrypted Data
Encrypted Result
108b
102a
Client 1
108a
Client 2
102b

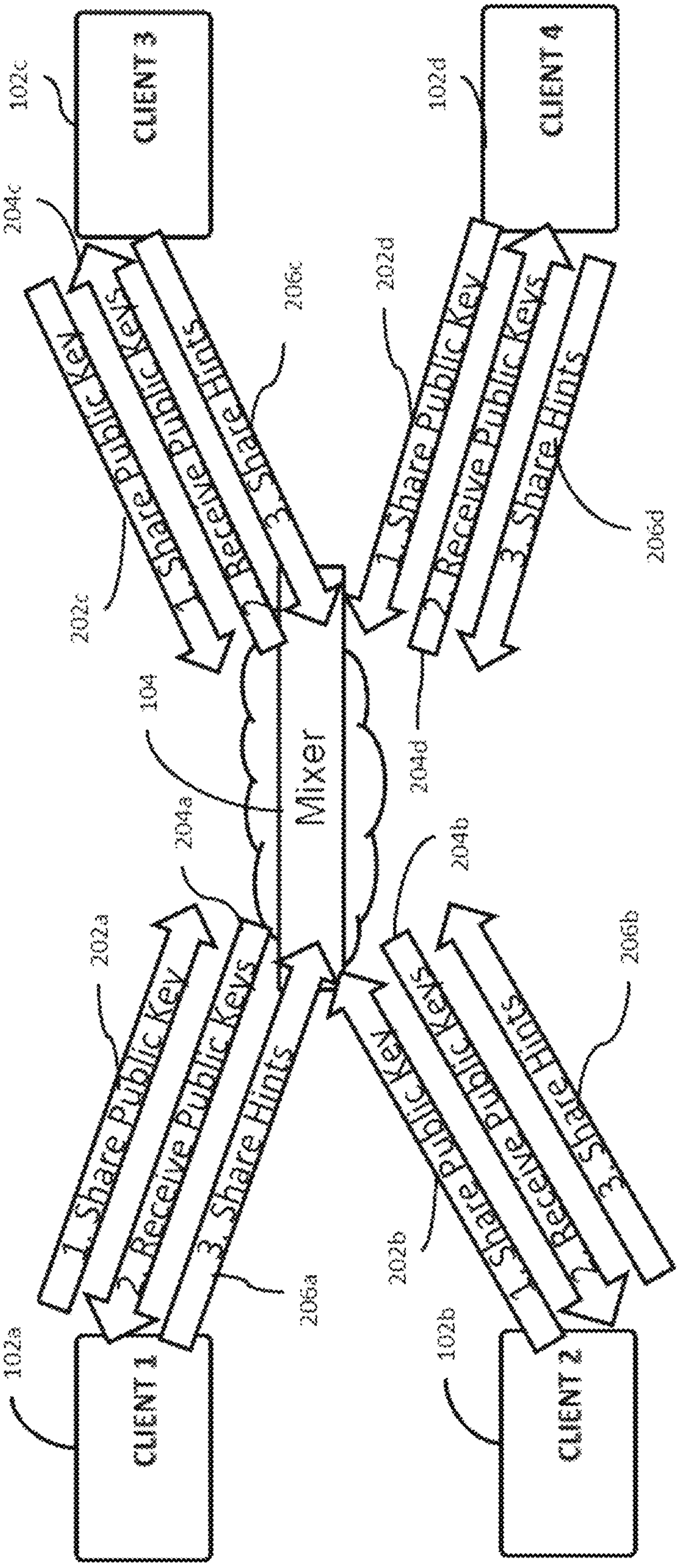
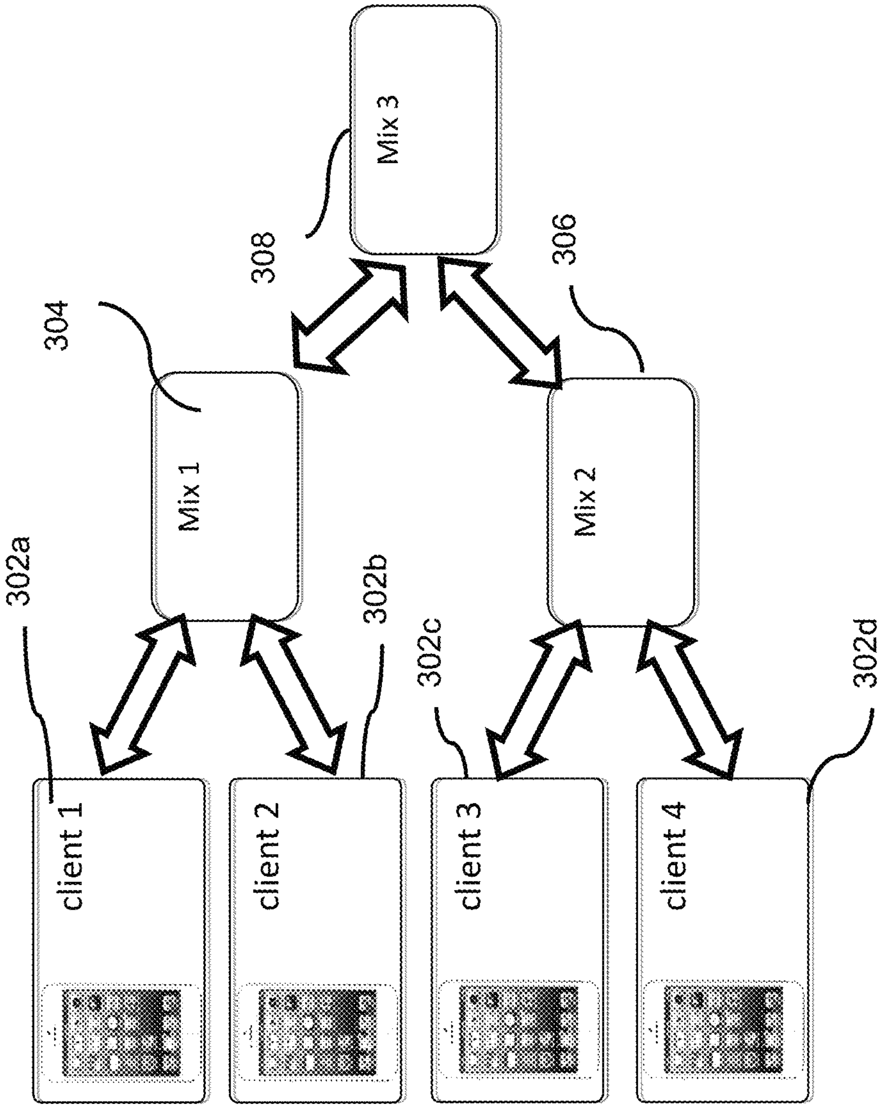

CLIENT 3
102c
CLIENT 4
102d
204c
206c
202c
202d
206d
204d
1. Share Public Key
2. Receive Public Keys
3. Share Hints
1. Share Public Key
2. Receive Public Keys
3. Share Hints
Mixer
104
204a
204b
202a
206a
202b
206b
1. Share Public Key
2. Receive Public Keys
3. Share Hints
1. Share Public Key
2. Receive Public Keys
3. Share Hints
CLIENT 1
102a
CLIENT 2
102b

FIG. 2

FIG. 3


Mix 3
308
304
306
Mix 1
Mix 2
302a
302b
302c
302d
client 1
client 2
client 3
client 4

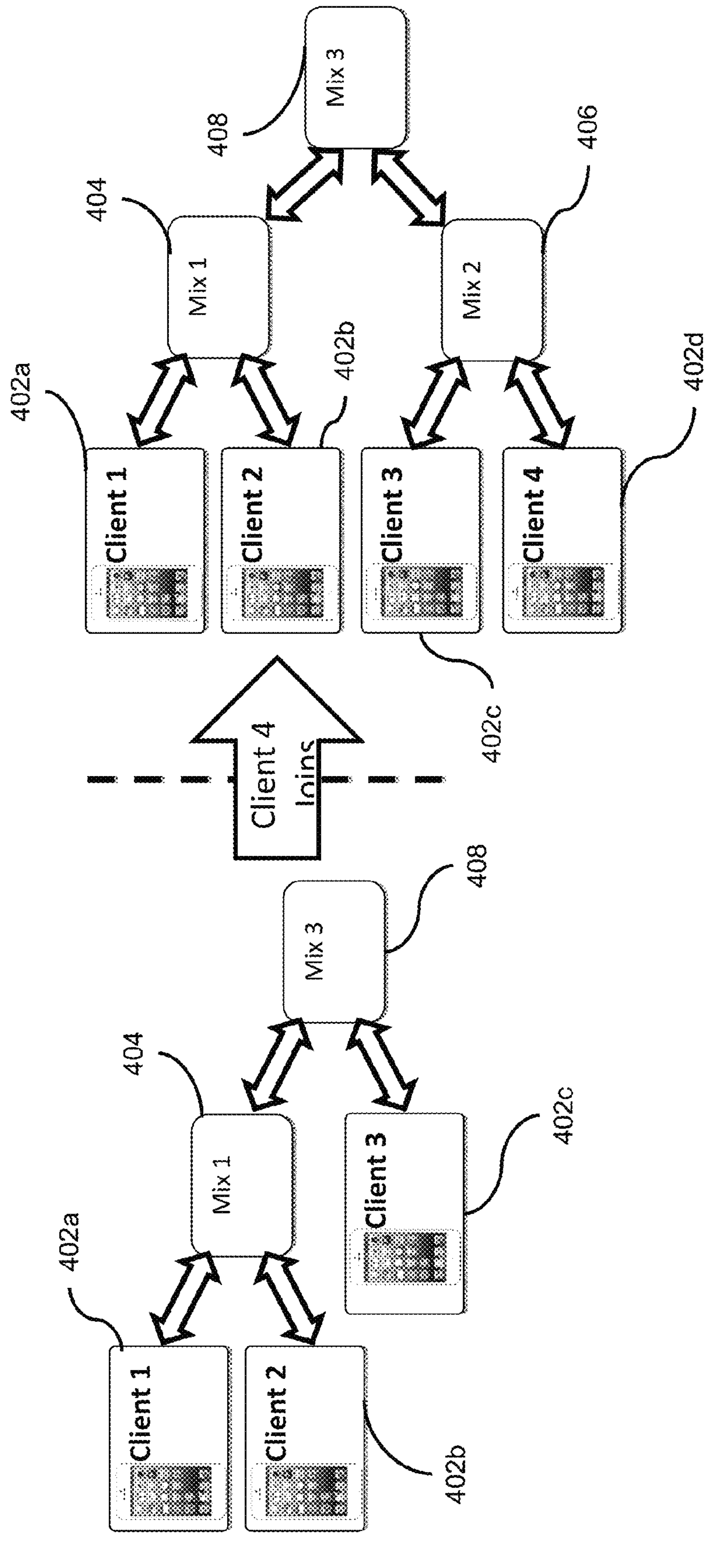

Client 1
Client 2
Client 3
402a
402b
402c
Mix 1
404
Mix 3
408
Client 4 Joins
Client 1
Client 2
Client 3
Client 4
402a
402b
402c
402d
Mix 1
404
Mix 2
406
Mix 3
408

FIG. 4A

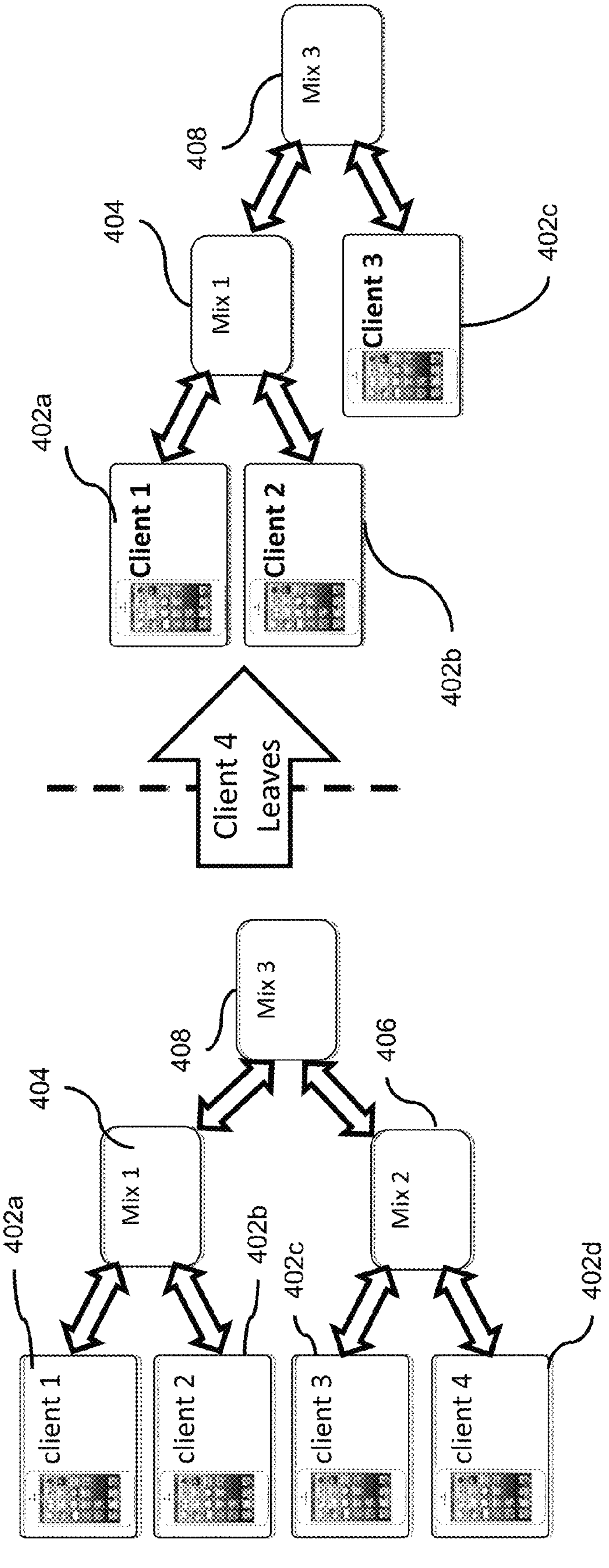

client 1
client 2
client 3
client 4
402a
402b
402c
402d
Mix 1
Mix 2
404
406
Mix 3
408
Client 4 Leaves
Client 1
Client 2
402a
402b
Mix 1
404
Client 3
402c
Mix 3
408

FIG. 4B

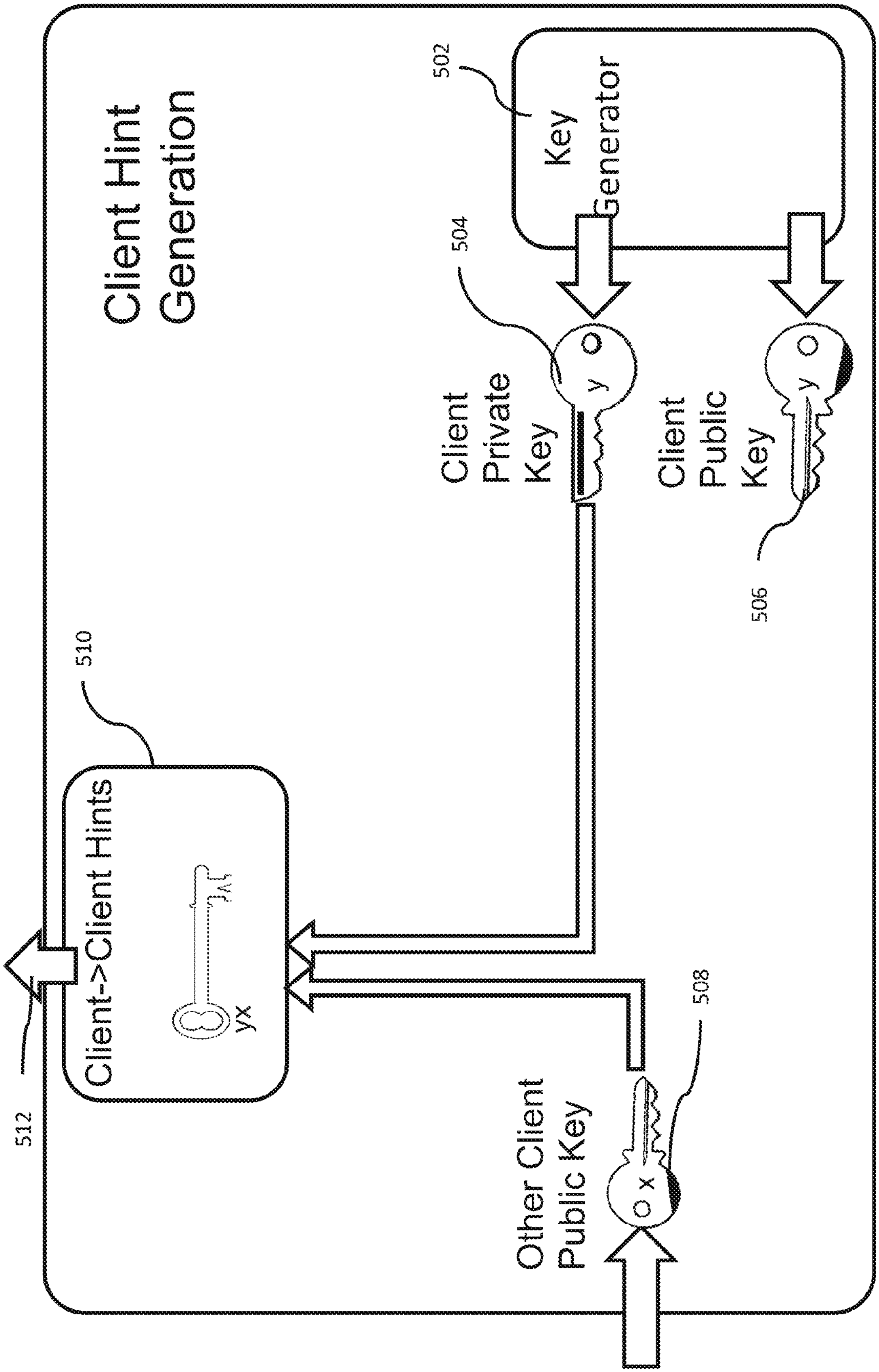

Client Hint Generation
502
Key Generator
504
Client Private Key
y
Client Public Key
y
506
510
Client->Client Hints
yx
508
Other Client Public Key
x
512

FIG. 5

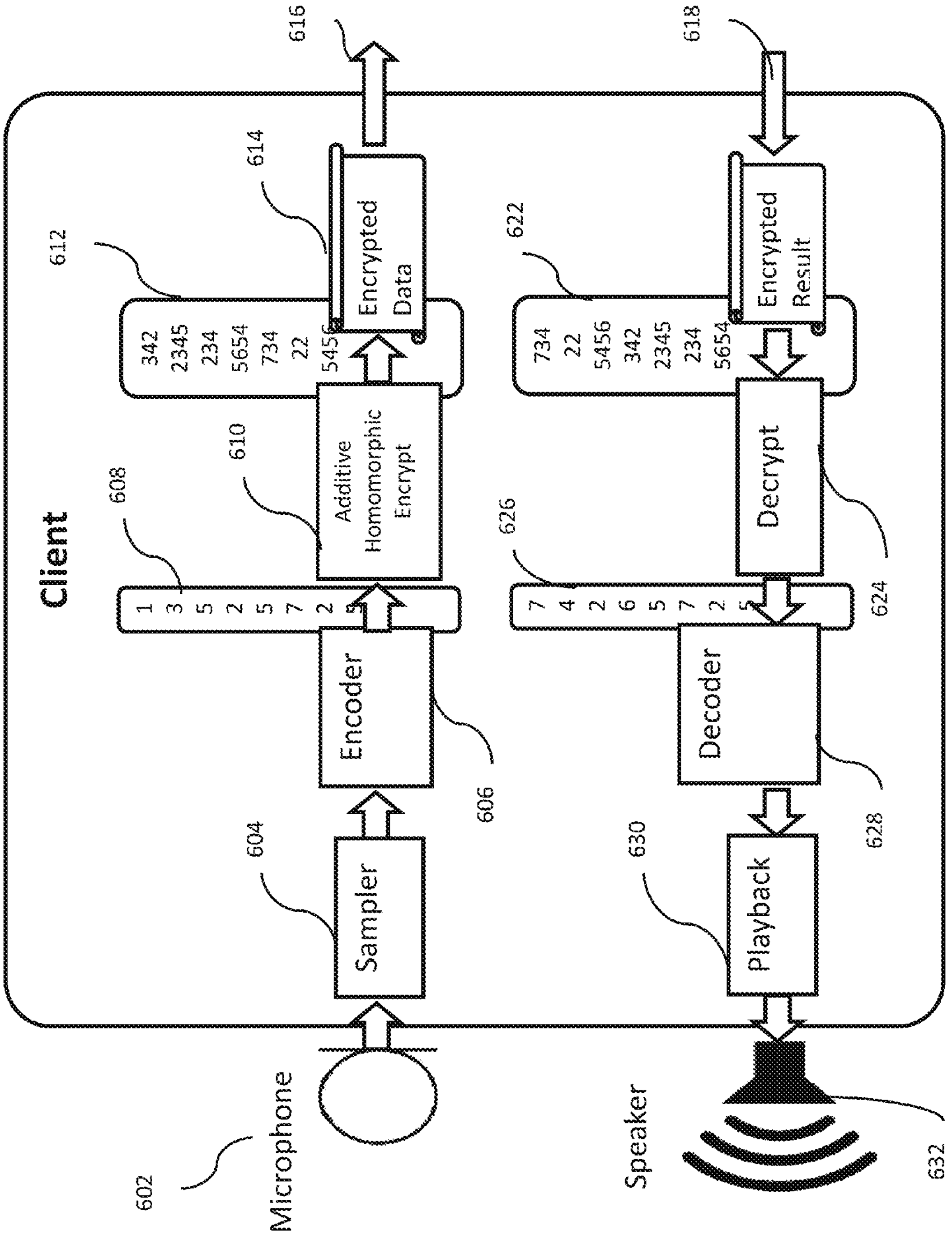

Client
602
Microphone
604
Sampler
606
Encoder
608
1 3 5 2 5 7 2 5
610
Additive Homomorphic Encrypt
612
342
2345
234
5654
734
22
5456
614
Encrypted Data
616
618
Encrypted Result
622
734
22
5456
342
2345
234
5654
624
Decrypt
626
7 4 2 6 5 7 2 5
628
Decoder
630
Playback
Speaker
632

FIG. 6

FIG. 7

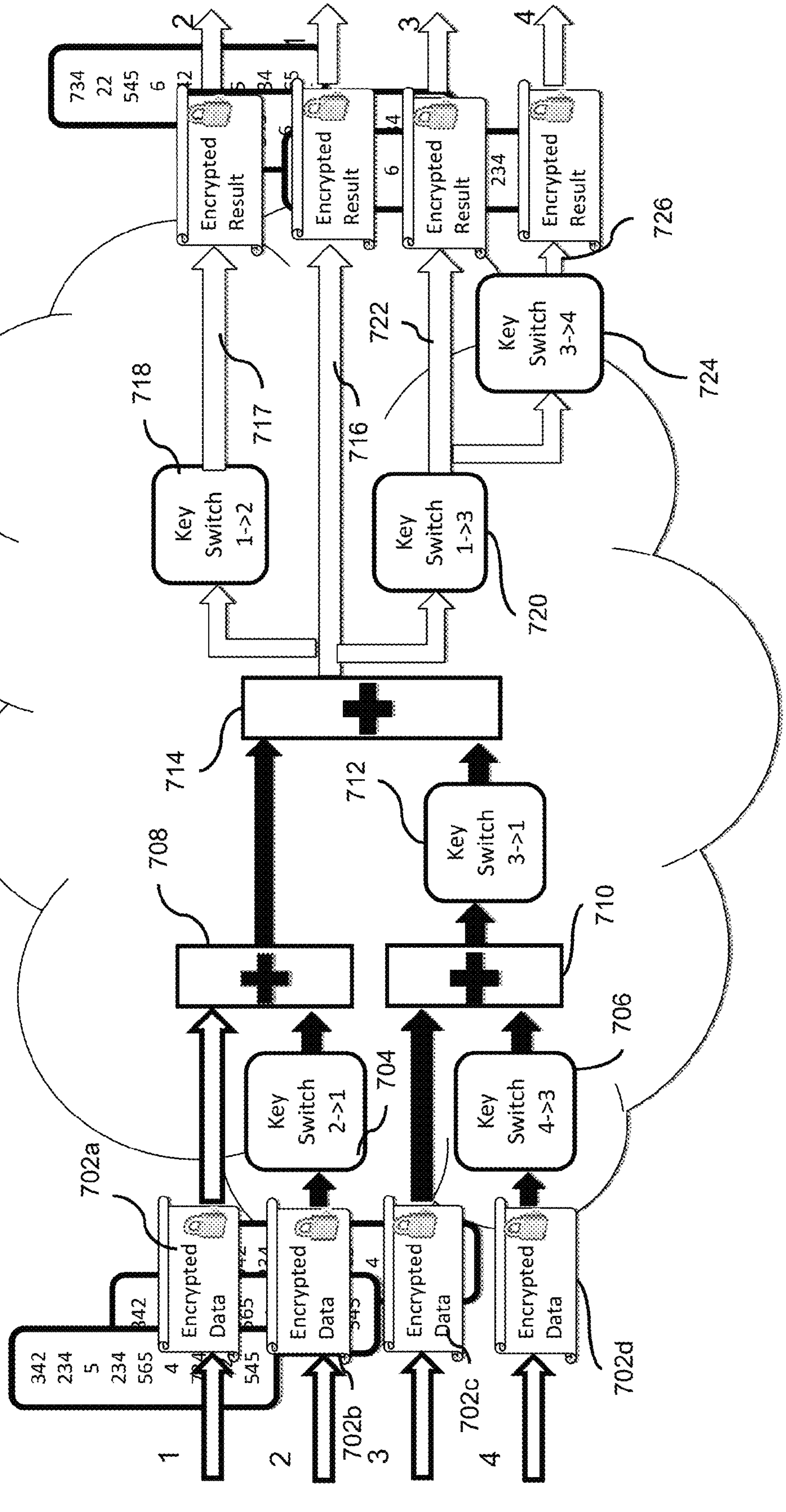
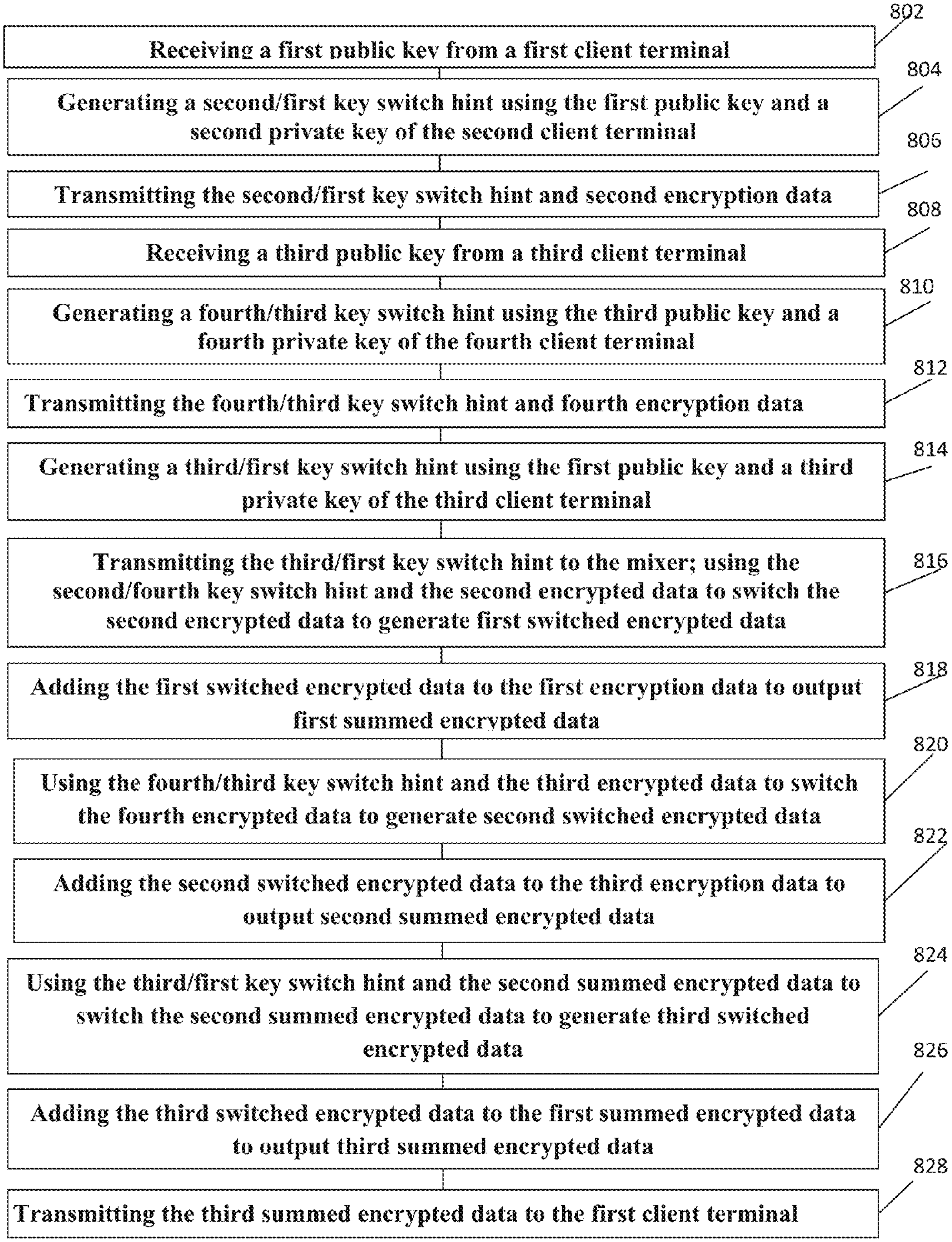

1
2
3
4
342
234
5
234
565
4
734
545
Encrypted Data
702a
702b
702c
702d
Key Switch 2->1
704
Key Switch 4->3
706
708
710
Key Switch 3->1
712
714
Key Switch 1->2
718
717
716
Key Switch 1->3
720
722
Key Switch 3->4
724
Encrypted Result
726
734
22
545
6
234
2
1
3
4

FIG. 8


802
Receiving a first public key from a first client terminal
804
Generating a second/first key switch hint using the first public key and a second private key of the second client terminal
806
Transmitting the second/first key switch hint and second encryption data
808
Receiving a third public key from a third client terminal
810
Generating a fourth/third key switch hint using the third public key and a fourth private key of the fourth client terminal
812
Transmitting the fourth/third key switch hint and fourth encryption data
814
Generating a third/first key switch hint using the first public key and a third private key of the third client terminal
816
Transmitting the third/first key switch hint to the mixer; using the second/fourth key switch hint and the second encrypted data to switch the second encrypted data to generate first switched encrypted data
818
Adding the first switched encrypted data to the first encryption data to output first summed encrypted data
820
Using the fourth/third key switch hint and the third encrypted data to switch the fourth encrypted data to generate second switched encrypted data
822
Adding the second switched encrypted data to the third encryption data to output second summed encrypted data
824
Using the third/first key switch hint and the second summed encrypted data to switch the second summed encrypted data to generate third switched encrypted data
826
Adding the third switched encrypted data to the first summed encrypted data to output third summed encrypted data
828
Transmitting the third summed encrypted data to the first client terminal

SYSTEM AND METHOD FOR MERGING ENCRYPTION DATA WITHOUT SHARING A PRIVATE KEY

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

This invention disclosure is related to a government contract number FA8750-11-C-0098. The U.S. Government has certain rights to this invention.

FIELD OF THE INVENTION

The present invention relates to data privacy and encryption and more specifically to a system and method for merging encryption data without sharing any private keys in a distributed communication system.

BACKGROUND

A typical system for enabling multiple entities to exchanging data or communicate with one another may include a form of a distributed communication system, in which multiple parties to a communication are connected to each other through a network and a central hub or switch. In many circumstances, where that data being exchanged includes sensitive information, it is important to maintain privacy from external security threats. Additionally, in some circumstances, the network itself may not be reliably secure or trustworthy. For example, various parties engaging in a teleconference may be speaking about sensitive information from various trusted locations throughout the world, but the telecommunication system or the central data mixer used to transmit data between the parties may not be secure or trustworthy.

There has been prior work on the mixing of data of different rates, however none of those approaches are compatible with the homomorphic encryption scheme such that privacy-preserving mixing can be performed, for example, for encrypted voice over IP (VoIP).

Moreover, these prior approaches do not cover encrypted VoIP teleconferencing, where encryption keys do not need to be shared with a VoIP mixer, in a manner that scales linearly with the number of participants (clients). Many consumer VoIP solutions do not support encryption of the signaling path or the media. As a result, the lack of encryption makes it relatively easy to eavesdrop on VoIP calls when access to the data network is possible.

SUMMARY OF THE INVENTION

In some embodiments, the present invention is directed to a system and method for merging encryption data using a tree-like mixing encryption key switching, and without sharing any private keys.

In some embodiments, the present invention is a method for data privacy in a distributed communication system including a plurality of client terminals. The method includes: receiving by a second client terminal of the plurality of client terminals, a first public key from a first client terminal of the plurality of client terminals; generating a second/first key switch hint for the first client terminal, by the second client terminal, using the first public key and a second private key of the second client terminal; transmitting the second/first key switch hint and second encryption data from the second client terminal to a mixer; receiving by a fourth client terminal of the plurality of client terminals, a third public key from a third client terminal of the plurality of client terminals; generating a fourth/third key switch hint for the third client terminal, by the fourth client terminal, using the third public key and a fourth private key of the fourth client terminal; transmitting the fourth/third key switch hint and fourth encryption data from the fourth client terminal to the mixer; receiving by the third client terminal, the first public key from the first client terminal; generating a third/first key switch hint for the first client terminal, by the third client terminal, using the first public key and a third private key of the third client terminal; transmitting the third/first key switch hint from the third client terminal to the mixer; and using, by the mixer, the second/firth key switch hint and the second encrypted data from the second client terminal to switch the second encrypted data to generate first switched encrypted data.

The method further includes: adding, by the mixer, the first switched encrypted data to the first encryption data received from the first client terminal to output first summed encrypted data; using, by the mixer, the fourth/third key switch hint and the third encrypted data from the third client terminal to switch the fourth encrypted data to generate second switched encrypted data; adding, by the mixer, the second switched encrypted data to the third encryption data received from the third client terminal to output second summed encrypted data; using, by the mixer, the third/first key switch hint and the second summed encrypted data to switch the second summed encrypted data to generate third switched encrypted data; adding, by the mixer, the third switched encrypted data to the first summed encrypted data to output third summed encrypted data; and transmitting the third summed encrypted data to the first client terminal to be decrypted by the first client terminal.

Additionally, the first client terminal receives the second public key from the second client terminal and generates a first/second key switch hint for the second client terminal, using the second public key and its own first private key. The first/second key switch hint and first encryption data from the first client terminal are then sent to the mixer. The mixer then the first/second key switch hint and the third summed encrypted data to switch the third summed encrypted data to generate fourth switched encrypted data. The fourth switched encrypted data is then sent to the second client terminal to be decrypted by the second client terminal.

This tree-like key switching scheme is repeated for the third client terminal receiving the first public key from the first client terminal and generating a third/first key switch hint for the first client terminal; and the third client terminal receiving the fourth public key from the fourth client terminal and generating a third/fourth key switch hint for the fourth client terminal

In some embodiments, the mixer combines the first, second, third and fourth encrypted data representation outputs in a matrix, a first column of the matrix including the first encryption data representation output, a second column of the matrix including the second encryption data representation output, a third column of the matrix including the third encryption data representation output, and a fourth column of the matrix including the fourth encryption data representation output.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the present invention, and many of the attendant features and aspects thereof, will become more readily apparent as the invention becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings in which like reference symbols indicate like components, wherein:

FIG. **1** shows an exemplary block diagram for a distributed communication system, according to some embodiments of the present invention.

FIG. **2** shows an exemplary block diagram depicting keys and hints sharing, according to some embodiments of the present invention.

FIG. **3** is an exemplary block diagram illustrating arrangement of client terminals, according to some embodiments of the present invention.

FIG. **4**A is an exemplary block diagram illustrating adding a new client terminal, according to some embodiments of the present invention.

FIG. **4**B is an exemplary block diagram depicting removing a new client terminal, according to some embodiments of the present invention.

FIG. **5** shows an exemplary hint generation approach, according to some embodiments of the present invention.

FIG. **6** shows data encryption and decryption by a client terminal, according to some embodiments of the present invention.

FIG. **7** depicts an exemplary block diagram of a mixer for mixing of encrypted data, according to some embodiments of the present invention.

FIG. **8** is an exemplary process flow, according to some embodiments of the present invention.

DETAILED DESCRIPTION

In some embodiments, the present invention is a system and method for merging encryption data using encryption key switching and without sharing any private keys in a distributed communication system, for example, Voice over IP (VoIP) teleconferencing systems, video conferencing systems, control systems, detection systems, accounting systems, and the like.

In some embodiments, the present invention provides a system and method for parties (e.g., several client terminals) to have privacy-preserving teleconferences, where communication privacy is maintained despite all communications of the clients being observed during the teleconference, even at the teleconference mixer. This approach uses an alternative key sharing capability, in which client terminals share their public keys with each other before a teleconference starts. The present invention improves upon the prior approaches, because in the scheme of the present invention, the public keys can be shared at any time prior to the start of the data communication that is convenient. This reduces the use of communication and computation resources at the start of the communication.

The invention uses key switch hints to delegate decryption capability from one client (terminal) to another. After delegating decryption capability to an intended client (terminal), the client can decrypt the encrypted data, which is delegated to it. As a result, the system and method of the present invention require less memory compared to methods, which require a VoIP mixer to store m key switch hints where m is the number of client terminals.

In some embodiments, in the case of teleconferencing, the clients encode their voice samples with an additive encoding scheme, encrypt their encoded voice data with an additive homomorphic encryption scheme, and send their encrypted voice (data) samples to a mixer. The mixer switches all encrypted data into respective data representations to respective client terminals, where each data representation can be decrypted by the intended (recipient) client. The mixer performs an encrypted homomorphic addition on the encrypted voice (data). The mixer sends the results back to the clients. The clients then decrypt, decode and play back the resulting decrypted voice (data). This scheme pre-shares public keys for an additive homomorphic encryption scheme, performs key switching and requires that the clients agree on a common additive encoding scheme.

FIG. **1** shows an exemplary block diagram for a distributed communication system, according to some embodiments of the present invention. Each of the clients **102***a*, **102***b*, **102***c* and **102***d* samples voice data (in the case of voice), encodes it, encrypts it and sends the encrypted data **106***a*, **106***b*, **106***c* or **106***d* to a mixer **104**. The mixer **104** operates on the encrypted data and sends the results **108***a*, **108***b*, **108***c* and **108***d* back to the respective client terminals, which are then decrypted, decoded and played back(in the case of voice) to the respective clients.

Any encryption system may be used with the system and method of the present invention that supports an additive homomorphism and key switching which could be implemented in a practical manner. A representational scheme is NTRU which can be made to both a Somewhat Homomorphic Encryption (SHE) scheme and a Fully Homomorphic Encryption (FHE) scheme, and which supports key switching.

FIG. **2** shows an exemplary block diagram depicting keys and hints sharing, according to some embodiments of the present invention. The diagram illustrates a circular way (ring configuration), in which the public encryption keys are shared among the clients and hints shared with the mixer, in some embodiments of the present invention. As depicted, client terminals (clients) **102***a*, **102***b*, **102***c* and **102***d* share their public keys **202***a*, **202***b*, **202***c* and **202***d*, in a circular manner through, for example, a mixer (or other entity) **104**. However, in some embodiments, a mixer need not be used to share keys, rather, other sources, including any of the client terminals may be used to share keys. This sharing only needs to be performed once and could be done in a batch manner, for example, every time a client joins, or every time a teleconference is organized. Mixer **104** sends public keys to clients and the clients receive the respected public keys (**204***a*, **204***b*, **204***c* and **204***d*) to generate respective key switch hints **206***a*, **206***b*, **206***c* and **206***d*. These key switch hints are then used to switch respective encrypted data to corresponding data representations for each client. For example, as shown, client **102***a* sends it public key **202***a* to be shared and receives from one of the other clients **102***b*, **102***c* or **102***d* its public keys (**202***b*, **202***c* or **202***d*), as shown by arrow **204***a*.

FIG. **5** shows an exemplary hint generation approach, according to some embodiments of the present invention. For every client terminal, a key switch hint to be sent from that client terminal to the mixer is generated. All the key switch hints, but none of the keys, are shared with the mixer. As shown, each client terminal receives other clients' respective public keys **508** (for example, from the mixer) and uses its own private key **504** to generate a client**1**-to-next-client hint **512**, by a key hint generation module **510**. For example, client **102***a* and receives client's **102***b* public key **202***b*, as shown by **508** in FIG. **5**. Client **102***a* then uses its own private key **504** to generate a client **102***a*-to-client **102***b* key switch hint **512**.

The key switch hint generation procedure depends on the specific type of additive homomorphic encryption scheme used. Because private keys are not shared, no other key switch hints can be generated to take the result and delegate its decryption to another entity. An example of the key switching for NTRU case would be to convert a ciphertext of degree of at most d, encrypted under a secret key f1, into a degree-1 ciphertext c2 encrypted under a secret key f2 (which may or may not be the same as f1). The "hint" is a12=m*f1ˆd*f2ˆ−1 mod q for a short mϵR congruent to 1 modulo p. Then, m=p*e+1 can be chosen for a Gaussian distributed e.). The key switch operation is then defined as the function *:

KeySwitch(c1, a12): c2=a12*c1 mod q.

FIG. **3** is an exemplary block diagram illustrating arrangement of client terminals, according to some embodiments of the present invention. As shown, the invention uses an arbitrary ordering of the clients. The clients (**302***a*, **302***b*, **302***c*, **302***d* . . .) are arbitrarily ordered from 1 to m and arranged in a tree like arrangement (tree structure). The clients are arranged in a hierarchy such that non-leaf-nodes in the tree representation of the clients is assigned the value of the lowest value clients in the tree. This minimum value up-flow is used when performing a mixing operation, such that when VoIP data is mixed, it is mixed according to the tree structure and the minimum node value is the key representation, in which the VoIP data is kept in. The encrypted data is mixed up through the tree and switched into the ciphertext representation of the client value assigned to each node. In the example of FIG. **3**, key switch hints are generated so that client **1**'s public key is sent to client **2** to generate a (second/first) key switch hint, client **3**'s public key is sent to client **4** to generate a (fourth/third) key switch hint, client **1**'s public key is sent to client **3** to generate a (third/first) key switch hint, and so forth. In some embodiments, the key switch hints are stored by the mixer. The mixer then performs a tree-like mixing of the data.

For example, client **2**'s (**302***b*) encrypted data is switched by the second/first key switch hint and them mixed with the encryption data from client **1** (**302***a*), by a first mixing circuit **304**. Similarly, client **4**'s (**302***d*) encrypted data is switched by the fourth/third key switch hint and them mixed with the encryption data from client **3** (**302***c*), by a second mixing circuit **306**. The output of the first mixing circuit **304** is then mixed with the second mixing circuit **306**, by a third mixing circuit **308**. In some embodiments the mixing circuits perform a summation operation.

FIG. **4**A is an exemplary block diagram illustrating adding a new client terminal, according to some embodiments of the present invention. Client terminals **402***a*, **402***b* and **402***c* are already in the tree structure configuration and client **4** needs to be added to the network (tree), for example, as a new user in a conference call or distributed data communication. As shown, when a new client **4** is added, it is added to the end of the list, as shown by client **4** **402***d*. The new (larger) tree configuration would include client **2** (**402***b*) receiving client **1**'s (**402***a*) public key to generate a (second/first) key switch hint, client **4** (**402***d*) receiving client **3**'s (**402***c*) public key to generate a (fourth/third) key switch hint, client **3** receiving client **1**'s public key to generate a (third/first) key switch hint, and so forth. In general, any binary tree balancing scheme may be used to add clients to the tree structure. These tree balancing algorithms ensure that the tree is of minimum depth by trimming or moving tree branches to minimize tree depth.

FIG. **4**B is an exemplary block diagram depicting removing a new client terminal, according to some embodiments of the present invention. As illustrated, when a client terminal **402***d* is removed, the tree structure is trimmed appropriately and internal node assignments are updated. Again, any tree balancing scheme may be used to reorganize the tree as nodes are removed. For example, **402***a*, **402***b* and **402***c* in the right side of FIG. **4**B. The new (smaller) tree configuration would include client **2** **402***b* receiving client**1**'s (**402***a*) public key, client **3** **402***c* receiving client **2**'s public key, and client**1** receiving client **3**'s public key.

FIG. **6** shows data encryption and decryption by a client terminal, according to some embodiments of the present invention. The example illustrated by FIG. **6** relates to voice conferencing and includes a microphone **602**, to capture the voice, a sampler **604** to sample the analog voice signals, and a playback **630** to play back the voice via a speaker **632**. However, in case of general data communication without voice, microphone **602**, sampler **604**, playback **630** and speaker **632** may not be needed. As shown, a client terminal receives the voice data from a microphone **602**, samples the voice data using the sampler **604** and feeds the sampled data to an encoder **606**, which encodes the data and generates a data vector **608**. The data vector **608** is then encrypted with client's private key by an additive homomorphic encryption module **610**, using an additive homomorphic encryption scheme. The encrypted data is represented by vector **612**, which is then sent **616** to a mixer to be operated on.

After the mixing operation is performed, the encrypted result **618** is received from the mixer, for example, in the form of a vector **622**. The result **618** is decrypted by a decryption module **624** to generate a vector **626** of decrypted data to be decoded by the decoder **628**. In case of voice data, the decrypted data is played back (**630**) over a speaker **632**. In the case of non-voice data communication, the decoded data is send to a desired destination, without any play back. Here, all the hints but none of the keys are shared with the mixer. The key switch hint generation procedure depends on the specific type of additive homomorphic encryption scheme used. Because private keys are not shared, no other key switch hints can be generated to take the result and delegate its decryption to another entity. In some embodiments, a NTRU algorithm is used as a representational additive homomorphic encryption scheme which provides encryption and decryption functions.

The NTRU encryption algorithm is lattice based, which, is based on the hardness of the shortest vector problem in a lattice. Operations are based on objects in a truncated integer polynomial ring with convolution multiplication.

FIG. **7** depicts an exemplary block diagram of a mixer for circular mixing of encrypted data, according to some embodiments of the present invention. In general, for a representational VoIP system with client terminals (**1**, . . . , m), data from client terminal **2** would be switched to client terminal **1** and added to the data from client terminal **1**. Data from client terminal **4** would be switched to client terminal **3** and added to the data from client terminal **3**. This result would be switched to client terminal **1** and added to the summation of the client terminal **1** and client terminal **2** data. This continues until the result of the summation of all clients represented under key **1** is obtained. This result would be sent to client terminal **1**. The result would then be switched to key **2** and sent to client terminal **2**. This result would then be switched to key **3** and sent to client terminal **3**. This tree-like process would continue until all clients receive the appropriate data.

As shown in FIG. **7**, encrypted data (**702***a*, **702***b*, **702***c* and **702***d*) and key switch hints (not shown) are received from respective client terminals. A first key switch operation **704** is performed (for example, by a mixer) on the encrypted data **702***b* from client **2**, using a second/first key switch hint generated by client **2** for client **1**. The result is added by an adder **708** to the encrypted data **702***a* from client **1**. Likewise, a second key switch operation **706** is performed on the encrypted data **702***d* from client **4**, using a fourth/third key switch hint generated by client **4** for client **3**. The result is added by an adder **710** to the encrypted data **702***c* from client **3**.

A third key switch operation **712** is performed on the output of the adder **710**, using a third/first key switch hint generated by client **3** for client **1** and added to the output of the adder **708**, by the adder **714**. The output **716** of the adder **714** is then sent to client **1** to be processed and decrypted by client terminal **1**. The output **716** of the adder **714** is also sent to a fourth key switch operation **718** to key switch the data representation, using a first/second key switch hint generated by client **1** for client **2**. The output **717** of the fourth key switch operation **718** is then sent to client **2** to be processed and decrypted by client terminal **2**.

The output **716** of the adder **714** is also sent to a fifth key switch operation **720** to key switch the data representation, using a first/third key switch hint generated by client **1** for client **3**. The output **722** of the fifth key switch operation **720** is then sent to client **3** to be processed and decrypted by client terminal **3**. The output **722** of the fifth key switch operation **720** is also sent to a sixth key switch operation **724** to key switch the data representation, using a third/fourth key switch hint generated by client **3** for client **4**. The output **726** of the sixth key switch operation **724** is then sent to client **4** to be processed and decrypted by client terminal **4**, hence, a tree-like key switching scheme.

In some embodiments, the encrypted data switch representation outputs (**716**, **717**, **724** and **726**) for the clients **1**, **2**, **3** and **4**, respectively, are combined in a matrix, in which each column of the matrix represents one of the encrypted data representation. The appropriate matrix column is then sent to the corresponding client. In some embodiments, the entire matrix may be sent to all the clients. Each client then extracts its own encrypted data representation (result) from the matrix. In the case of voice, it may be desired not to send back the same voice generated by a specific client to that specific client. Consequently, the entire matrix, minus the column to the specific client is sent to that specific client.

In some embodiments, for a representational NTRU-based additive homomorphic encryption scheme, the mixer would need to know the ring dimension and ciphertext modulus. This information may be embedded in the key switch hints. In some embodiments, each of the clients uses an authentication scheme to guarantee they are receiving public keys from intended recipients of their data. Conventional authentication schemes are used to authenticate a first client to a second client.

FIG. **8** is an exemplary process flow, according to some embodiments of the present invention. In block **802**, a first public key is received from a first client terminal of the plurality of client terminals. A second/first key switch hint is generated for the first client terminal, by the second client terminal, using the first public key and a second private key of the second client terminal, in block **804**. For example, client **2** receives the public key of cleint **1** and then using its own private key, cleint **2** generates a second/first key switch hint for the client**1**. The second/first key switch hint and second encryption data from the second client terminal is then transmitted to a mixer or equivalent thereof, in block **806**.

In block **808**, a third public key is received from a third client terminal and a fourth/third key switch hint for the third client terminal is generated by the fourth client terminal, using the third public key and a fourth private key of the fourth client terminal, in block **810**. The fourth/third key switch hint and fourth encryption data are then transmitted from the fourth client terminal to the mixer, in block **812**. Similarly, in block **814**, a third/first key switch hint is generated for the first client terminal by the third client terminal, using the first public key and a third private key of the third client terminal. The third/first key switch hint and third encryption data from the third client terminal data are then transmitted to the mixer, and the mixer uses the second/fourth key switch hint and the second encrypted data to switch the second encrypted data to generate first switched encrypted data, in block **816**.

In block **818**, the mixer adds the first switch encrypted data to the first encryption data to output first summed encrypted data. In block **820**, the mixer uses the fourth/third key switch hint and the third encrypted data from the third client terminal to switch the fourth encrypted data to generate second switched encrypted data, and adds the second switched encrypted data to the third encryption data received from the third client terminal to output second summed encrypted data, in block **822**.

The mixer then uses the third/first key switch hint and the second summed encrypted data to switch the second summed encrypted data to generate third switched encrypted data, in block **824**; and adds the third switched encrypted data to the first summed encrypted data to output third summed encrypted data, in block **826**. The third summed encrypted data is then transmitted to the first client terminal to be decrypted by the first client terminal.

Additionally, the first client terminal receives the second public key from the second client terminal and generates a first/second key switch hint for the second client terminal, using the second public key and its own first private key. The first/second key switch hint and first encryption data from the first client terminal are then sent to the mixer. The mixer then the first/second key switch hint and the third summed encrypted data to switch the third summed encrypted data to generate fourth switched encrypted data, as shown by output **717** in FIG. **7**. The fourth switched encrypted data is then sent to the second client terminal to be decrypted by the second client terminal.

Moreover, the third client terminal receives the first public key from the first client terminal; generates a third/first key switch hint for the first client terminal, using the first public key and a third private key of the third client terminal; and transmits the third/first key switch hint and third encryption data to the mixer. The mixer then uses the third/first key switch hint and the third summed encrypted data to switch the third summed encrypted data to generate fifth switched encrypted data, as shown by output **722** in FIG. **7**. The fifth switched encrypted data is then sent to the third client terminal to be decrypted by the third client terminal.

Furthermore, the third client terminal receives the fourth public key from the fourth client terminal; generates a third/fourth key switch hint for the fourth client terminal, using the fourth public key and the third private key of the third client terminal; and sends the third/fourth key switch hint from the third client terminal to the mixer. The mixer then uses the third/fourth key switch hint and the fifth switched encrypted data to switch the fifth switched encrypted data to generate sixth switched encrypted data as shown by output **726** in FIG. **7**. The sixth switched encrypted data is then sent to the fourth client terminal to be decrypted by the fourth client terminal. This configuration describes a tree-structure key switching scheme, in which the public keys can be shared at any time prior to the start of the data communication that is convenient.

In some embodiments, for example, in the case of voice communication, for the situation where a client would not want to receive its own voice data in the summation, the summation operations would be over a matrix addition where the added data in each column is the result for each client. This added column may be set to 0, if the corresponding recipient of the column is not intended to receive the voice data being added and all other columns would be the data being added. Redundant column data need not be carried through the process. For example, if cij represents the ciphertext from client i in the key j representation, the first summation would be [c22,c12,c12+c22]. The result of the 2nd summation would be [c23+c33,c13+c33,c13+c23, c13+c23+c33]. The result of a 3rd summation would be [c24+c34,c44,c14+c34+c44,c14+c24+c34,c14+c24+c34+c44].

It will be recognized by those skilled in the art that various modifications may be made to the illustrated and other embodiments of the invention described above, without departing from the broad inventive scope thereof. It will be understood therefore that the invention is not limited to the particular embodiments or arrangements disclosed, but is rather intended to cover any changes, adaptations or modifications which are within the scope and spirit of the invention as defined by the appended claims.

What is claimed is:

1. A computer implemented method for voice and video data encryption and decryption without sharing a private key, in a distributed video conferencing system including a plurality of client terminals communicating data at different data rates, the method comprising:

upon initiating a video conference amongst the plurality of client terminals, receiving by a second client terminal of the plurality of client terminals, a first public key from a first client terminal of the plurality of client terminals;

generating a second/first key switch hint for the first client terminal, by the second client terminal, using the first public key and a second private key of the second client terminal;

transmitting the second/first key switch hint and a second encrypted data from the second client terminal to a mixer;

receiving by a fourth client terminal of the plurality of client terminals, a third public key from a third client terminal of the plurality of client terminals;

generating a fourth/third key switch hint for the third client terminal, by the fourth client terminal, using the third public key and a fourth private key of the fourth client terminal;

transmitting the fourth/third key switch hint and fourth encrypted data from the fourth client terminal to the mixer;

receiving by the third client terminal, the first public key from the first client terminal;

generating a third/first key switch hint for the first client terminal, by the third client terminal, using the first public key and a third private key of the third client terminal;

transmitting the third/first key switch hint from the third client terminal to the mixer;

using, by the mixer, the second/first key switch hint and the second encrypted data from the second client terminal to switch the second encrypted data to generate a first switched encrypted data;

adding, by the mixer, the first switched encrypted data to the first encrypted data received from the first client terminal to output a first summed encrypted data;

using, by the mixer, the fourth/third key switch hint and a third encrypted data from the third client terminal to switch the fourth encrypted data to generate a second switched encrypted data;

adding, by the mixer, the second switched encrypted data to the third encrypted data received from the third client terminal to output a second summed encrypted data;

using, by the mixer, the third/first key switch hint and the second summed encrypted data to switch the second summed encrypted data to generate a third switched encrypted data;

adding, by the mixer, the third switched encrypted data to the first summed encrypted data to output a third summed encrypted data, wherein each encrypted data is encrypted voice or video data, and wherein a private key of each client terminal is not shared by any other client terminal; and

transmitting the third summed encrypted data to the first client terminal for decryption and playing back by the first client terminal.

2. The method of claim **1**, further comprising

receiving by the first client terminal, a second public key from the second client terminal;

generating a first/second key switch hint for the second client terminal, by the first client terminal, using the second public key and a first private key of the first client terminal;

transmitting the first/second key switch hint and first encrypted data from the first client terminal to the mixer;

using, by the mixer, the first/second key switch hint and the third summed encrypted data to switch the third summed encrypted data to generate fourth switched encrypted data; and

transmitting the fourth switched encrypted data to the second client terminal for decryption by the second client terminal.

3. The method of claim **2**, further comprising

receiving by the third client terminal, the first public key from the first client terminal;

generating a third/first key switch hint for the first client terminal, by the third client terminal, using the first public key and a third private key of the third client terminal;

transmitting the third/first key switch hint and third encrypted data from the third client terminal to the mixer;

using, by the mixer, the third/first key switch hint and the third summed encrypted data to switch the third summed encrypted data to generate a fifth switched encrypted data; and

transmitting the fifth switched encrypted data to the third client terminal for decryption by the third client terminal.

4. The method of claim **3**, further comprising

receiving by the third client terminal, a fourth public key from the fourth client terminal;

generating a third/fourth key switch hint for the fourth client terminal, by the third client terminal, using the fourth public key and the third private key of the third client terminal;

transmitting the third/fourth key switch hint from the third client terminal to the mixer;

using, by the mixer, the third/fourth key switch hint and the fifth switched encrypted data to switch the fifth switched encrypted data to generate a sixth switched encrypted data; and

transmitting the sixth switched encrypted data to the fourth client terminal for decryption by the fourth client terminal.

5. The method of claim **4**, further comprising: combining the third summed encrypted data, the fourth switched encrypted data, the fifth switched encrypted data and the sixth switched encrypted data in a matrix, a first column of the matrix including the third summed encrypted data, a second column of the matrix including fourth switched encrypted data, a third column of the matrix including the fifth switched encrypted data, and a fourth column of the matrix including the sixth switched encrypted data.

6. The method of claim **5**, further comprising sending one or more columns of the matrix to a respective client terminal.

7. The method of claim **5**, further comprising sending the matrix to all of the client terminals.

8. The method of claim **5**, further comprising replacing the content of a respective column of the matrix corresponding to a respective client terminal with all zeroes, before sending the matrix to the respective client terminal.

9. The method of claim **1**, wherein the first encrypted data, the second encrypted data, the third encrypted data and the fourth encrypted data are encoded before being encrypted by the respective client terminal.

10. A distributed video conferencing system for communicating data at different data rates and performing voice and video data encryption and decryption without sharing a private key comprising:

a second client terminal that, upon initiating a video conference amongst a plurality of client terminals, receives a first public key from a first client terminal and generates a second/first key switch hint for the first client terminal, using the first public key and a second private key of the second client terminal;

a mixer that receives the second/first key switch hint and a second encrypted data from the second client terminal; and

a fourth client terminal that receives a third public key from a third client terminal; generates a fourth/third key switch hint for the third client terminal, using the third public key and a fourth private key of the fourth client terminal; and transmits the fourth/third key switch hint and a fourth encrypted data to the mixer, wherein

the third client terminal receives the first public key from the first client terminal; generates a third/first key switch hint for the first client terminal, using the first public key and a third private key of the third client terminal; and transmits the third/first key switch hint to the mixer, and wherein the mixer uses the second/first key switch hint and the second encrypted data from the second client terminal to switch the second encrypted data to generate a first switched encrypted data; and adds the first switched encrypted data to the first encrypted data received from the first client terminal to output a first summed encrypted data;

uses the second/first key switch hint and the second encrypted data from the second client terminal to switch the second encrypted data to generate a first switched encrypted data; and adds the first switched encrypted data to the first encrypted data received from the first client terminal to output a first summed encrypted data;

uses the fourth/third key switch hint and a third encrypted data from the third client terminal to switch the fourth encrypted data to generate a second switched encrypted data; and adds the second switched encrypted data to the third encrypted data received from the third client terminal to output a second summed encrypted data;

uses the third/first key switch hint and the second summed encrypted data to switch the second summed encrypted data to generate a third switched encrypted data; and adds the third switched encrypted data to the first summed encrypted data to output a third summed encrypted data, wherein each encrypted data is encrypted voice or video data, and wherein a private key of each client terminal is not shared by any other client terminal; and

transmits the third summed encrypted data to the first client terminal for decryption and playing back by the first client terminal.

11. The distributed video conferencing system of claim **10**, wherein the first client terminal receives a second public key from the second client terminal; generates a first/second key switch hint for the second client terminal, using the second public key and a first private key of the first client terminal; and transmits the first/second key switch hint and first encrypted data from the first client terminal to the mixer, and wherein

the mixer adds the first/second key switch hint and the third summed encrypted data to switch the third summed encrypted data to generate a fourth switched encrypted data; and transmits the fourth switched encrypted data to the second client terminal for decryption by the second client terminal.

12. The distributed video conferencing system of claim **11**, wherein the third client terminal receives the first public key from the first client terminal; generates a third/first key switch hint for the first client terminal, by the third client terminal, using the first public key and a third private key of the third client terminal; and transmits the third/first key switch hint and third encrypted data from the third client terminal to the mixer, and wherein

the mixer uses the third/first key switch hint and the third summed encrypted data to switch the third summed encrypted data to generate a fifth switched encrypted data; and transmits the fifth switched encrypted data to the third client terminal for decryption by the third client terminal.

13. The distributed video conferencing system of claim **12**, wherein the third client terminal receives a fourth public key from the fourth client terminal; generates a third/fourth key switch hint for the fourth client terminal, by the third client terminal, using the fourth public key and the third private key of the third client terminal; and transmits the third/fourth key switch hint from the third client terminal to the mixer, and wherein

the mixer uses the third/fourth key switch hint and the fifth switched encrypted data to switch the fifth switched encrypted data to generate a sixth switched encrypted data; and transmits the sixth switched encrypted data to the fourth client terminal for decryption by the fourth client terminal.

14. The distributed video conferencing system of claim **13**, wherein the mixer combines the third summed encrypted data, the fourth switched encrypted data, the fifth switched encrypted data and the sixth switched encrypted data in a matrix, a first column of the matrix including the third summed encrypted data, a second column of the matrix including fourth switched encrypted data, a third column of the matrix including the fifth switched encrypted data, and a fourth column of the matrix including the sixth switched encrypted data.

15. The distributed video conferencing system of claim **14**, wherein the mixer sends one or more columns of the matrix to a respective client terminal.

16. The distributed video conferencing system of claim **14**, wherein the mixer sends the matrix to all of the client terminals.

17. The distributed video conferencing system of claim **14**, wherein the mixer replaces the content of a respective column of the matrix corresponding to a respective client terminal with all zeroes, before sending the matrix to the respective client terminal.

18. The distributed video conferencing system of claim **10**, wherein the first encrypted data, the second encrypted data, the third encrypted data and the fourth encrypted data are encoded by the respective client terminals before being encrypted by the respective client terminal.

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