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Kawai

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(54) ENCRYPTED TAG GENERATION APPARATUS, SEARCHABLE ENCRYPTION SYSTEM, ENCRYPTED TAG GENERATION METHOD, AND COMPUTER READABLE MEDIUM

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(51) **Int. Cl.**

H04L 29/06	(2006.01)
G06F 7/58	(2006.01)
G06F 21/60	(2013.01)
G06F 21/62	(2013.01)

(52) **U.S. Cl.**
CPC ***G06F 21/6227*** (2013.01); ***G06F 7/588*** (2013.01); ***G06F 21/602*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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(57) ABSTRACT

A logical expression acquisition unit (**502**) acquires a logical expression that represents a condition under which searchable encryption is permitted, by a logical structure with a plurality of attribute values and a logical operator. An encrypted tag generation unit (**504**) sets a secret sharing value which reflects the logical structure, to each of the plurality of attribute values, and generates an encrypted tag to be used for the searchable encryption, using a plurality of secret sharing values set to the plurality of attribute values.

6 Claims, 16 Drawing Sheets

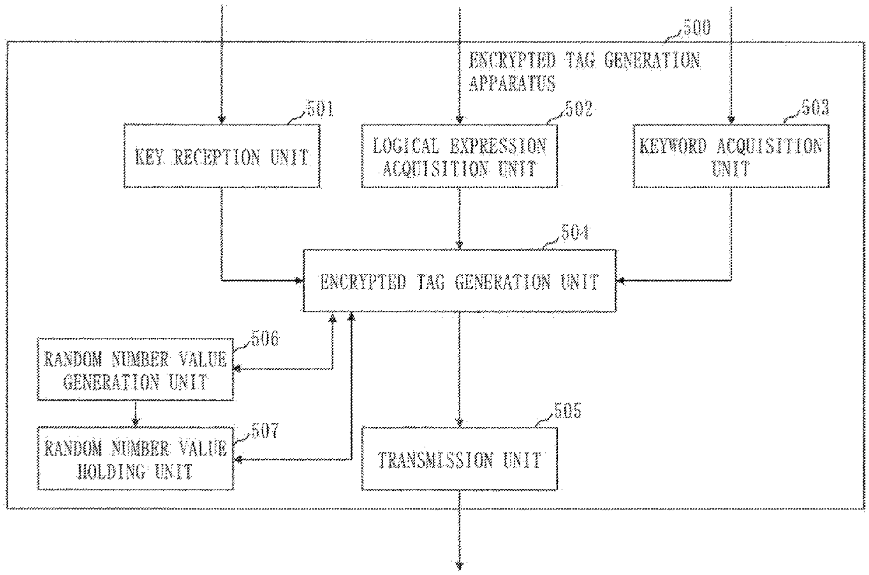
500
ENCRYPTED TAG GENERATION APPARATUS
501
KEY RECEPTION UNIT
502
LOGICAL EXPRESSION ACQUISITION UNIT
503
KEYWORD ACQUISITION UNIT
504
ENCRYPTED TAG GENERATION UNIT
506
RANDOM NUMBER VALUE GENERATION UNIT
507
RANDOM NUMBER VALUE HOLDING UNIT
505
TRANSMISSION UNIT

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Fig. 1

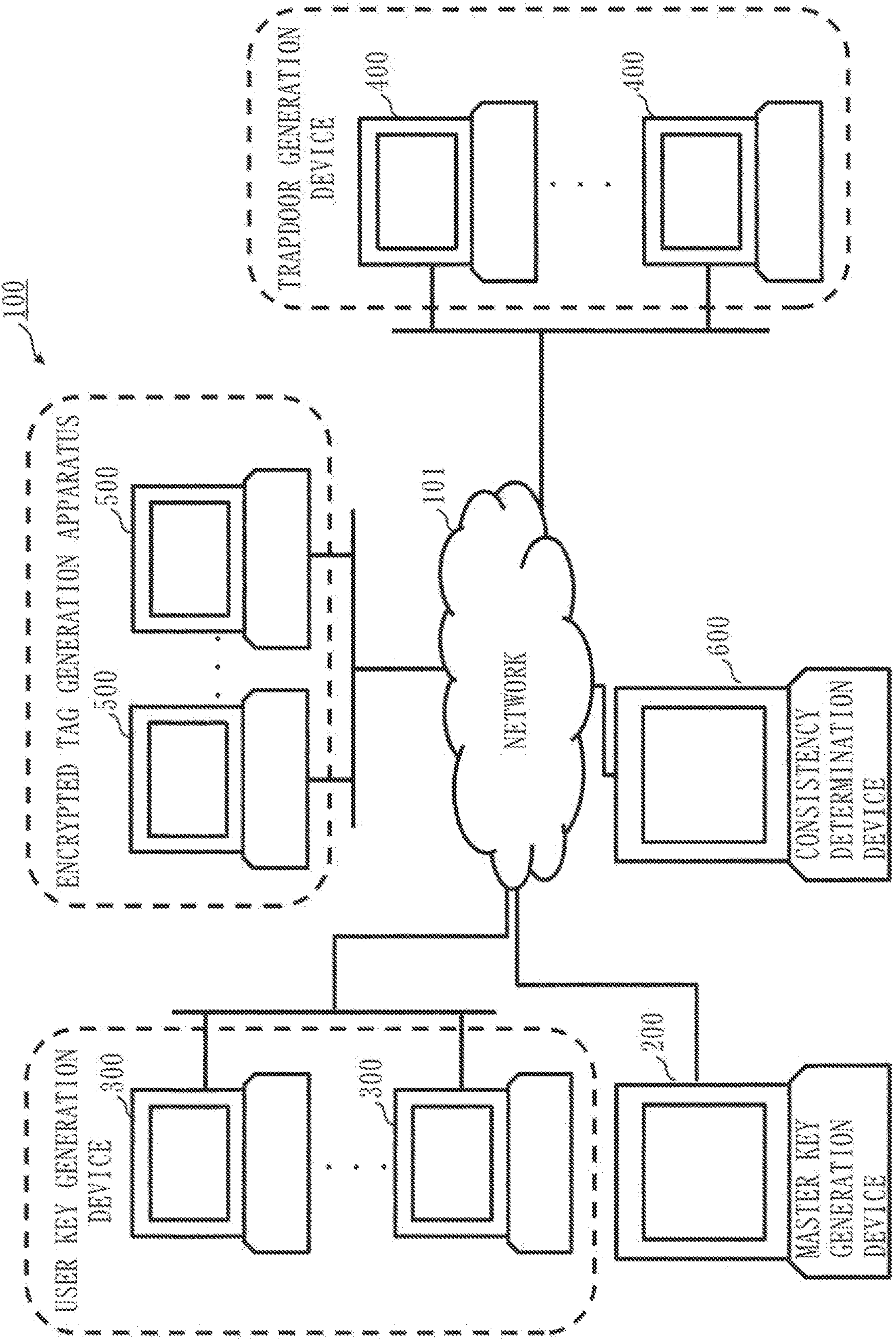

100
TRAPDOOR GENERATION DEVICE
400
400
ENCRYPTED TAG GENERATION APPARATUS
500
500
101
NETWORK
600
CONSISTENCY DETERMINATION DEVICE
USER KEY GENERATION DEVICE
300
300
200
MASTER KEY GENERATION DEVICE

Fig. 2

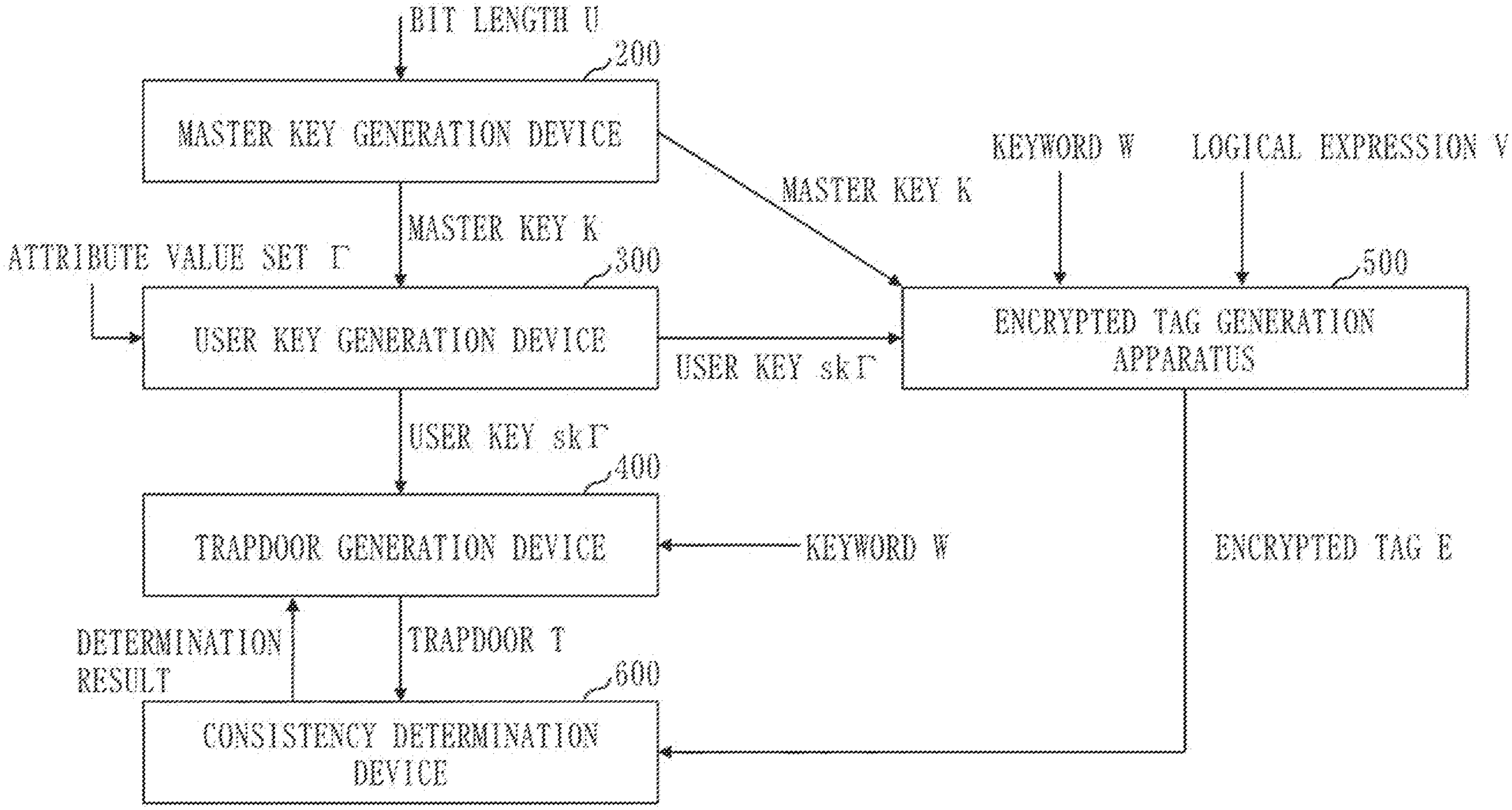

BIT LENGTH U
200
MASTER KEY GENERATION DEVICE
MASTER KEY K
MASTER KEY K
KEYWORD W
LOGICAL EXPRESSION V
ATTRIBUTE VALUE SET Γ
300
USER KEY GENERATION DEVICE
500
ENCRYPTED TAG GENERATION APPARATUS
USER KEY skΓ
USER KEY skΓ
400
TRAPDOOR GENERATION DEVICE
KEYWORD W
ENCRYPTED TAG E
DETERMINATION RESULT
TRAPDOOR T
600
CONSISTENCY DETERMINATION DEVICE

Fig. 3

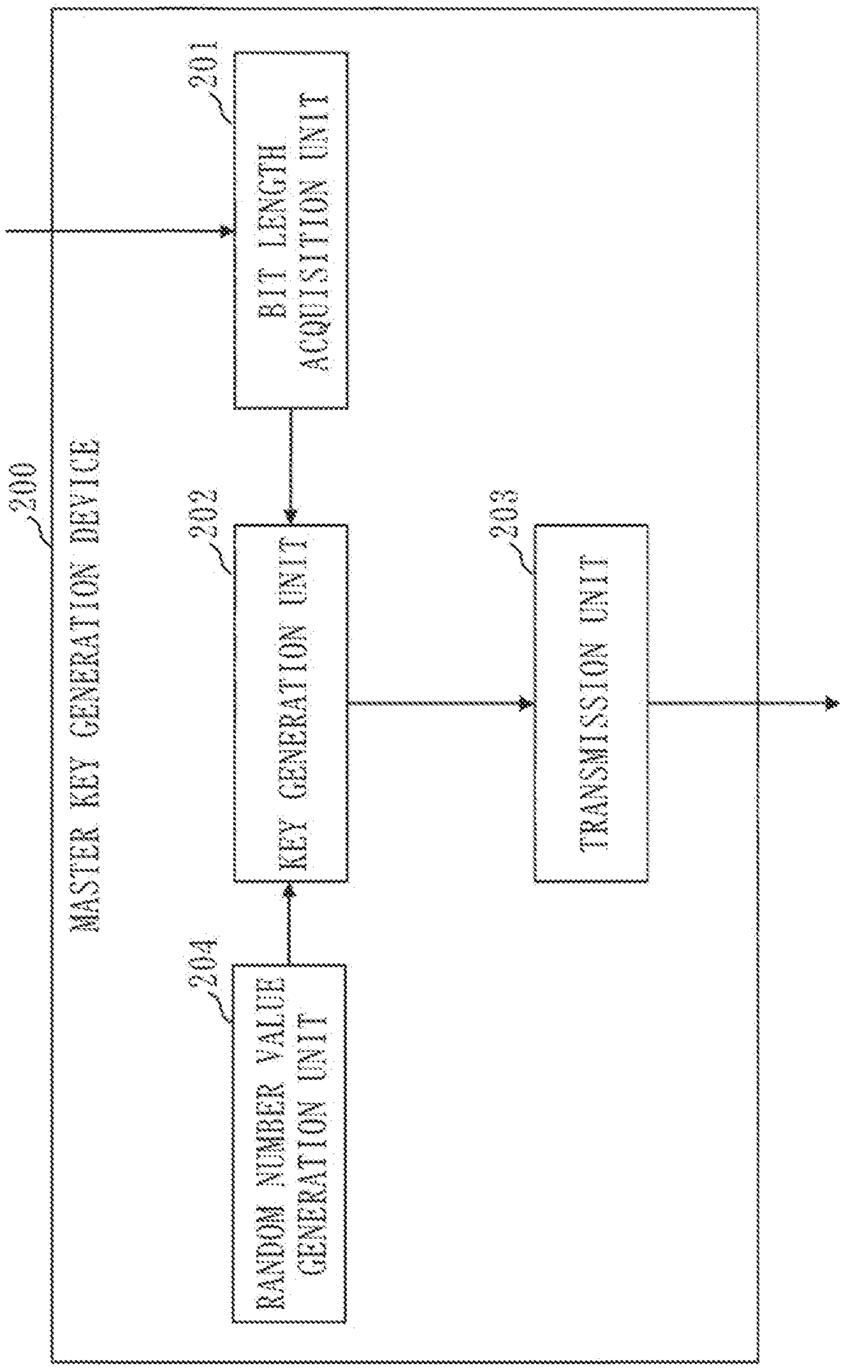

200
MASTER KEY GENERATION DEVICE
201
BIT LENGTH ACQUISITION UNIT
202
KEY GENERATION UNIT
203
TRANSMISSION UNIT
204
RANDOM NUMBER VALUE GENERATION UNIT

Fig. 4

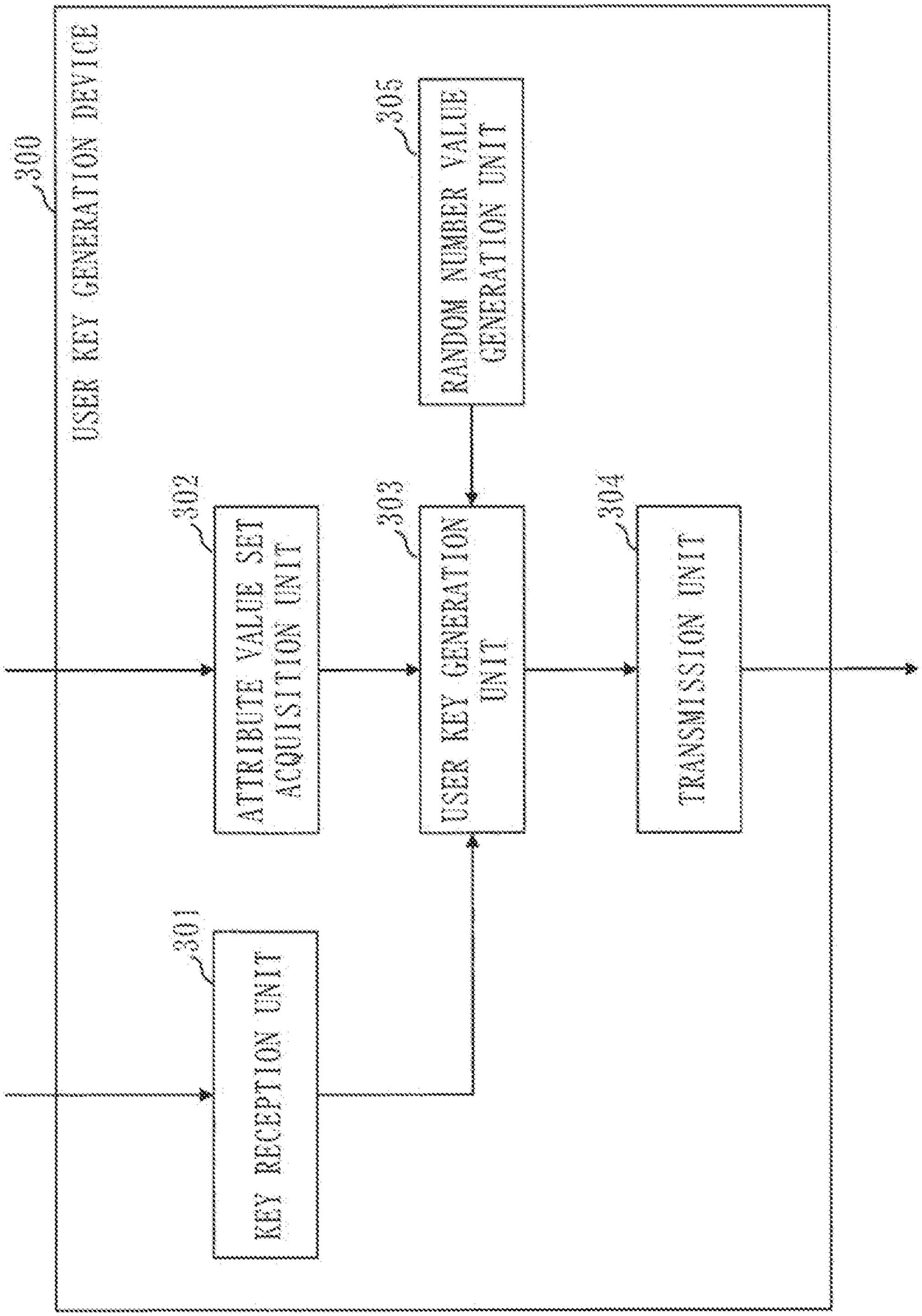

300
USER KEY GENERATION DEVICE
301
KEY RECEPTION UNIT
302
ATTRIBUTE VALUE SET ACQUISITION UNIT
303
USER KEY GENERATION UNIT
304
TRANSMISSION UNIT
305
RANDOM NUMBER VALUE GENERATION UNIT

Fig. 5

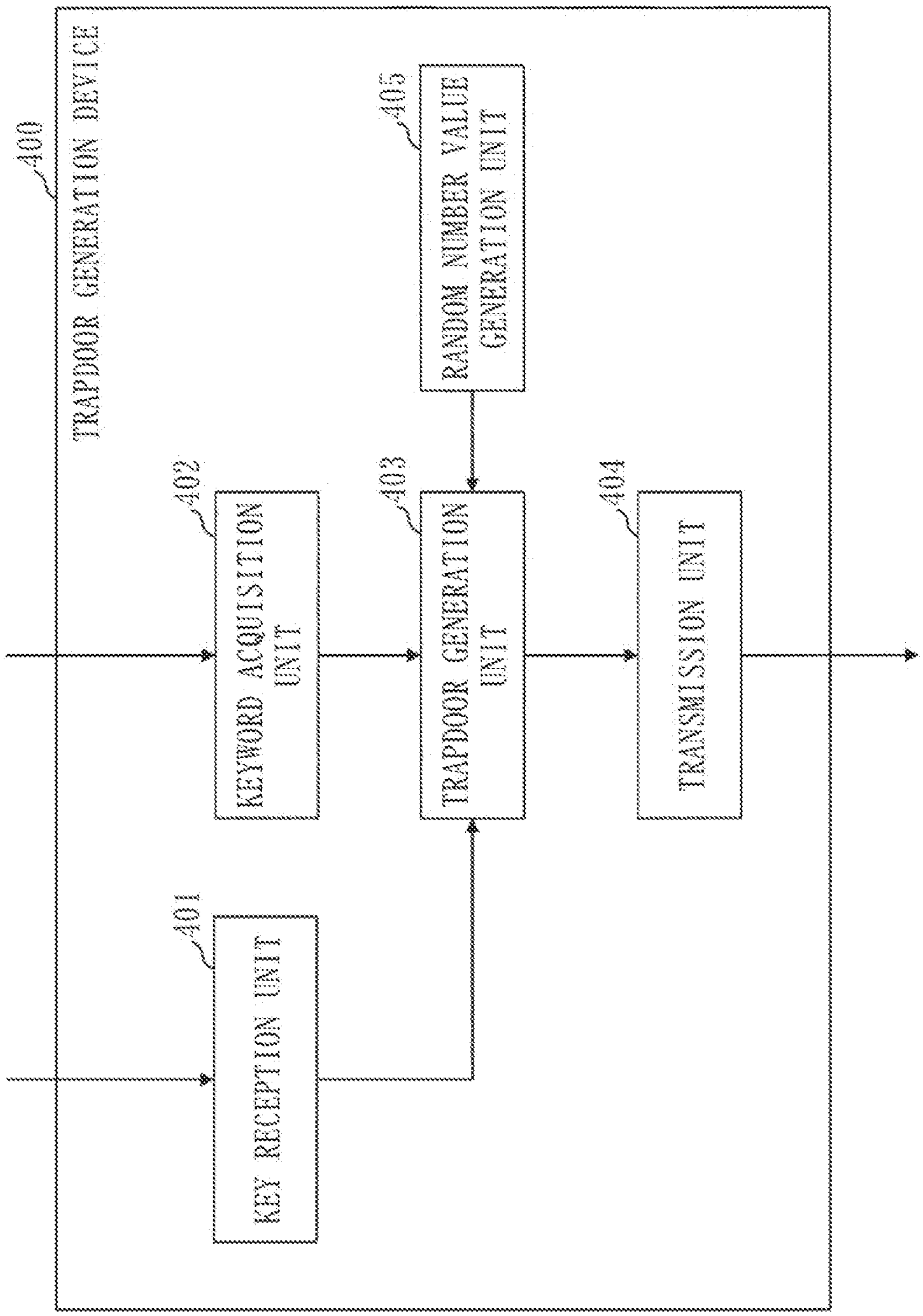

400
TRAPDOOR GENERATION DEVICE
401
KEY RECEPTION UNIT
402
KEYWORD ACQUISITION UNIT
403
TRAPDOOR GENERATION UNIT
404
TRANSMISSION UNIT
405
RANDOM NUMBER VALUE GENERATION UNIT

Fig. 6

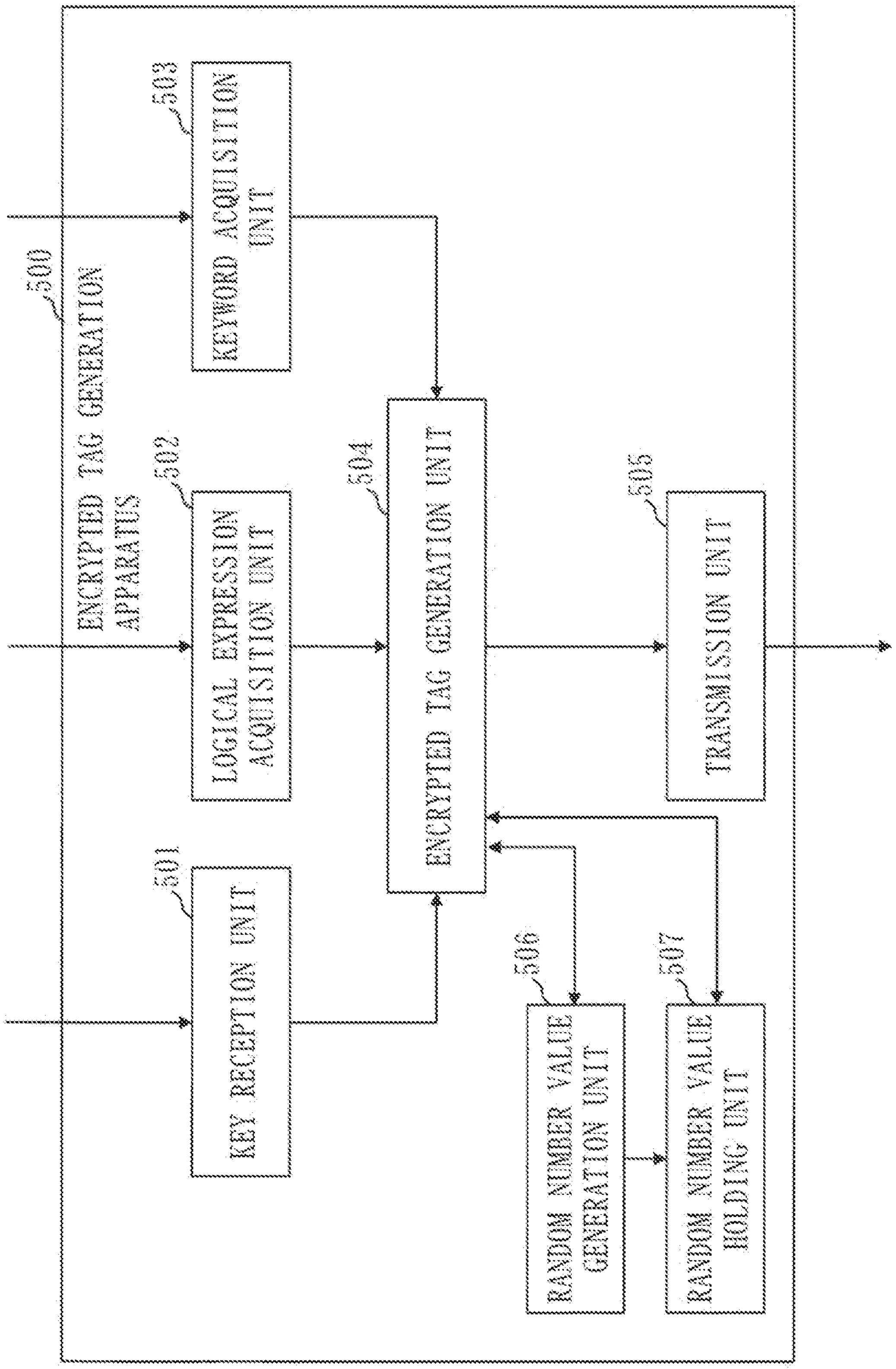

500
ENCRYPTED TAG GENERATION APPARATUS
501
KEY RECEPTION UNIT
502
LOGICAL EXPRESSION ACQUISITION UNIT
503
KEYWORD ACQUISITION UNIT
504
ENCRYPTED TAG GENERATION UNIT
505
TRANSMISSION UNIT
506
RANDOM NUMBER VALUE GENERATION UNIT
507
RANDOM NUMBER VALUE HOLDING UNIT

Fig. 7

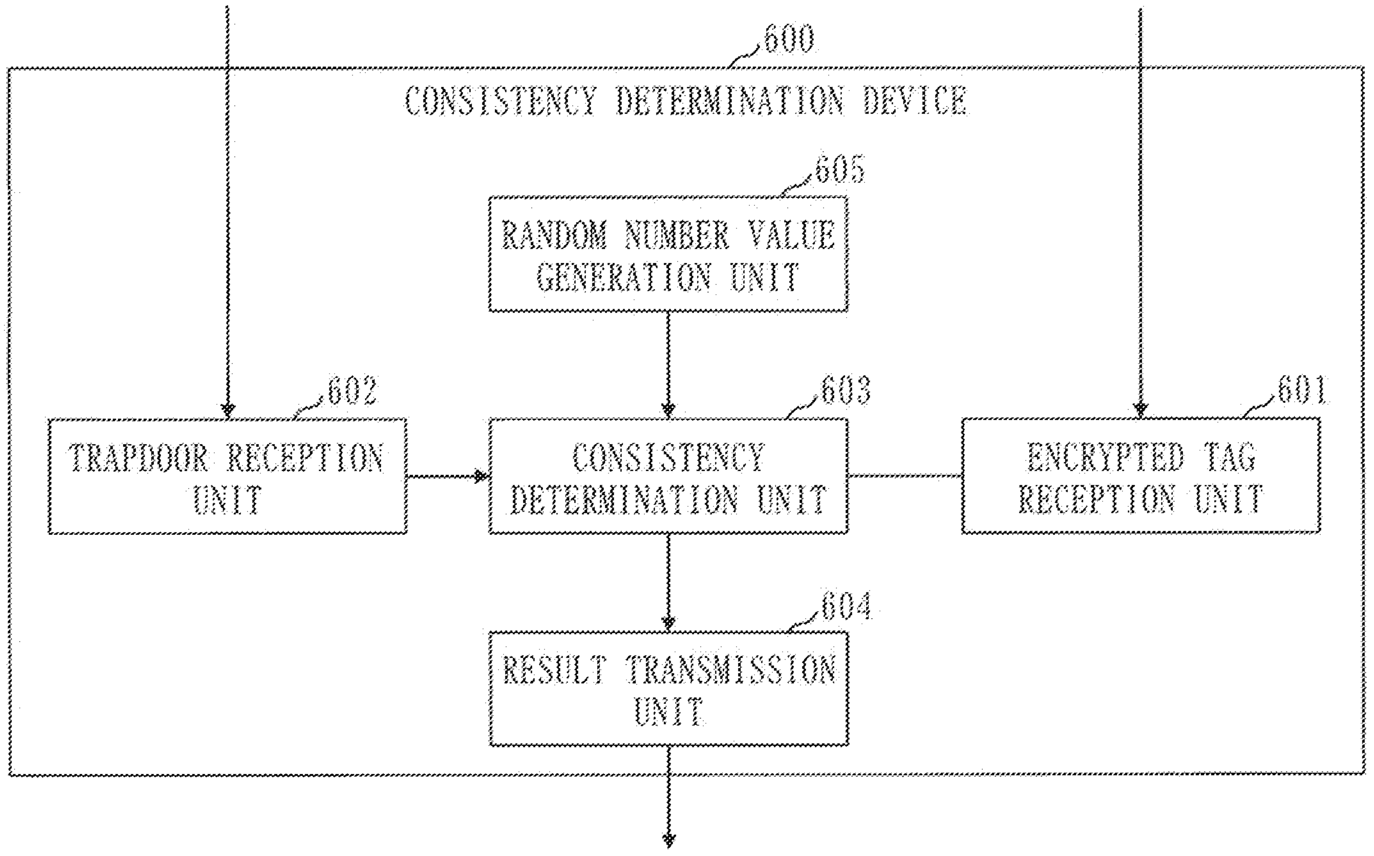

600
CONSISTENCY DETERMINATION DEVICE
605
RANDOM NUMBER VALUE GENERATION UNIT
602
TRAPDOOR RECEPTION UNIT
603
CONSISTENCY DETERMINATION UNIT
601
ENCRYPTED TAG RECEPTION UNIT
604
RESULT TRANSMISSION UNIT

Fig. 8

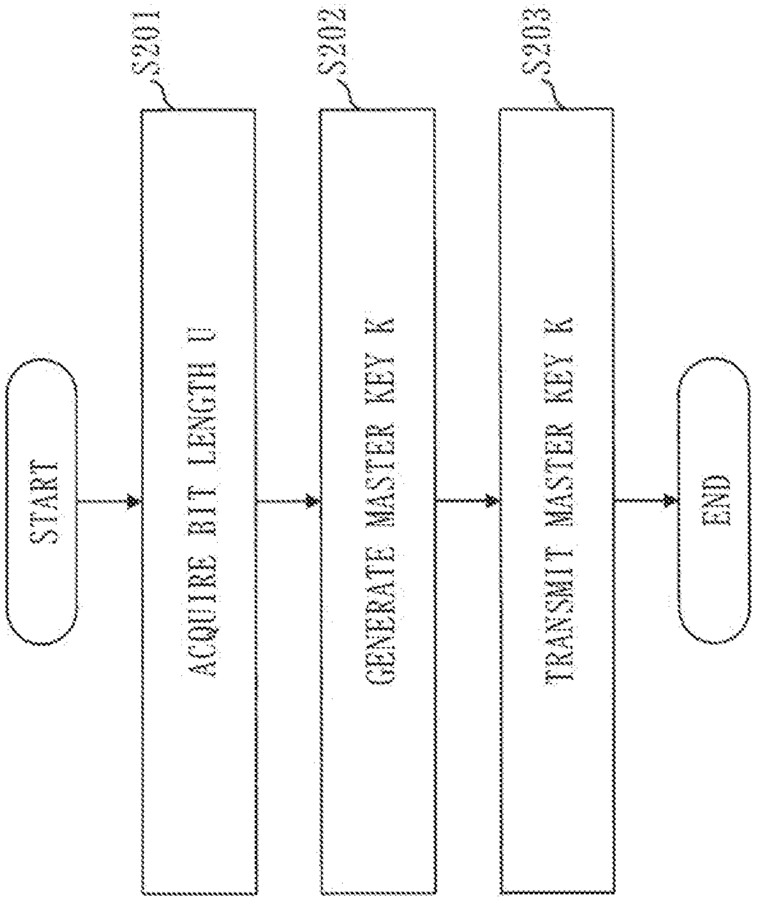

START
ACQUIRE BIT LENGTH U
S201
GENERATE MASTER KEY K
S202
TRANSMIT MASTER KEY K
S203
END

Fig. 9

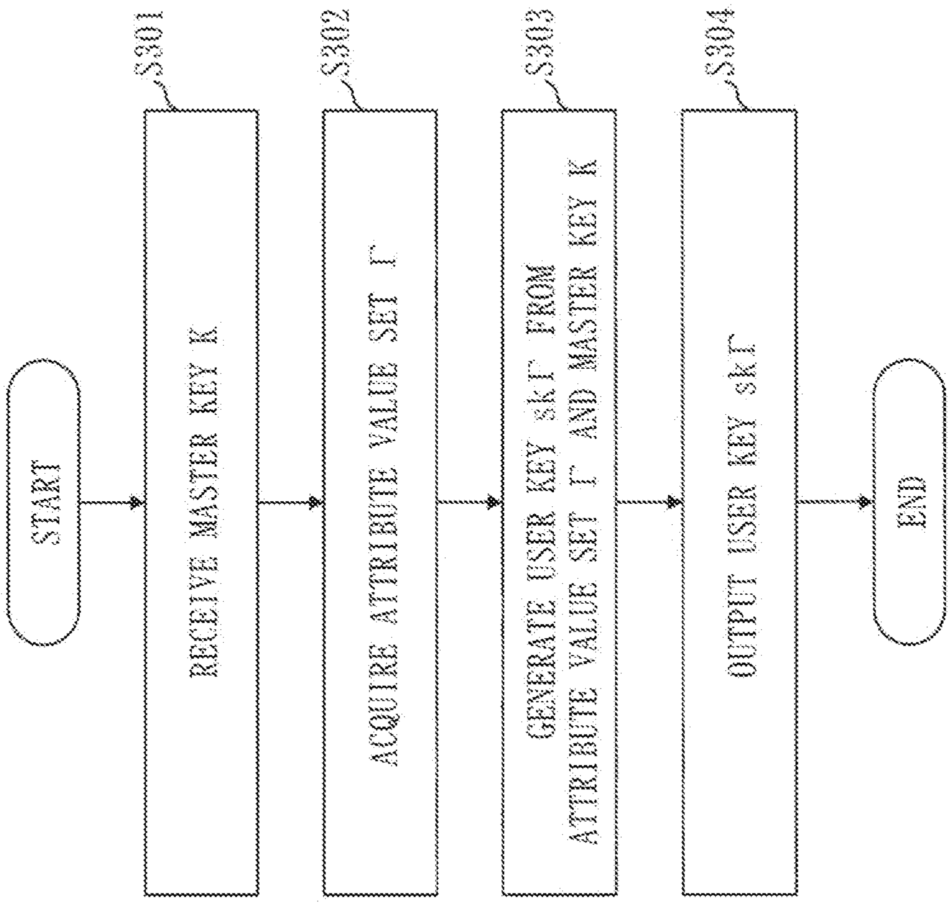

START
RECEIVE MASTER KEY K
S301
ACQUIRE ATTRIBUTE VALUE SET Γ
S302
GENERATE USER KEY skΓ FROM ATTRIBUTE VALUE SET Γ AND MASTER KEY K
S303
OUTPUT USER KEY skΓ
S304
END

Fig. 10

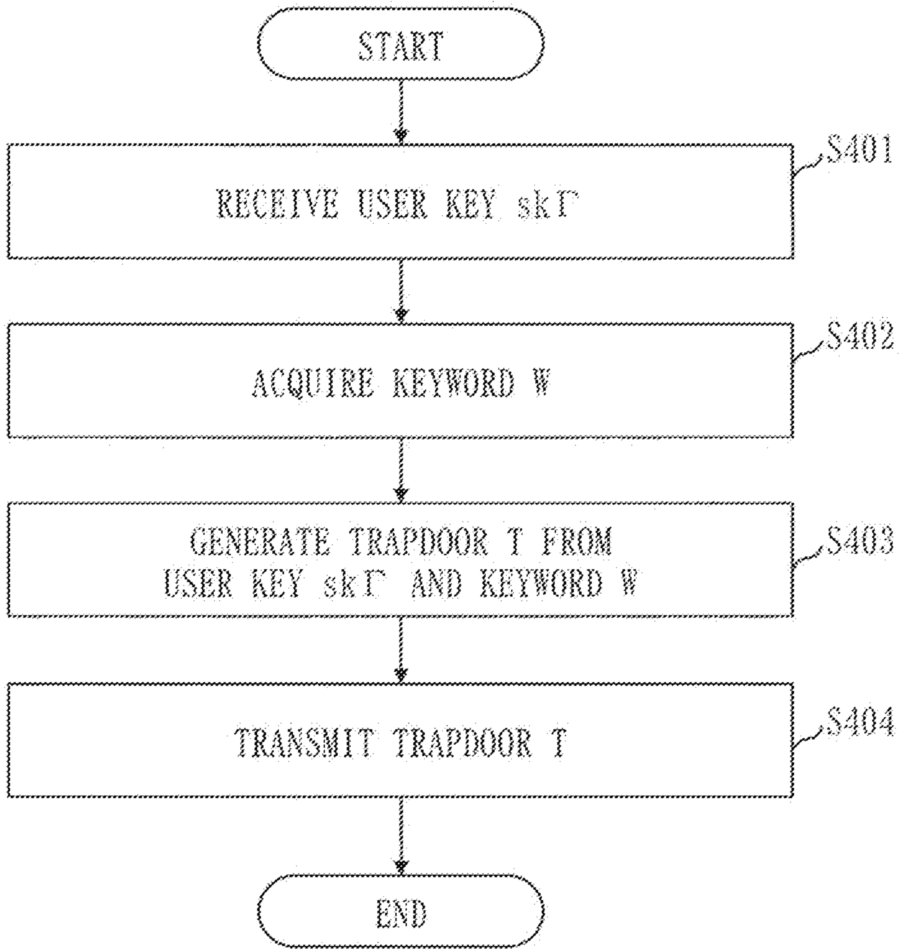

START
RECEIVE USER KEY skΓ
S401
ACQUIRE KEYWORD W
S402
GENERATE TRAPDOOR T FROM USER KEY skΓ AND KEYWORD W
S403
TRANSMIT TRAPDOOR T
S404
END

Fig. 11

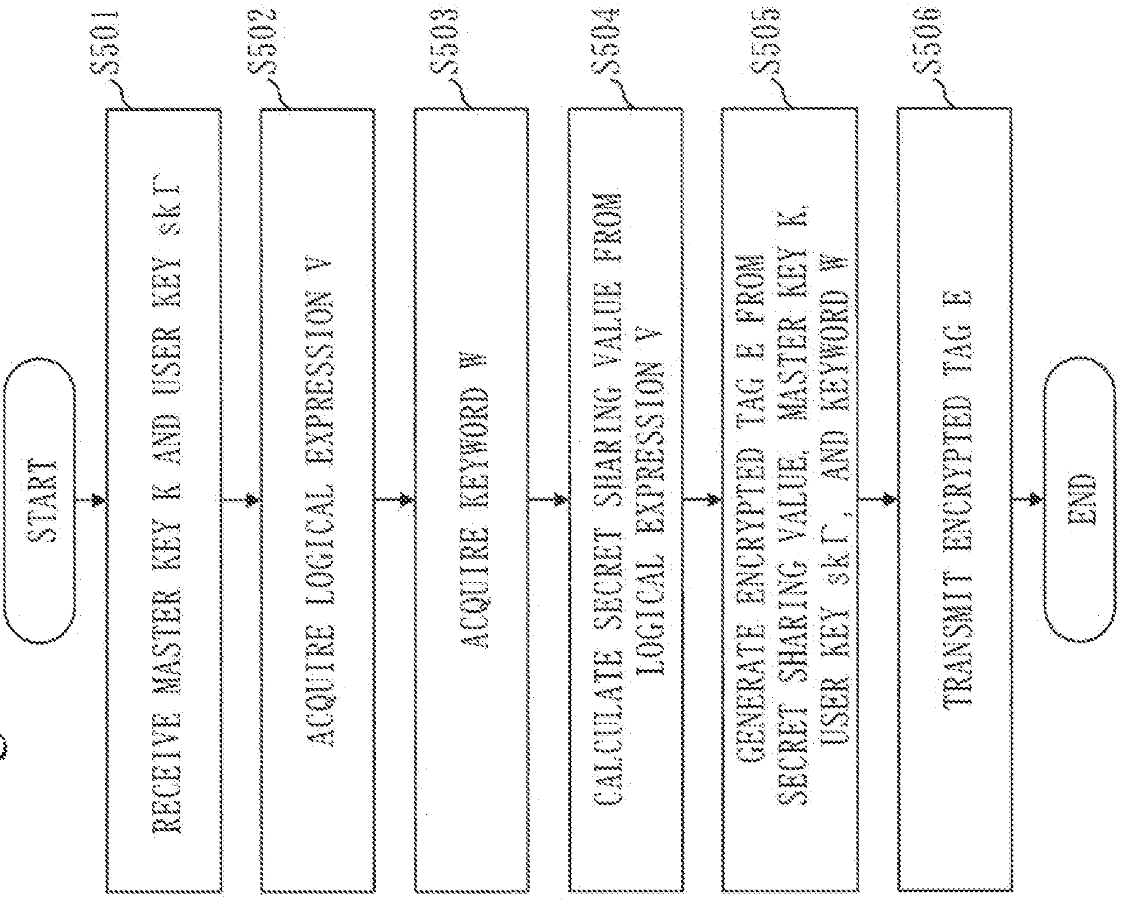

START
S501
RECEIVE MASTER KEY K AND USER KEY skΓ
S502
ACQUIRE LOGICAL EXPRESSION V
S503
ACQUIRE KEYWORD W
S504
CALCULATE SECRET SHARING VALUE FROM LOGICAL EXPRESSION V
S505
GENERATE ENCRYPTED TAG E FROM SECRET SHARING VALUE, MASTER KEY K, USER KEY skΓ, AND KEYWORD W
S506
TRANSMIT ENCRYPTED TAG E
END

Fig. 12

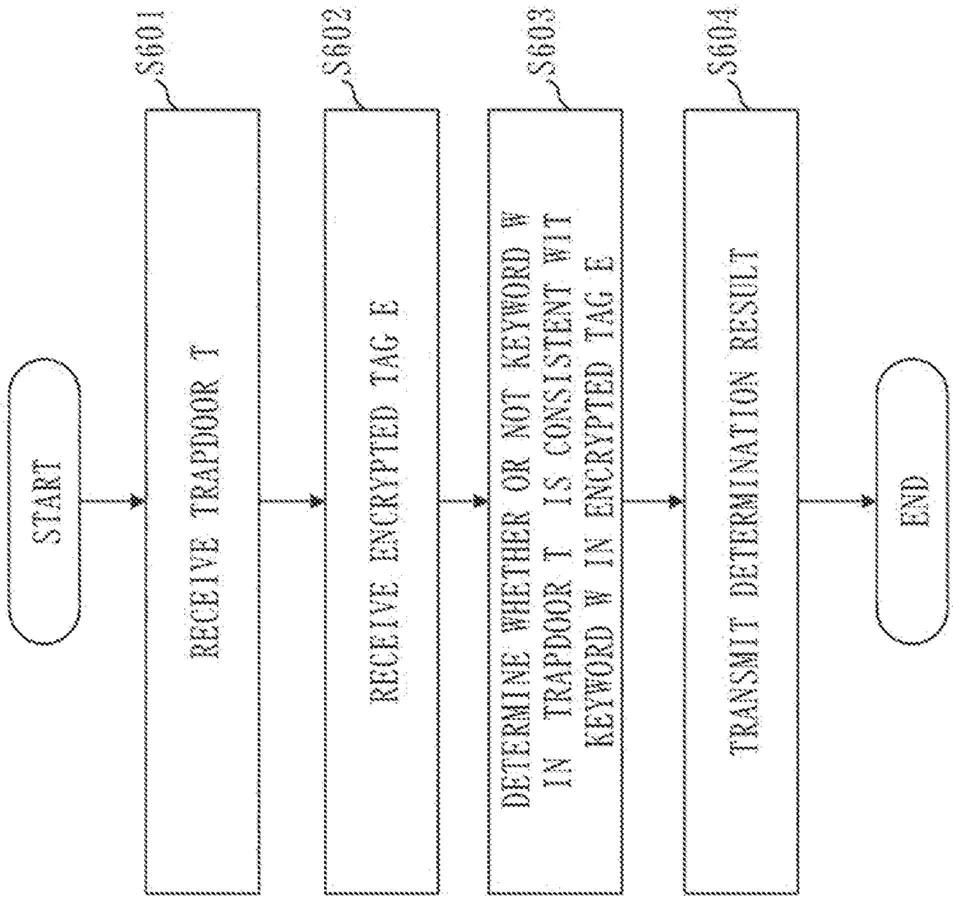

START
S601
RECEIVE TRAPDOOR T
S602
RECEIVE ENCRYPTED TAG E
S603
DETERMINE WHETHER OR NOT KEYWORD W IN TRAPDOOR T IS CONSISTENT WIT KEYWORD W IN ENCRYPTED TAG E
S604
TRANSMIT DETERMINATION RESULT
END

Fig. 13

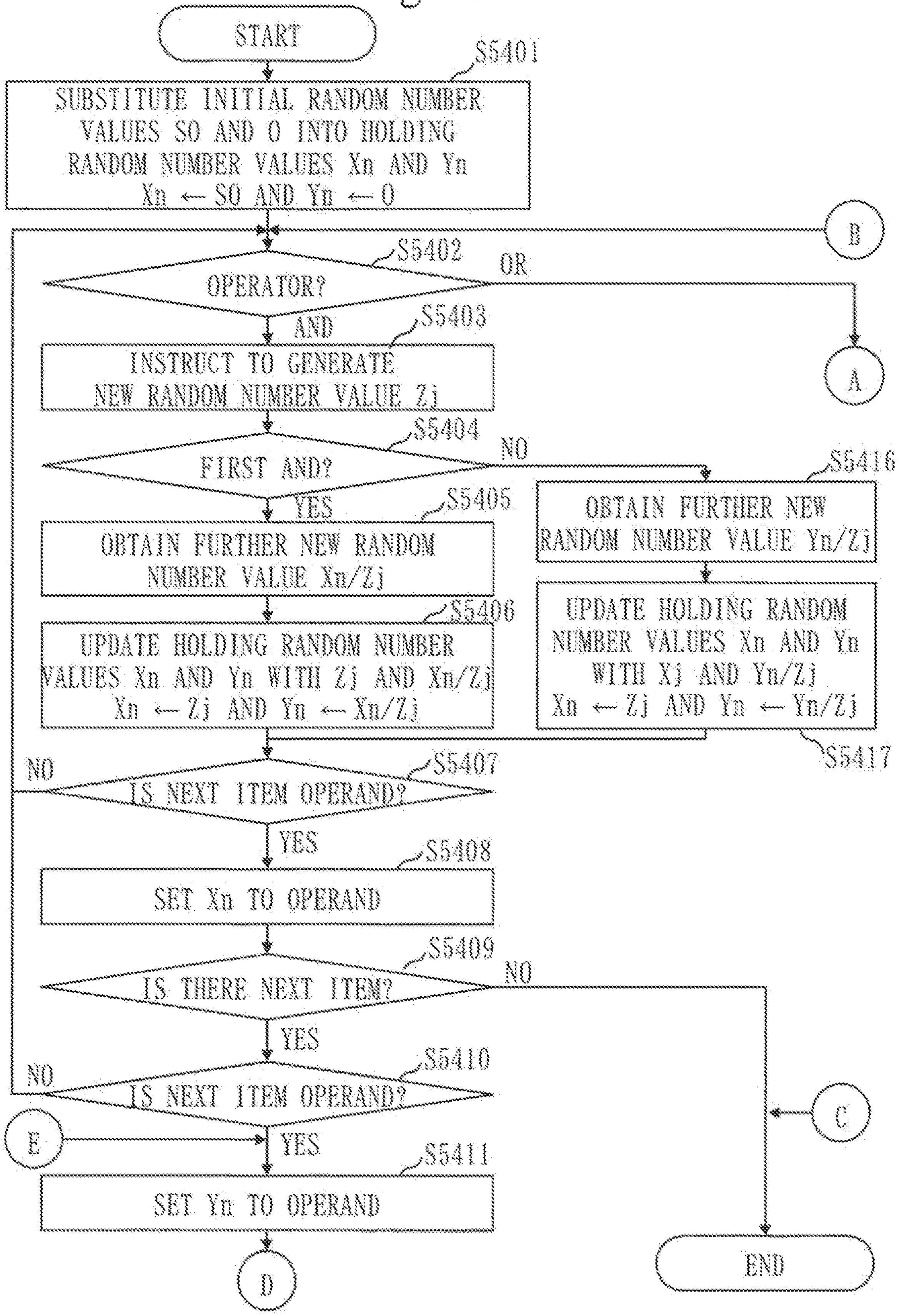

START
S5401
SUBSTITUTE INITIAL RANDOM NUMBER VALUES S0 AND 0 INTO HOLDING RANDOM NUMBER VALUES Xn AND Yn
Xn ← S0 AND Yn ← 0
B
S5402
OPERATOR?
OR
AND
A
S5403
INSTRUCT TO GENERATE NEW RANDOM NUMBER VALUE Zj
S5404
FIRST AND?
NO
YES
S5405
OBTAIN FURTHER NEW RANDOM NUMBER VALUE Xn/Zj
S5416
OBTAIN FURTHER NEW RANDOM NUMBER VALUE Yn/Zj
S5406
UPDATE HOLDING RANDOM NUMBER VALUES Xn AND Yn WITH Zj AND Xn/Zj
Xn ← Zj AND Yn ← Xn/Zj
UPDATE HOLDING RANDOM NUMBER VALUES Xn AND Yn WITH Xj AND Yn/Zj
Xn ← Zj AND Yn ← Yn/Zj
S5417
S5407
NO
IS NEXT ITEM OPERAND?
YES
S5408
SET Xn TO OPERAND
S5409
IS THERE NEXT ITEM?
NO
YES
S5410
NO
IS NEXT ITEM OPERAND?
C
E
YES
S5411
SET Yn TO OPERAND
D
END

Fig. 14

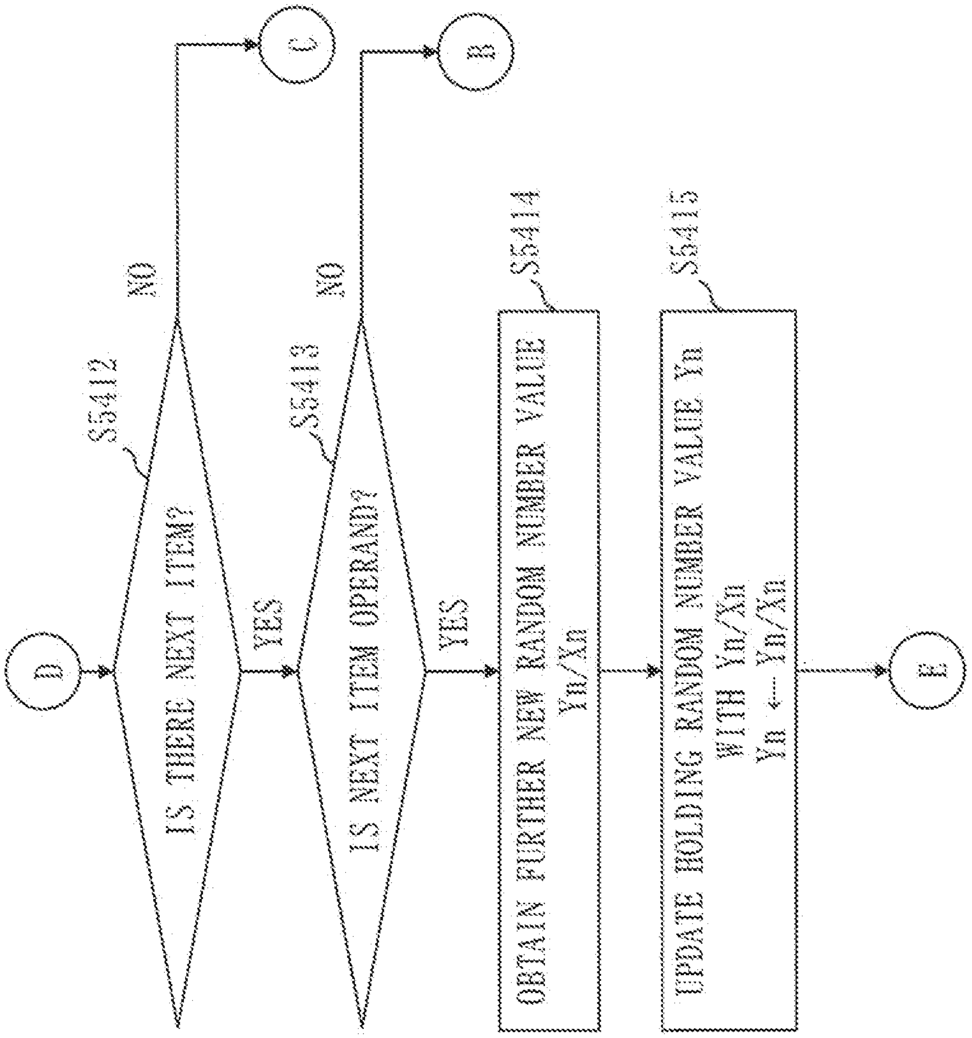

D
IS THERE NEXT ITEM?
S5412
YES
NO
C
IS NEXT ITEM OPERAND?
S5413
YES
NO
B
OBTAIN FURTHER NEW RANDOM NUMBER VALUE
Yn/Xn
S5414
UPDATE HOLDING RANDOM NUMBER VALUE Yn
WITH Yn/Xn
Yn ← Yn/Xn
S5415
E

Fig. 15

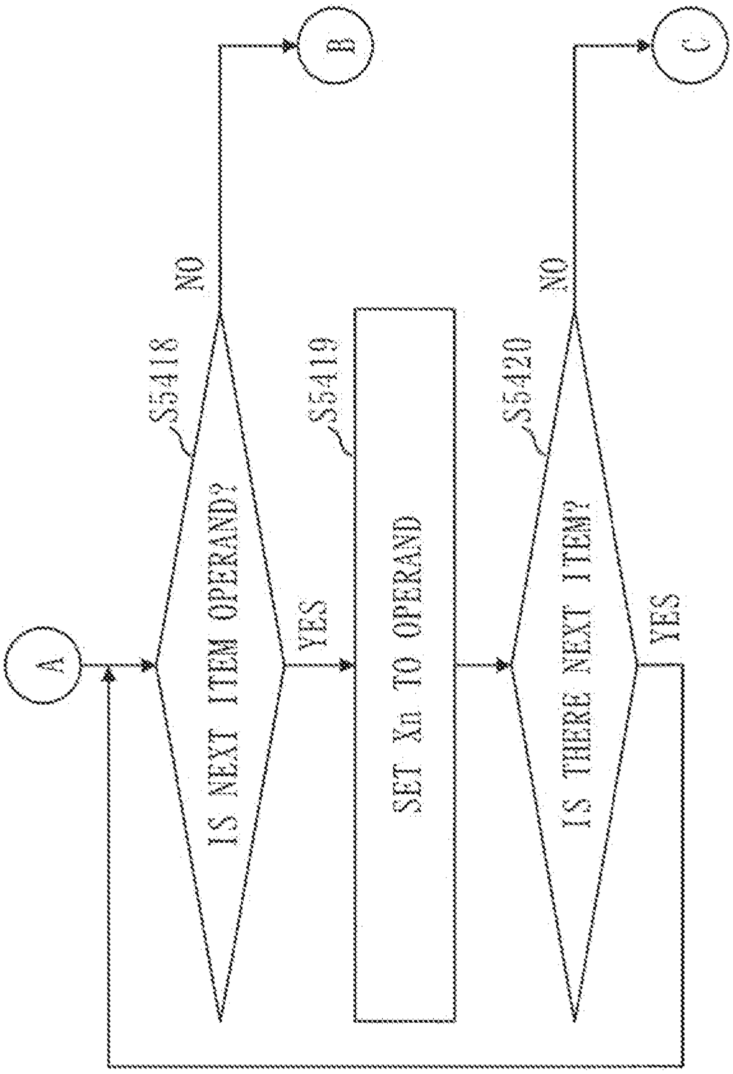
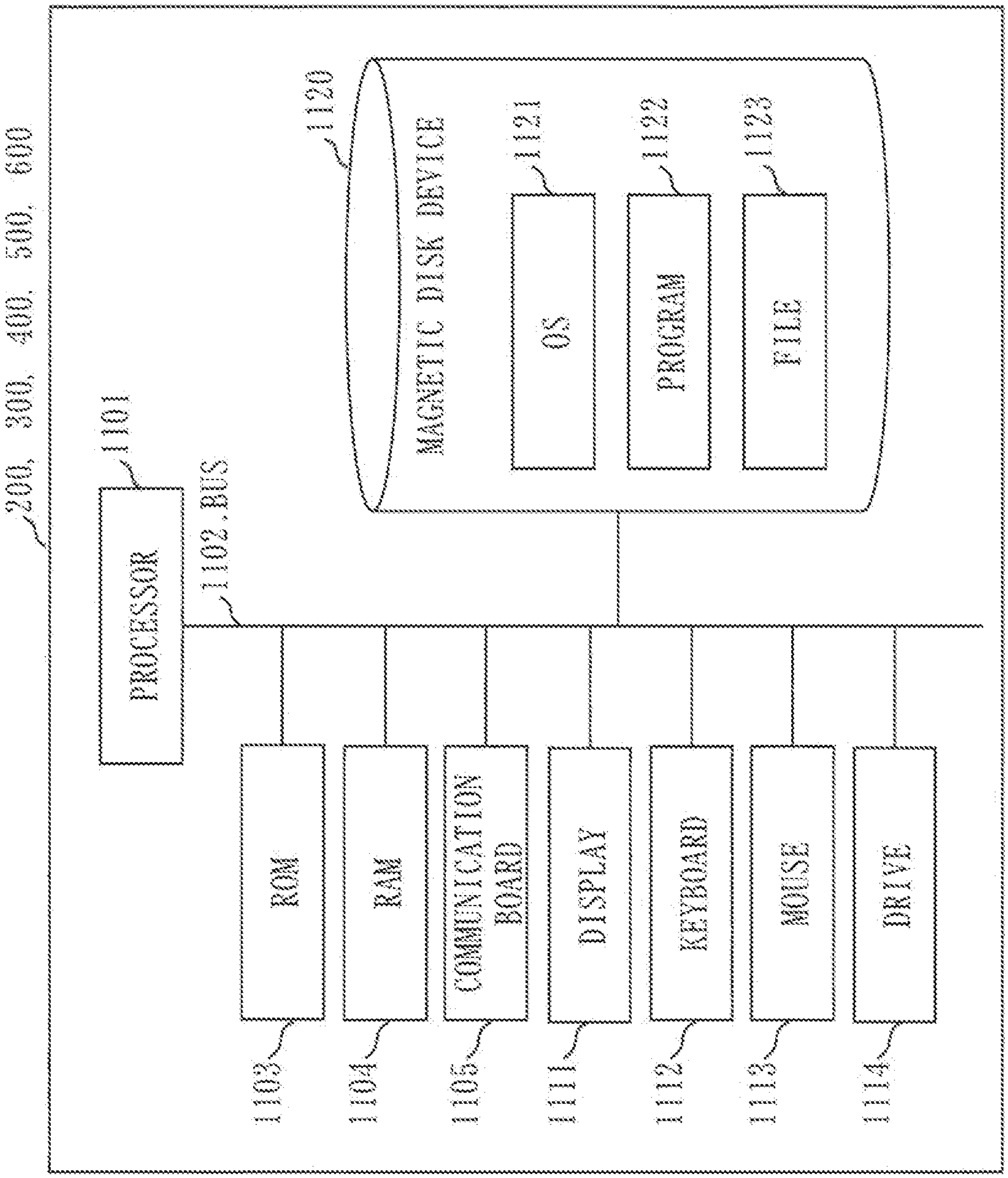

A
IS NEXT ITEM OPERAND?
S5418
YES
NO
B
SET Xn TO OPERAND
S5419
IS THERE NEXT ITEM?
S5420
YES
NO
C

Fig. 16


200, 300, 400, 500, 600
1101
PROCESSOR
1102, BUS
1120
MAGNETIC DISK DEVICE
1121
OS
1122
PROGRAM
1123
FILE
ROM
1103
RAM
1104
COMMUNICATION BOARD
1105
DISPLAY
1111
KEYBOARD
1112
MOUSE
1113
DRIVE
1114

ENCRYPTED TAG GENERATION APPARATUS, SEARCHABLE ENCRYPTION SYSTEM, ENCRYPTED TAG GENERATION METHOD, AND COMPUTER READABLE MEDIUM

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a Continuation of PCT International Application No. PCT/JP2021/022276 filed on Jun. 11, 2021, which is hereby expressly incorporated by reference into the present application.

TECHNICAL FIELD

The present disclosure relates to a searchable encryption technique.

The searchable encryption technique is a technique for searching for data (hereinafter referred to as encrypted data) that has been encrypted, using a keyword that has been encrypted while the keyword remains encrypted.

BACKGROUND ART

Nowadays, as cloud services start prevailing, cloud storage usage of which can start inexpensively and effortlessly, is being widely in use. On the other hand, when data that includes confidential information is managed in cloud, in order to avoid a risk of information leakage, it is necessary to encrypt the data and store the encrypted data.

Searchable encryption enables searching for the encrypted data without decryption, thus can achieve both safety and functionality.

The searchable encryption uses two encrypted keywords to realize the search.

The first is an encrypted tag. The encrypted tag is an encrypted keyword that is associated with encrypted data. The second is a trapdoor. The trapdoor is an encrypted keyword that is used for a search condition.

At time of registration, the encrypted data and the encrypted tag are associated with each other and registered in a storage server such as cloud storage. The encrypted tag is associated with the encrypted data itself or an identifier of the encrypted data. The encrypted tag is stored in the storage server as an encrypted index.

In the searchable encryption, a searcher transmits a trapdoor to the storage server.

The storage server finds an encrypted tag that is consistent with the trapdoor without decrypting the trapdoor. Then, the storage server extracts encrypted data associated with the encrypted tag, and transmits the extracted encrypted data to the searcher.

Thereby, in the searchable encryption, it is possible to search for data without exposing the data and a keyword.

The searchable encryption can be broadly classified into common key type searchable encryption and public key type searchable encryption.

The public key type searchable encryption uses different keys for generation of an encrypted tag and a trapdoor, while the common key type searchable encryption uses the same key for generation of an encrypted tag and a trapdoor.

Further, in general, the common key type searchable encryption can perform search at a higher speed than that of the public key type searchable encryption.

As techniques relating to the present disclosure, there are the technique described in Patent Literature 1 and the technique described in Non-Patent Literature 1.

Patent Literature 1 and Non-Patent Literature 1 describe an access control method for the common key type searchable encryption.

CITATION LIST

Patent Literature

Patent Literature 1: WO 2019/142268 A1

Non-Patent Literature

Non-Patent Literature 1: R. A. Popa, N. Zeldovich, “Multi-Key Searchable Encryption”, IACR Cryptology ePrint Archive: Report 2013/508

SUMMARY OF INVENTION

Technical Problem

In the techniques described in Patent Literature 1 and Non-Patent Literature 1, an access control pattern is decided before operation of a searchable encryption system starts, and access control is performed according to the decided access control pattern. The access control pattern is a logical expression that represents a condition under which searchable encryption is permitted, by a logical structure with a plurality of attribute values and a logical operator (simply referred to as an operator).

In the techniques described in Patent Literature 1 and Non-Patent Literature 1, the logical structure in the access control pattern is previously decided, such as a logical expression with one logical sum operator, or a logical expression with two logical product operators, for example. Then, in the techniques described in Patent Literature 1 and Non-Patent Literature 1, the access control is performed according to the previously decided logical structure.

In this way, in the techniques described in Patent Literature 1 and Non-Patent Literature 1, once the access control pattern is decided, it is not allowed to perform the access control using an access control pattern different from the decided access control pattern.

Therefore, in the techniques described in Patent Literature 1 and Non-Patent Literature 1, in order to perform the access control using a new access pattern, reconstruction of the searchable encryption system is necessary, thus there is a problem of extremely low convenience.

The present disclosure mainly aims to solve a problem such as above. That is, the present disclosure mainly aims to realize searchable encryption that enables more flexible access control.

Solution to Problem

An encrypted tag generation apparatus according to the present disclosure includes:

a logical expression acquisition unit to acquire a logical expression that represents a condition under which searchable encryption is permitted, by a logical structure with a plurality of attribute values and a logical operator; and

an encrypted tag generation unit to set a secret sharing value which reflects the logical structure, to each of the plurality of attribute values, and to generate an encrypted tag to be used for the searchable encryption, using a plurality of secret sharing values set to the plurality of attribute values.

Advantageous Effects of Invention

In the present disclosure, a secret sharing value which represents a logical structure by a logical expression is set to each attribute value, and an encrypted tag is generated using the secret sharing value set to each attribute value. Therefore, according to the present disclosure, it is possible to freely decide the logical structure represented by the logical expression, and to realize more flexible access control in searchable encryption.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a diagram illustrating a configuration example of a searchable encryption system according to Embodiment 1.

FIG. **2** is a diagram illustrating a data flow according to Embodiment 1.

FIG. **3** is a diagram illustrating a functional configuration example of a master key generation device according to Embodiment 1.

FIG. **4** is a diagram illustrating a functional configuration example of a user key generation device according to Embodiment 1.

FIG. **5** is a diagram illustrating a functional configuration example of a trapdoor generation device according to Embodiment 1.

FIG. **6** is a diagram illustrating a functional configuration example of an encrypted tag generation apparatus according to Embodiment 1.

FIG. **7** is a diagram illustrating a functional configuration example of a consistency determination device according to Embodiment 1.

FIG. **8** is a flowchart illustrating a flow of processing of the master key generation device according to Embodiment 1

FIG. **9** is a flowchart illustrating a flow of processing of the user key generation device according to Embodiment 1.

FIG. **10** is a flowchart illustrating a flow of processing of the trapdoor generation device according to Embodiment 1.

FIG. **11** is a flowchart illustrating a flow of processing of the encrypted tag generation apparatus according to Embodiment 1.

FIG. **12** is a flowchart illustrating a flow of processing of the consistency determination device according to Embodiment 1.

FIG. **13** is a flowchart illustrating details of processing of the encrypted tag generation apparatus according to Embodiment 1.

FIG. **14** is a flowchart illustrating details of processing of the encrypted tag generation apparatus according to Embodiment 1.

FIG. **15** is a flowchart illustrating details of processing of the encrypted tag generation apparatus according to Embodiment 1.

FIG. **16** is a diagram illustrating an example of hardware resources of the searchable encryption system according to Embodiment 1.

DESCRIPTION OF EMBODIMENTS

Embodiments will be described hereinafter with reference to the drawings. In the following description of the embodiments and the drawings, portions denoted by the same reference signs indicate the same or corresponding portions.

Embodiment 1

Overview

The present embodiment describes a searchable encryption system that realizes flexible access control in common key type searchable encryption.

In the searchable encryption system according to the present embodiment, an encrypted tag is generated using a logical expression that represents a condition (hereinafter referred to as a searchable condition) of a user who is permitted to perform searchable encryption, by a logical structure with a plurality of attribute values (values that represent a job title, a division which the user belongs to, and the like) and a logical operator (a logical sum operator or a logical product operator). Then, in the searchable encryption system according to the present embodiment, there is no need to set a constraint on the length of the logical expression (that is, the number of attribute values included in the logical expression) used for generation of the encrypted tag. Therefore, the flexible access control is possible.

In order to enable the logical expression whose length has no constraint, it is necessary to generate a parameter for each attribute value. Conventionally, since there is only one parameter, it is necessary to decide in advance how may attribute values are included in the one parameter, that is, the length of the logical expression the one parameter should generate. In the searchable encryption system according to the present embodiment, since a parameter is generated for each attribute value, no upper limit is needed on the number of attribute values included in the logical expression. When a parameter is generated for each attribute value in this way, the encrypted tag needs to accurately reflect the logical structure of the logical expression.

For example, a logical expression "A AND B" and a logical expression "A OR B" include the same two attribute values (A and B). In this case, encrypted tags need be generated so that logical structures represented by the two logical expressions are distinguished from each other. That is, the encrypted tags need be generated so that it is distinguishable that a logical operator included in each logical expression is the logical product operator (AND) or the logical sum operator (OR).

In the present embodiment, a secret sharing value which reflects a logical structure of a logical expression is set to each attribute value, and an encrypted tag is generated using the secret sharing value set to each attribute value. That is, when the logical product operator (AND) is included in the logical expression, to each of attribute values (logical product attribute values) which are connected by the logical product operator (AND), a secret sharing value which reflects that each of logical product attribute values is connected by the logical product operator (AND) is set. Further, when the logical sum operator (OR) is included in the logical expression, to each of attribute values (logical sum attribute values) which are connected by the logical sum operator (OR), a secret sharing value which reflects that each of logical sum attribute values is connected by the logical sum operator (OR) is set.

Specifically, in a case of the logical expression "A AND B" described above, a secret sharing value s**1** is set to an attribute value A, and a secret sharing value s**2** is set to an attribute value B, where s=s**1**+s**2**. Further, in a case of the logical expression "A OR B", the secret sharing value s is set to both of the attribute value A and the attribute value B.

Thus, in the searchable encryption system according to the present embodiment, it is possible to freely decide a logical structure represented by a logical expression, and to realize more flexible access control than the conventional.

Description of Functional Configuration

FIG. **1** illustrates a configuration example of a searchable encryption system **100** according to the present embodiment.

As illustrated in FIG. **1**, the searchable encryption system **100** includes a master key generation device **200**, a plurality of user key generation devices **300**, a plurality of trapdoor generation devices **400**, a plurality of encrypted tag generation apparatuses **500**, and a consistency determination device **600**.

The master key generation device **200**, the plurality of user key generation devices **300**, the plurality of trapdoor generation devices **400**, the plurality of encrypted tag generation apparatuses **500**, and the consistency determination device **600** are interconnected via a network **101**.

The network **101** is, for example, the Internet.

A network other than the Internet may be used as the network **101**. For example, a Local Area Network (LAN) may be used as the network **101**. When the LAN is used as the network **101**, the master key generation device **200**, the plurality of user key generation devices **300**, the plurality of trapdoor generation devices **400**, the plurality of encrypted tag generation apparatuses **500**, and the consistency determination device **600** are installed within the same company.

Each of the master key generation device **200**, the user key generation device **300**, the trapdoor generation device **400**, the encrypted tag generation apparatus **500**, and the consistency determination device **600** is a computer.

Each of the master key generation device **200**, the user key generation device **300**, the trapdoor generation device **400**, the encrypted tag generation apparatus **500**, and the consistency determination device **600** is, for example, a Personal Computer (PC). The consistency determination device **600** is, for example, a storage server.

The master key generation device **200** generates a master key K according to a bit length U.

Then, as illustrated in FIG. **2**, the master key generation device **200** transmits the generated master key K to the user key generation device **300** and the encrypted tag generation apparatus **500**, via the network **101**.

As illustrated in FIG. **2**, the user key generation device **300** receives the master key K.

Further, the master key generation device **200** acquires an attribute value set Γ which is a set of attribute values of a user, and generates a user key skΓ, using the master key K and the attribute value set Γ.

Then, the user key generation device **300** transmits the generated user key skΓ to the trapdoor generation device **400** and the encrypted tag generation apparatus **500**, via the network **101**. The user key skΓ may be sent by means such as mail without going through the network **101**.

As illustrated in FIG. **2**, the trapdoor generation device **400** receives the user key skΓ.

Further, the trapdoor generation device **400** acquires a keyword W, and generates a trapdoor T, using the user key skΓ and the keyword W. The keyword W is a keyword used for searchable encryption.

Then, the trapdoor generation device **400** transmits the generated trapdoor T to the consistency determination device **600** via the network **101**.

As illustrated in FIG. **2**, the encrypted tag generation apparatus **500** receives the master key K and the user key skΓ.

Further, the encrypted tag generation apparatus **500** acquires a keyword W and a logical expression V, and generates an encrypted tag E, using the master key K, the user key skΓ, the keyword W, and the logical expression V.

As described above, the logical expression V is a logical expression that represents a searchable condition by a logical structure with a plurality of attribute values and a logical operator. The searchable condition is a condition of an attribute of a user under which searchable encryption is permitted.

The encrypted tag generation apparatus **500** transmits the generated encrypted tag E to the consistency determination device **600**, via the network **101**.

An operation procedure of the encrypted tag generation apparatus **500** is equivalent to an encrypted tag generation method. Further, a program that implements operation of the encrypted tag generation apparatus **500** is equivalent to an encrypted tag generation program.

As illustrated in FIG. **2**, the consistency determination device **600** receives the trapdoor T and the encrypted tag E.

Then, the consistency determination device **600** determines whether or not the keyword W included in the trapdoor T and the keyword W included in the encrypted tag E are consistent with each other.

Then, the consistency determination device **600** transmits a determination result to the trapdoor generation device **400**, via the network **101**.

FIG. **3** illustrates a functional configuration example of the master key generation device **200** according to the present embodiment.

As illustrated in FIG. **3**, the master key generation device **200** includes a bit length acquisition unit **201**, a key generation unit **202**, a transmission unit **203**, and a random number value generation unit **204**.

Although it is not illustrated, the master key generation device **200** includes a storage medium for storing data used in each element illustrated in FIG. **3**.

The bit length acquisition unit **201** acquires the bit length U of a key used in the searchable encryption system **100**.

The key generation unit **202** generates the master key K which is a basis for computation to be performed in the searchable encryption system **100** in such a way that the master key K conforms to the bit length U, according to a common key searchable encryption scheme.

The key generation unit **202** generates the master key K, using a random number value generated by the random number value generation unit **204**.

The random number value generation unit **204** generates the random number value used for the generation of the master key K.

The transmission unit **203** transmits the master key K generated by the key generation unit **202**, to the user key generation device **300** and the encrypted tag generation apparatus **500**.

FIG. **4** illustrates a functional configuration example of the user key generation device **300** according to the present embodiment.

As illustrated in FIG. **4**, the user key generation device **300** includes a key reception unit **301**, an attribute value set acquisition unit **302**, a user key generation unit **303**, a transmission unit **304**, and a random number value generation unit **305**.

Although it is not illustrated, the user key generation device **300** includes a storage medium for storing data used in each element illustrated in FIG. **4**.

The key reception unit **301** receives the master key K from the master key generation device **200**.

The attribute value set acquisition unit **302** acquires the attribute value set Γ which is a set of attribute values of a user to be set to a user key.

The user key generation unit **303** generates the user key skΓ, using the master key K, the attribute value set Γ, and a random number value generated by the random number value generation unit **305**.

The random number value generation unit **305** generates the random number value used for the generation of the user key skΓ.

The transmission unit **304** transmits the user key skΓ generated by the user key generation unit **303**, to the trapdoor generation device **400** and the encrypted tag generation apparatus **500**.

FIG. **5** illustrates a functional configuration example of the trapdoor generation device **400** according to the present embodiment.

As illustrated in FIG. **5**, the trapdoor generation device **400** includes a key reception unit **401**, a keyword acquisition unit **402**, a trapdoor generation unit **403**, a transmission unit **404**, and a random number value generation unit **405**.

Although it is not illustrated, the trapdoor generation device **400** includes a storage medium for storing data used in each element illustrated in FIG. **5**.

The key reception unit **401** receives the user key skΓ from the user key generation device **300**.

The keyword acquisition unit **402** acquires the keyword W.

The trapdoor generation unit **403** generates the trapdoor T, using the user key skΓ, the keyword W, and a random number value generated by the random number value generation unit **405**.

The trapdoor generation unit **403** generates the trapdoor T, using a random number value (a common random number value) common to a plurality of trapdoors T.

The random number value generation unit **405** generates the random number value used for the generation of the trapdoor T.

The transmission unit **404** transmits the trapdoor T generated by the trapdoor generation unit **403**, to the consistency determination device **600**.

FIG. **6** illustrates a functional configuration example of the encrypted tag generation apparatus **500** according to the present embodiment.

As illustrated in FIG. **6**, the encrypted tag generation apparatus **500** includes a key reception unit **501**, a logical expression acquisition unit **502**, a keyword acquisition unit **503**, an encrypted tag generation unit **504**, a transmission unit **505**, a random number value generation unit **506**, and a random number value holding unit **507**.

Although it is not illustrated, the encrypted tag generation apparatus **500** includes a storage medium for storing data used in each element illustrated in FIG. **6** except for the random number value generation unit **506** and the random number value holding unit **507**. As described below, a random number value generated by the random number value generation unit **506** is held as a holding random number value. The holding random number value is used in a secret sharing value. In order to more clearly show that the random number value is held as the holding random number value, FIG. **6** particularly illustrates the random number value holding unit **507** that holds the random number value.

The key reception unit **501** receives the master key K and the user key skΓ.

The logical expression acquisition unit **502** acquires the logical expression V that represents a searchable condition L.

A process performed by the logical expression acquisition unit **502** is equivalent to a logical expression acquisition process.

The keyword acquisition unit **503** acquires the keyword W.

The encrypted tag generation unit **504** generates the encrypted tag E, using the master key K, the user key skΓ, the logical expression V, the keyword W, the random number value generated by the random number value generation unit **506**, and the holding random number value held by the random number value holding unit **507**.

A process performed by the encrypted tag generation unit **504** is equivalent to an encrypted tag generation process.

The random number value generation unit **506** generates the random number value used for the generation of the encrypted tag E.

The random number value holding unit **507** holds the random number value generated by the random number value generation unit **506**.

When the random number value generation unit **506** generates a new random number value and the encrypted tag generation unit **504** generates a further new random number value, the random number value holding unit **507** updates the holding random number value with the new random number value and/or the further new random number value.

The transmission unit **505** transmits the encrypted tag E generated by the encrypted tag generation unit **504**, to the consistency determination device **600**.

FIG. **7** illustrates a functional configuration example of the consistency determination device **600** according to the present embodiment.

As illustrated in FIG. **7**, the consistency determination device **600** includes an encrypted tag reception unit **601**, a trapdoor reception unit **602**, a consistency determination unit **603**, a result transmission unit **604**, and a random number value generation unit **605**.

Although it is not illustrated, the consistency determination device **600** includes a storage medium for storing data used in each element illustrated in FIG. **7**.

The encrypted tag reception unit **601** receives the encrypted tag E.

The trapdoor reception unit **602** receives the trapdoor T.

The consistency determination unit **603** performs consistency determination.

Specifically, the consistency determination unit **603** determines whether or not the keyword W included in the encrypted tag E is consistent with the keyword W included in the trapdoor T, using a random number value generated by the random number value generation unit **605**.

The result transmission unit **604** transmits a determination result of the consistency determination unit **603**, to the trapdoor generation device **400**.

For example, when the consistency determination unit **603** determines that the keyword W included in the encrypted tag E is consistent with the keyword W included in the trapdoor T, the result transmission unit **604** transmits "0" as the determination result. On the other hand, when inconsistency is determined, the result transmission unit **604** transmits "1" as the determination result. The result transmission unit **604** may use other numerical values, characters, or symbols, as the determination result.

When the keyword W included in the encrypted tag E is consistent with the keyword W included in the trapdoor T, the result transmission unit **604** may acquire **20** from, for example, a database not illustrated, encrypted data associated with the encrypted tag E, instead of the transmission of the determination result. Then, the result transmission unit **604** may transmit the acquired encrypted data to the trapdoor generation device **400**.

Regarding Cryptography

Next, cryptography that is a premise for operation of the searchable encryption system **100** according to the present embodiment will be described.

Attribute-based encryption is cryptography which enables decryption only by a user who possesses a user key generated from an attribute value set Γ which is a set of attribute values that satisfy a searchable condition L. The attribute-based encryption is composed of, for example, algorithms described below.

Setup ABESETUP

A master key K and a public key pk corresponding to an acquired bit length, are generated.

User Key Generation ABEKEYGEN

A user key skΓ corresponding to the attribute value set Γ is generated using the master key K and the attribute value set Γ.

Encryption ABEENC

A key KK for common key encryption is generated using the public key pk and the searchable condition L, and a ciphertext P is generated using the key KK.

Decryption ABEDEC

It is determined using the user key skΓ and the ciphertext P, whether or not the attribute value set Γ is consistent with the searchable condition L used when the ciphertext P is generated. When the attribute value set Γ is consistent with the searchable condition L, the key KK used for the encryption of the ciphertext P is output.

In common key cryptography, a plaintext M is encrypted using the master key K. Further, in the common key cryptography, a ciphertext C is decrypted using the master key K to obtain the plaintext M.

The master key K is a random value. The common key cryptography is composed of, for example, algorithms described below.

Encryption SKEENC

The plaintext M is encrypted using the master key K, and the ciphertext C is output.

Decryption SKEDEC

The ciphertext C is decrypted using the master key K, and the plaintext M is output.

In the embodiment, counter mode cryptography using a block cipher is used among the common key cryptography. In the following, an encryption process is referred to as SCTRENC and a decryption process is referred to as SCTRDEC, in the counter mode cryptography using the block cipher.

Auxiliary information (counter value) is in a counter mode. In the following, the auxiliary information (counter value) is referred to as auxC.

In the counter mode cryptography using the block cipher, encryption is performed in the following.

$$C=\mathrm{SCTRENC}(K,\mathrm{auxC})+M$$

C is a cyphertext. M is a plaintext. K is a master key. Further, "+" indicates an exclusive OR.

Further, in the counter mode cryptography using the block cipher, decryption is performed in the following.

$$M=\mathrm{SCTRENC}(K,\mathrm{auxC})+C$$

Description of Operation

Next, an operational example of the searchable encryption system **100** according to the present embodiment will be described.

FIG. **8** illustrates an operational example of the master key generation device **200** according to the present embodiment.

First, in step S**201**, the bit length acquisition unit **201** acquires the bit length U of the key.

Next, in step S**202**, the random number value generation unit **204** generates an M-bit random number value, and the key generation unit **202** generates the master key K, using the random number value. The key generation unit **202** may use the M-bit random number value itself as the master key K.

Lastly, in step S**203**, the transmission unit **203** transmits the master key K to the user key generation device **300** and the encrypted tag generation apparatus **500**.

FIG. **9** illustrates an operational example of the user key generation device **300** according to the present embodiment.

First, in step S**301**, the key reception unit **301** receives the master key K.

Next, in step S**302**, the attribute value set acquisition unit **302** acquires the attribute value set Γ.

Next, in step S**303**, the user key generation unit **303** generates the user key skΓ.

Specially, the user key generation unit **303** generates the user key skΓ in the following.

Note that Γ={Qi}(i=1, . . . , n). Qi is an attribute included in the attribute value set Γ. Further, H means a hash operation in the following.

$$ski=H(K,Qi)(i=1,\ldots,n)$$

$$sk\Gamma=(sk1,\ldots,skn)$$

Lastly, in step S**304**, the transmission unit **304** transmits the user key skΓ to the trapdoor generation device **400** and the encrypted tag generation apparatus **500**.

FIG. **10** illustrates an operational example of the trapdoor generation device **400** according to the present embodiment

First, in step S**401**, the key reception unit **401** receives the user key skΓ.

Next, in step S**402**, the keyword acquisition unit **402** acquires the keyword W.

Next, in step S**403**, the trapdoor generation unit **403** generates the trapdoor T.

Specially, the trapdoor generation unit **403** generates the trapdoor T in the following. r means a random number value in the following. The random number value generation unit **405** generates the random number value.

$$T0=H(K,W)+r$$

$$\text{For }(i=1,\ldots,n),$$

$$Ti1=H(ski,w),\ Ti2=H(Ti1,r)$$

$$T=(\Gamma,T0,(T11,T12),\ldots,(Tn1,Tn2))$$

Lastly, in step **404**, the transmission unit **404** transmits the trapdoor T to the consistency determination device **600**.

FIG. **11** illustrates an operational example of the encrypted tag generation apparatus **500** according to the present embodiment.

First, in step S**501**, the key reception unit **501** receives the master key K and the user key skΓ.

Next, in step S**502**, the logical expression acquisition unit **502** acquires the logical expression V that represents the searchable condition L.

Next, in step S503, the keyword acquisition unit **503** acquires the keyword W.

Next, in step S504, the encrypted tag generation unit **504** calculates a secret sharing value from the logical expression V.

Details of step S**504** will be described below.

Next, in step S**505**, the encrypted tag generation unit **504** generates the encrypted tag E from the secret sharing value generated in step S**504**, the master key K, the user key skΓ, and the keyword W.

Details of step S**505** will be described below.

Lastly, in step S**506**, the transmission unit **505** transmits the encrypted tag E to the consistency determination device **600**.

FIG. **12** illustrates an operational example of the consistency determination device **600** according to the present embodiment.

First, in step S**601**, the trapdoor reception unit **602** receives the trapdoor T.

Next, in step **602**, the encrypted tag reception unit **601** receives the encrypted tag E.

The order of steps S**601** and S**602** may be interchanged. Alternatively, steps S**601** and S**602** may be performed in parallel.

Next, in step **603**, the consistency determination unit **603** performs the consistency determination.

Details of step S**603** will be described below.

Lastly, in step S**604**, the result transmission unit **604** transmits the determination result to the trapdoor generation device **400**.

As described above, for example, when the consistency determination unit **603** determines that the keyword W included in the encrypted tag E is consistent with the keyword W included in the trapdoor T, the result transmission unit **604** transmits "0" as the determination result. On the other hand, when inconsistency is determined, the result transmission unit **604** transmits "1" as the determination result.

Next, the details of step S**504** in FIG. **11** will be described.

In step S**504**, the encrypted tag generation unit **504** sets to each of a plurality of attribute values, a secret sharing value which reflects the logical structure represented by the logical expression V. Here, "setting the secret sharing value to each of the plurality of attribute values" means relating the secret sharing value to each attribute value.

Further, details of "the secret sharing value which reflects the logical structure" will be described below.

The logical expression V includes a plurality of attribute values and a logical operator.

The logical operator is the logical sum operator (OR) or the logical product operator (AND). In the following, the logical sum operator (OR) is referred to as a logical sum (OR) or OR, and the logical product operator (AND) is referred to as a logical product (AND) or AND.

When the logical expression V includes the logical sum (OR), the encrypted tag generation unit **504** sets to each of two or more logical sum attribute values which are two or more attribute values connected by the logical sum (OR), a secret sharing value which reflects that each of two or more logical sum attribute values is connected by the logical sum (OR). More specifically, the encrypted tag generation unit **504** sets to each of two or more logical sum attribute values, the holding random number value as a secret sharing value. The holding random number value is a random number value held by the random number value holding unit **507**.

Further, when the logical expression V includes the logical product operator (AND), the encrypted tag generation unit **504** sets to each of two or more logical product attribute values which are two or more attribute values connected by the logical product operator (AND), a secret sharing value which reflects each of two or more logical product attribute values is connected by the logical product operator (AND). More specifically, the encrypted tag generation unit **504** causes the random number value generation unit **506** to generate a new random number value, and generate a further new random number value by performing calculation using the new random number value and the holding random number value. Then, the encrypted tag generation unit **504** sets to each of two or more logical product attribute values, either of the new random number value and the further new random number value, as a secret sharing value.

The details of step S504 of FIG. **11** will be described below using flowcharts.

FIGS. **13**, **14**, and **15** are the flowcharts illustrating the details of step S**504**.

In the following, the random number value holding unit **507** holds holding random number values Xn and Yn. Note that n=1, 2, ...

Further, the encrypted tag generation unit **504** converts the logical expression V based on Polish notation, and scans the converted logical expression V from the top.

First, in step S**5401**, the encrypted tag generation unit **504** substitutes initial random number values S**0** and 0 into the holding random number values Xn and Yn (Xn←S**0** and Yn←0). That is, the encrypted tag generation unit **504** causes the random number value holding unit **507** to hold the initial random number values S**0** and 0, as the holding random number values Xn and Yn.

The initial random number value is a random number value initially generated by the random number value generation unit **506**.

Next, in step S**5402**, the encrypted tag generation unit **504** determines whether the logical operator included in the logical expression V is the logical product (AND) or the logical sum (OR).

When the first operator is the logical product (AND), processing proceeds to step S**5403**. On the other hand, when the first operator is the logical sum (OR), processing proceeds to step S**5418** (FIG. **15**).

In step S**5403**, the encrypted tag generation unit **504** causes the random number value generation unit **506** to generate a new random number value Zj. Here, j=1, 2, ...

Next, in step S**5404**, the encrypted tag generation unit **504** determines whether or not the logical product (AND) current concerned is the first AND.

When the logical product (AND) currently concerned is the first AND, processing proceeds to step S**5405**.

On the other hand, when the logical product (AND) currently concerned is not the first AND, processing proceeds to step S**5416**.

In step S**5405**, the encrypted tag generation unit **504** acquires the new random number value Zj from the random number value generation unit **506**, and divides the current holding random number value Xn by the new random number value Zj to obtain a further new random number value (Xn/Zj).

Next, in step S**5406**, the encrypted tag generation unit **504** updates the current holding random number values Xn and Yn, with the new random number value Zj and the further new random number value (Xn/Zj) (Xn←Zj and Yn←(Xn/Zj)).

That is, the encrypted tag generation unit **504** causes the random number value holding unit **507** to hold the new random number value Zj and the further new random number value (Xn/Zj), as the updated holding random number values Xn and Yn.

Next, in step S**5407**, the encrypted tag generation unit **504** determines whether or not the item next to the logical product (AND) in the logical expression V is an operand (attribute value).

When the item next to the logical product (AND) is the operand (attribute value), processing proceeds to step S**5408**.

When the item next to the logical product (AND) is not the operand (attribute value), the next item is a logical operator. Therefore, processing returns to step S**5402**, and the encrypted tag generation unit **504** determines whether or not the logical operator is the logical product (AND) or the logical sum (OR).

In step S**5408**, the encrypted tag generation unit **504** sets the holding random number value Xn as a secret sharing value, to the operand (attribute value) which is the item next to the logical product (AND). The holding random number value Xn set here is the random number value updated in step S**5406** or step S**5417** to be described below.

Next, in step S**5409**, the encrypted tag generation unit **504** determines whether or not there is the next item in the logical expression V.

When there is the next item, processing proceeds to step S**5410**.

On the other hand, when there is no next item, processing ends.

In step S**5410**, the encrypted tag generation unit **504** determines whether or not the next item is an operand (attribute value).

When the next item is the operant (attribute value), processing proceeds to step S**5411**.

When the next item is not the operant (attribute value), the next item is a logical operator. Therefore, processing returns to step S**5402**, and the encrypted tag generation unit **504** determines whether the logical operator is the logical product (AND) or the logical sum (OR).

In step S**5411**, the encrypted tag generation unit **504** sets the holding random number value Yn as a secret sharing value, to the operand (attribute value) which is the next item. The holding random number value Yn set here is the random number value updated in step S**5406** or step S**5417** to be described below.

Next, in step S**5412** of FIG. **14**, the encrypted tag generation unit **504** determines whether or not there is the next item in the logical expression V.

When there is the next item, processing proceeds to step S**5413**.

On the other hand, when there is not next item, processing ends.

In step S**5413**, the encrypted tag generation unit **504** determines whether or not the next item is an operand (attribute value).

When the next item is the operant (attribute value), processing proceeds to step S**5414**.

When the next item is not the operant (attribute value), the next item is a logical operator. Therefore, processing returns to step S**5402**, the encrypted tag generation unit **504** determines whether or not the logical operator is the logical product (AND) or the logical sum (OR).

In step S**5414**, the encrypted tag generation unit **504** divides the current holding random number value Yn by the current holding random number value Xn to obtain a further new random number value (Yn/Xn). Note that (Yn/Xn) ={Xn−1/(Zj*Zj)}.

Next, in step S**5415**, the encrypted tag generation unit **504** updates the current holding random number value Yn with the further new random number value (Yn/Xn) (Yn←(Yn/Xn)).

Next, processing returns to step S**5411**, and the encrypted tag generation unit **504** sets the holding random number value Yn as a secret sharing value, to the operant (attribute value) which is the next item. The holding random number value Yn set here is the random number value updated in step S**5415** (specifically (Yn/Xn)={Xn−1/(Zj*Zj)}).

After that, processing from step S**5412** is performed.

When the logical product (AND) concerned in step S**5404** is not the first AND (when AND is the second AND or after the second AND), in step S**5416**, the encrypted tag generation unit **504** obtains from the random number value generation unit **506**, the new random number value Zj, and divides a current holding random number value Yn by the new random number value Zj to obtain a further new random number value (Yn/Zj).

Next, in step S**5417**, the encrypted tag generation unit **504** updates the current holding random number values Xn and Yn with the new random number value Zj and the further new random number value (Yn/Zj) (Xn←Zj and Yn←(Yn/Zj)).

That is, the encrypted tag generation unit **504** causes the random number value holding unit **507** to hold the new random number value Zj and the further new random number value (Yn/Zj) as the updated holding random number values Xn and Yn.

After that, processing from step S**5407** is performed.

In step S**5402**, when the operator included in the logical expression V is the logical sum (OR), in step S**5418** of FIG. **15**, the encrypted tag generation unit **504** determines whether or not the item next to the logical sum (OR) is an operand (attribute value).

When the item next to the logical sum (OR) is the operand (attribute value), processing proceeds to step S**5419**.

When the item next to the logical sum (OR) is not the operand (attribute value), the next item is a logical operator. Therefore, processing returns to step S**5402**, and the encrypted tag generation unit **504** determines whether or not the logical operator is the logical product (AND) or the logical sum (OR).

In step S**5419**, the encrypted tag generation unit **504** sets the random holding number value as a secret sharing value, to the operand (attribute value) which is the next item.

Next, in step S**5420**, the encrypted tag generation unit **504** determines whether or not there is the next item in the logical expression V.

When there is the next item, processing returns to step S**5418**.

On the other hand, when there is no next item, processing ends.

By performing the procedures in FIGS. **13**, **14**, and **15**, the encrypted tag generation unit **504** can set a secret sharing value to an operand (attribute value) included in the logical expression V.

Here, the procedures illustrated in FIGS. **13**, **14**, and **15** will be described using a specific example.

In the following, for example, the description will be given using a logical expression "(A OR B) AND (C AND D)". If this logical expression is converted according to the Polish notation, it is "AND OR A B AND C D". Each of two "ANDs" and "OR" is a logical operator, and each of "A", "B", "C", and "D" is an operand (attribute value).

According to step S**5401**, the encrypted tag generation unit **504** substitutes the initial random number values S**0** and 0 into the holding random number values X**1** and Y**1** (X**1**←S**0** and Y**1**←0).

The encrypted tag generation unit **504** scans the logical expression “AND OR A B AND C D” from the left. Since the first logical operator is “AND” (“AND” in step S**5402**), processing proceeds to step S**5403**.

In step S**5403**, the encrypted tag generation unit **504** instructs the random number value generation unit **506** to generate the new random number value Zj.

Here, it is assumed that Z**1** is generated as the new random number value Zj.

Further, since the “AND” currently concerned is the first AND (“YES” in step S**5404**), processing proceeds to step S**5405**.

In step S**5405**, the encrypted tag generation unit **504** obtains the new random number value Z**1** from the random number value generation unit **506**, and divides the current holding random number value X**1** by the new random number value Z**1** to obtain a further new holding random number value (X**1**/Z**1**) (=(S**0**/Z**1**)).

Next, in step S**5406**, the encrypted tag generation unit **504** updates the current holding random number values X**1** and Y**1** with the new random number value Z**1** and the further new random number value (X**1**/Z**1**) (X**2**←Z**1** and Y**2**←(X**1**/Z**1**) (=(S**0**/Z**1**)).

Next, in step S**5407**, the encrypted tag generation unit **504** determines whether or not the item next to “AND” is an operand (attribute value).

In the logical expression “AND OR A B AND C D”, the item next to “AND” is “OR”. Therefore, processing returns to step S**5402**.

Further, as a result of determination of step S**5402**, processing proceeds to step S**5418** of FIG. **15**.

In step S**5418**, it is determined whether or not the item next to “OR” is an operand (attribute value).

In the logical expression “AND OR A B AND C D”, the item next to “OR” is “A”. Therefore, processing proceeds to step S**5419**.

In step S**5419**, the encrypted tag generation unit **504** sets the holding random number value X**2** (=Z**1**) as a secret sharing value, to the operand (attribute value “A”) which is the next item.

Next, in step S**5420**, the encrypted tag generation unit **504** determines whether or not there is the next item

In the logical expression “AND OR A B AND C D”, there is “B” next to “A”. Therefore, processing proceeds to step S**5418**.

Then, since “B” which is the next item is an operand (attribute value), processing proceeds to step S**5419**.

As a result, in step S**5419**, the encrypted tag generation unit **504** sets the holding random number value X**2** (=Z**1**) as a secret sharing value, to the operand (attribute value B") which is the next item.

Next, in step S**5420**, the encrypted tag generation unit **504** determines whether or not there is the next item.

In the logical expression “AND OR A B AND C D”, there is “AND” next to “B”. Therefore, processing proceeds to step S**5418**.

Then, since “AND” which is the next item is a logical operator, processing proceeds to step S**5402** of FIG. **13**.

Since the logical operator is “AND” (“AND” in step S**5402**), processing proceeds to step S**5403**.

In step S**5403**, the encrypted tag generation unit **504** instructs the random number value generation unit **506** to generate the new random number value Zj.

Here, it is assumed that Z**2** is generated as the new random number value Zj.

Next, the “AND” currently concerned is the second AND (“NO” in step S**5404**). Therefore, processing proceeds to step S**5416**.

In step S**5416**, the encrypted tag generation unit **504** obtains the new random number value Z**2** from the random number value generation unit **506**, and divides the current holding random number value Y**2** by the new random number value Z**2** to obtain a further new random number value (Y**2**/Z**2**) (={S**0**/(Z**1***Z**2**)}).

Next, in step S**5417**, the encrypted tag generation unit **504** updates the current holding random number values X**2** and Y**2** with the new random number value Z**2** and the further new random number value (Y**2**/Z**2**) (X**3**←Z**2** and Y**3**←(Y**2**/Z**2**)).

Next, in step S**5407**, the encrypted tag generation unit **504** determines whether or not the item next to “AND” is an operand (attribute value).

In the logical expression “AND OR A B AND C D”, the item next to “AND” is “C”. Therefore, processing proceeds to step S**5408**.

In step S**5408**, the encrypted tag generation unit **504** sets the holding random number value X**3** (=Z**2**) as a secret sharing value, to the operand (attribute value “C”) which is the item next to “AND”.

Next, in step S**5409**, the encrypted tag generation unit **504** determines whether or not there is the next item.

In the logical expression “AND OR A B AND C D”, there is “D” next to “C”. Therefore, processing proceeds to step S**5410**. Then, since “D” is an operand (attribute value), processing proceeds to step S**5411**.

In step S**5411**, the encrypted tag generation unit **504** sets the holding random number value Y**3** (=(Y**2**/Z**2**)) as a secret sharing value, for the attribute value “D”.

Next, in step S**5412** of FIG. **14**, the encrypted tag generation unit **504** determines whether or not there is the next item.

In the logical expression “AND OR A B AND C D”, “D” is the last item. Therefore, processing ends.

By the above processing, the secret sharing values X**2**=Z**1**, X=Z**1**, X**3**=Z**2**, and (Y**2**/Z**2**) (={S**0**/(Z**1***Z**2**)}) are set to “A”, “B”, “C”, and “D”, respectively.

To “A” and “B” connected by the logical sum (OR), the common secret sharing value “Z**1**” is set. Therefore, it can be identified that both are connected by the logical sum (OR).

Further, as described above, in the present embodiment, in the case of the logical expression “A AND B”, the basic principle is to set the secret sharing value s**1** that satisfies s=s**1**+s**2** to the attribute value A, and the secret sharing value s**2** to the attribute value B. According to this basic principle, the encrypted tag generation unit **504** sets the secret sharing value “Z**1**” to “A” and “B”, sets the secret sharing value “Z**2**” to “C”, and sets the secret sharing value {S**0**/(Z**1***Z**2**)} obtained by computation using “Z**1**” and “Z**2**” to “D”. Therefore, it can be identified that “A”, “B”, “C” and “D” are connected by the logical product (AND).

Next, the details of step S**505** of FIG. **11** will be described.

After processing of step S**504** is performed, a secret sharing value is set to all operands.

In the following, it is assumed that m pieces of secret sharing values (S**1**, . . . , Sm) are set.

In step S**505**, the encrypted tag generation unit **504** calculates the following.

$$E0=H(K,W)+S0$$

$$\text{For } (i=1, \ldots ,m),$$

$$Ei1=H(H(ski,W),Ri)+Si \text{ and } Ei2=Ri$$

$$E=(L,E0,(E11,E12), \ldots ,(Em1,Em2))$$

Note that **S0** is an initial random number value. Further, L is a searchable condition. Ri is a random number value.

Next, the details of step S**603** of FIG. **12** will be described.

First, the consistency determination unit **603** compares the searchable condition L with the attribute value set Γ.

Then, the consistency determination unit **603** extracts the minimum attribute that satisfies the searchable condition L, from among the attribute Qi included in elements of the attribute value set Γ. Here, it is assumed that the consistency determination unit **603** extracts the minimum attribute that satisfies the searchable condition L, as (QQ**1**, . . . , QQu).

For example, when the logical expression "A OR B" is given as the searchable condition L, the searchable condition L is satisfied with QQ**1**=A and QQ**2**=B, or even QQ**1**=A only.

The consistency determination unit **603** extracts from among combinations of attributes that satisfy the searchable condition L such as above, a combination of attributes in which the number of attributes is the smallest, as "the minimum attribute that satisfies the searchable condition L".

Further, here, F is assumed to be a calculation formula for extracting the minimum attribute that satisfies the searchable condition L. The consistency determination unit **603** executes the calculation formula F to extract the minimum attribute (QQ**1**, . . . , QQu) that satisfies the searchable condition L.

Then, the consistency determination unit **603** extracts according to the following calculations, components of the encrypted tag E and components of the trapdoor T corresponding to the minimum attribute (QQ**1**, . . . , QQu) that satisfies the searchable condition L, as follows.

$$E0=H(K,W)+S0$$

$$\text{For } i=1, \ldots ,u,$$

$$Ei1=H(H(ski,W),Ri)+Si \text{ and } Ei2=Ri$$

$$T0=H(K,W)+r$$

$$\text{For } i=1, \ldots ,u,$$

$$Ti1=H(ski,W) \text{ and } Ti2=H(Ti1,r)$$

Note that each of Ri and r is a random number value.

Next, the consistency determination unit **603** calculates the secret sharing value Si by the following calculation.

$$\text{For } i=1, \ldots , u,$$

$$Si=Ei1+H(Ti1,Ei2)$$

Then, the consistency determination unit **603** calculates **S0** that satisfies a condition, from the calculated secret sharing value Si, using the calculation formula F.

Specifically, the consistency determination unit **603** performs calculation as follows.

$$r=H(E0+S0)+T0$$

The above "condition" is, for example, the logical product (multiplication) of two attribute values in the case of the logical expression "A AND B". In the case of this example, the encrypted tag generation unit **504** is supposed to have set the secret sharing value Z**1** to "A" and the secret sharing value (S**0**/Z**1**) to "B". Therefore, when the consistency determination unit **603** executes the calculation formula F (multiplication in the case of this example), the initial random number value **S0** is restored.

Regarding the relation between the calculation formula F and the condition, if the operand in the logical expression is "OR", the calculation formula F is addition, and if the operand in the logical expression is "AND", the calculation formula F is multiplication.

Next, the consistency determination unit **603** determines whether or not Ti**2**=H(Ti**1**,r) is satisfied for (i=1, . . . , n).

If Ti**2**=H(Ti**1**,r) is satisfied for all of (i=1, . . . , n), the consistency determination unit **603** determines that the keywords W are consistent. On the other hand, if even one of (i=1, . . . , n) does not satisfy Ti**2**=H (Ti**1**,r), the consistency determination unit **603** determines that the keywords W are not consistent.

Description of Effects of Embodiment

As described above, in the searchable encryption system according to the present embodiment, there is no need to set a constraint on the length of a logical expression (that is, the number of attribute values included in the logical expression) used for generation of an encrypted tag. Therefore, it is possible to realize searchable encryption that enables more flexible access control.

Only a part of the procedures described in the present embodiment may be implemented.

Alternatively, at least a part of the procedures described in the present embodiment and a procedure not described in the present embodiment may be implemented in combination.

Alternatively, the configurations and procedures described in the present embodiment may be modified as necessary.

Description of Hardware Configuration

Lastly, a hardware configuration example of the master key generation device **200**, the user key generation device **300**, the trapdoor generation device **400**, the encrypted tag generation apparatus **500**, and the consistency determination device **600** will be described.

FIG. **16** illustrates the hardware configuration example of the master key generation device **200**, the user key generation device **300**, the trapdoor generation device **400**, the encrypted tag generation apparatus **500**, and the consistency determination device **600**.

In FIG. **16**, each of the master key generation device **200**, the user key generation device **300**, the trapdoor generation device **400**, the encrypted tag generation apparatus **500**, and the consistency determination device **600** includes a processor **1101**.

The processor **1101** is, for example, a Central Processing Unit (CPU).

The processor **1101** is connected to a plurality of hardware devices via a bus **1102**. The processor **1101** is connected to, for example, a Read Only Memory (ROM) **1103** and a Random Access Memory (RAM) **1104**. Further, the processor **1101** may be connected to a communication board **1105**, a display **1111** (display device), a keyboard **1112**, and a mouse **1113**. Further, the processor **1101** may be connected to a drive **1114** and a magnetic disk device **1120**.

The processor **1101** controls these hardware devices.

The drive **1114** is a device that reads and writes a storage medium such as a Flexible Disk Drive (FD), a Compact Disc (CD), or a Digital Versatile Disc (DVD).

The ROM **1103**, the RAM **1104**, the magnetic disk device **1120**, and the drive **1114** are examples of a storage device.

The keyboard **1112**, the mouse **1113**, and the communication board **1105** are examples of an input device.

The display **1111** and the communication board **1105** are examples of an output device.

The communication board **1105** is wired or wirelessly connected to a communication network such as a Local Area Network (LAN), the Internet, or a telephone line.

The magnetic disk device **1120** stores an Operating System (OA) **1121**, a program **1122**, and a file **1123**.

The program **1122** includes a program that executes a function described as "unit" in the present embodiment. The program (for example, the encrypted tag generation program or the consistency determination program) is read and executed by the processor **1101**. In other words, the program causes a computer to function as "unit", and causes the computer to execute a procedure and a method of "unit".

The file **1123** includes various data (input, output, determination result, calculation result, processing result, and the like) used in "unit" described in the present embodiment.

In the present embodiment, arrows included in the configuration diagrams and the flowcharts mainly indicate input/output of data or a signal.

The processing of the present embodiment described based on the flowcharts or the like, is executed using hardware such as the processor **1101**, a storage device, an input device, or an output device.

An object described as "unit" in the present embodiment may be a "circuit", "device", or "equipment", and may be a "step", "procedure", "process", or "circuitry". In other words, the object described as "unit" may be implemented in firmware, software, hardware, or a combination of these.

Further, each of the master key generation device **200**, the user key generation device **300**, the trapdoor generation device **400**, the encrypted tag generation apparatus **500**, and the consistency determination device **600** may be implemented by a processing circuit.

The processing circuit is, for example, a logic Integrated Circuit (IC), a Gate Array (GA), an Application Specific Integrated Circuit (ASIC), or a Field-Programmable Gate Array (FPGA).

In this case, each of objects described as "unit" is implemented as a part of the processing circuit.

In the present description, a superordinate concept of the processor and the processing circuit is referred to as "processing circuitry".

That is, each of the processor and the processing circuit is a specific example of the "processing circuitry".

REFERENCE SIGNS LIST

100: searchable encryption system; **101**: network; **200**: master key generation device; **201**: bit length acquisition unit; **202**: key generation unit; **203**: transmission unit; **204**: random number value generation unit; **300**: user key generation device; **301**: key reception unit; **302**: attribute value set acquisition unit; **303**: user key generation unit; **304**: transmission unit; **305**: random number value generation unit; **400**: trapdoor generation device; **401**: key reception unit; **402**: keyword acquisition unit; **403**: trapdoor generation unit; **404**: transmission unit; **405**: random number value generation unit; **500**: encrypted tag generation apparatus; **501**: key reception unit; **502**: logical expression acquisition unit; **503**: keyword acquisition unit; **504**: encrypted tag generation unit; **505**: transmission unit; **506**: random number value generation unit; **507**: random number value holding unit; **600**: consistency determination device; **601**: encrypted tag reception unit; **602**: trapdoor reception unit; **603**: consistency determination unit; **604**: result transmission unit; **605**: random number value generation unit; **1101**: processor; **1102**: bus; **1103**: ROM; **1104**: RAM; **1105**: communication board; **1111**: display; **1112**: keyboard; **1113**: mouse; **1114**: drive; **1120**: magnetic disk device; **1121**: OS; **1122**: program; **1123**: file.

The invention claimed is:

1. An encrypted tag generation apparatus comprising:

processing circuitry:

to acquire a logical expression that represents a condition under which searchable encryption is permitted, by a logical structure with a plurality of attribute values and at least one of a logical sum operator and a logical product operator;

to generate a random number value;

to hold the random number value generated, as a holding random number value; and

to: when the logical expression includes the logical sum operator, set to each of two or more logical sum attribute values which are two or more attribute values connected by the logical sum operator, the holding random number value as a secret sharing value which reflects that each of the two or more logical sum attribute values is connected by the logical sum operator; when the logical expression includes the logical product operator, generate a new random number value, generate a further new random number value by performing calculation using the new random number value and the holding random number value, and set to each of two or more logical product attribute values which are two or more attribute values connected by the logical product operator, one of the new random number value and the further new random number value, as a secret sharing value which reflects that each of the two or more logical product attribute values is connected by the logical product operator; and generate an encrypted tag to be used for the searchable encryption, using a plurality of secret sharing values set to the plurality of attribute values.

2. The encrypted tag generation apparatus according to claim **1**, wherein

when the new random number value is generated and the further new random number value is generated, the processing circuitry updates the holding random number value with at least one of the new random number value and the further new random number value.

3. The encrypted tag generation apparatus according to claim **1**, wherein

the processing circuitry generates a plurality of encrypted tags, using a master key based on a common key scheme, a user key generated from the master key, a keyword for the searchable encryption, an initial random number value which is a random number value initially generated, and the plurality of secret sharing values.

4. A searchable encryption system comprising:

an encrypted tag generation apparatus described in claim **3**;

a trapdoor generation device to generate a plurality of trapdoors, using a common random number value which is a random number value common to the plurality of trapdoors, and the master key based on a common key scheme, the user key generated from the master key, and a keyword for searchable encryption; and a consistency determination device to acquire a plurality of encrypted tags generated by the encrypted tag generation apparatus described in claim **3** and the plurality of trapdoors, to calculate a plurality of secret sharing values which reflects a logical structure of a logical expression that represents a condition under which the searchable encryption is permitted, using the plurality of encrypted tags and the plurality of trapdoors, to restore an initial random number value which is a random number value initially generated by the encrypted tag generation apparatus described in claim **3**, using the calculated plurality of secret sharing values, to calculate the common random number value, using the restored initial random number value, and to determine whether or not the keyword used for generation of the plurality of encrypted tags is consistent with the keyword used for generation of the plurality of trapdoors, using the calculated common random number value.

5. An encrypted tag generation method comprising:

acquiring a logical expression that represents a condition under which searchable encryption is permitted, by a logical structure with a plurality of attribute values and at least one of a logical sum operator and a logical product operator;

generating a random number value;

holding the random number value generated, as a holding random number value;

when the logical expression includes the logical sum operator, setting to each of two or more logical sum attribute values which are two or more attribute values connected by the logical sum operator, the holding random number value as a secret sharing value which reflects that each of the two or more logical sum attribute values is connected by the logical sum operator;

when the logical expression includes the logical product operator, generating a new random number value, generating a further new random number value by performing calculation using the new random number value and the holding random number value, and setting to each of two or more logical product attribute values which are two or more attribute values connected by the logical product operator, one of the new random number value and the further new random number value, as a secret sharing value which reflects that each of the two or more logical product attribute values is connected by the logical product operator; and

generating an encrypted tag to be used for the searchable encryption, using a plurality of secret sharing values set to the plurality of attribute values.

6. A non-transitory computer readable medium storing an encrypted tag generation program causing a computer to execute:

a logical expression acquisition process to acquire a logical expression that represents a condition under which searchable encryption is permitted, by a logical structure with a plurality of attribute values and at least one of a logical sum operator and a logical product operator;

a random number value generation process to generate a random number value;

a random number value holding process to hold the random number value generated by the random number value generation process, as a holding random number value; and

an encrypted tag generation process to: when the logical expression includes the logical sum operator, set to each of two or more logical sum attribute values which are two or more attribute values connected by the logical sum operator, the holding random number value as a secret sharing value which reflects that each of the two or more logical sum attribute values is connected by the logical sum operator; when the logical expression includes the logical product operator, generate a new random number value by the random number value generation process, generate a further new random number value by performing calculation using the new random number value and the holding random number value, and set to each of two or more logical product attribute values which are two or more attribute values connected by the logical product operator, one of the new random number value and the further new random number value, as a secret sharing value which reflects that each of the two or more logical product attribute values is connected by the logical product operator; and generate an encrypted tag to be used for the searchable encryption, using a plurality of secret sharing values set to the plurality of attribute values.

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