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(54) **METHOD AND APPARATUS FOR REVERSIBLE TOKENIZATION WITH SUPPORT FOR EMBEDDABLE ROLE-BASED ACCESS CONTROL**

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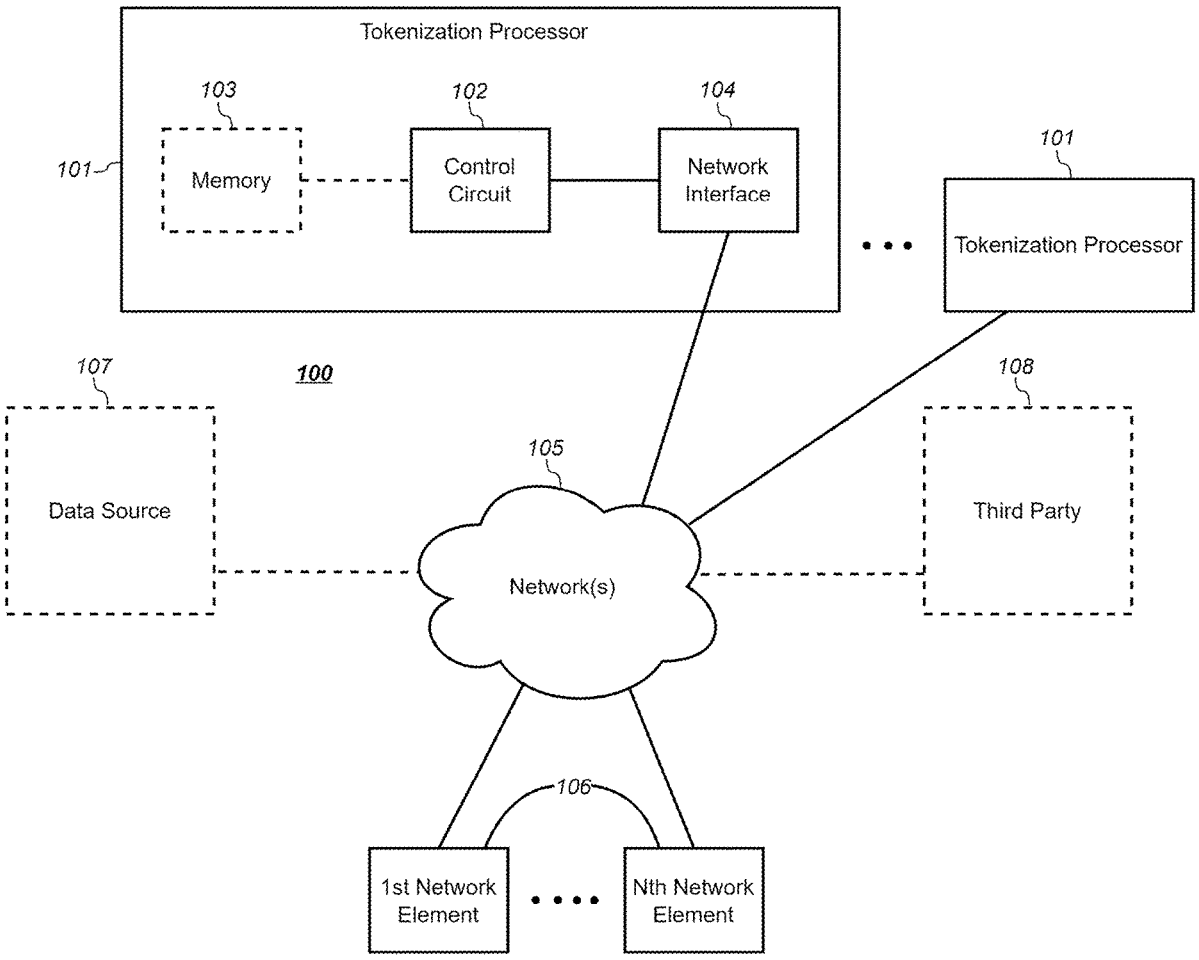
H04L 9/40 (2006.01)

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

CPC ***H04L 9/3213*** (2013.01); ***H04L 63/105*** (2013.01)

(57) **ABSTRACT**

Participants as requestors using a requesting network element request one or more tokenization processors to generate tokens that represent a sanitized version of data such that the resultant tokens are amenable to comparison across participants. As circumstances warrant, one or more such tokens can be submitted to the tokenization processor(s) to privately retrieve the original data. Role-based access control scope parameters and tokenization processor-specific tokenization processor secrets can be embedded into reversible tokens that remain invariant under updating of the tokenization processor secrets across tokenization processors. By another approach, role-based access control scope parameters and tokenization processor-specific tokenization processor secrets are embedded into tokens and corresponding key tokens such that upon authorized presentation of a token by a requestor, the corresponding key token is recovered so that the keying material that was used to generate ciphertext is retrievable in order to recover the corresponding plaintext.



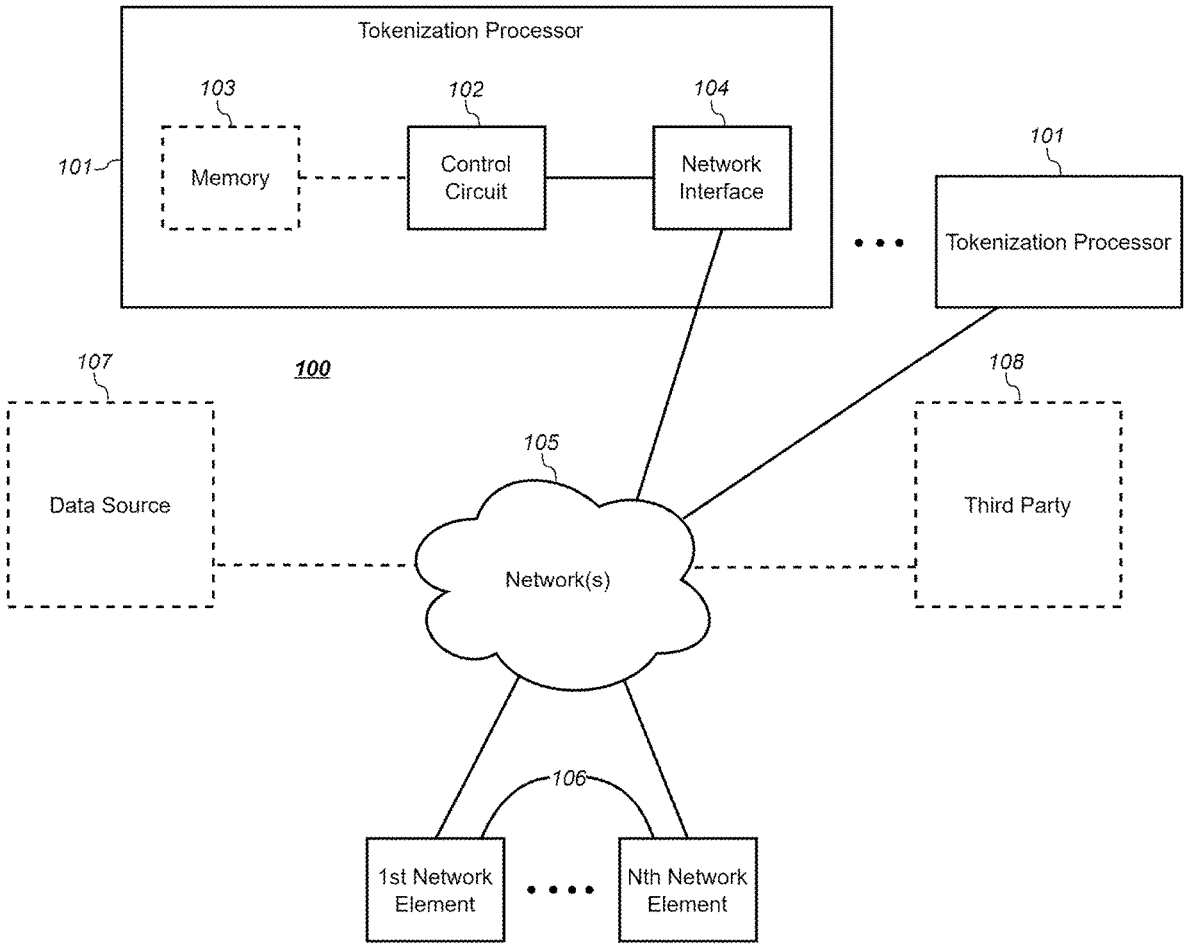

Tokenization Processor
103
102
104
101
Memory
Control Circuit
Network Interface
101
Tokenization Processor
107
100
108
105
Data Source
Third Party
Network(s)
106
1st Network Element
Nth Network Element

FIG. 1

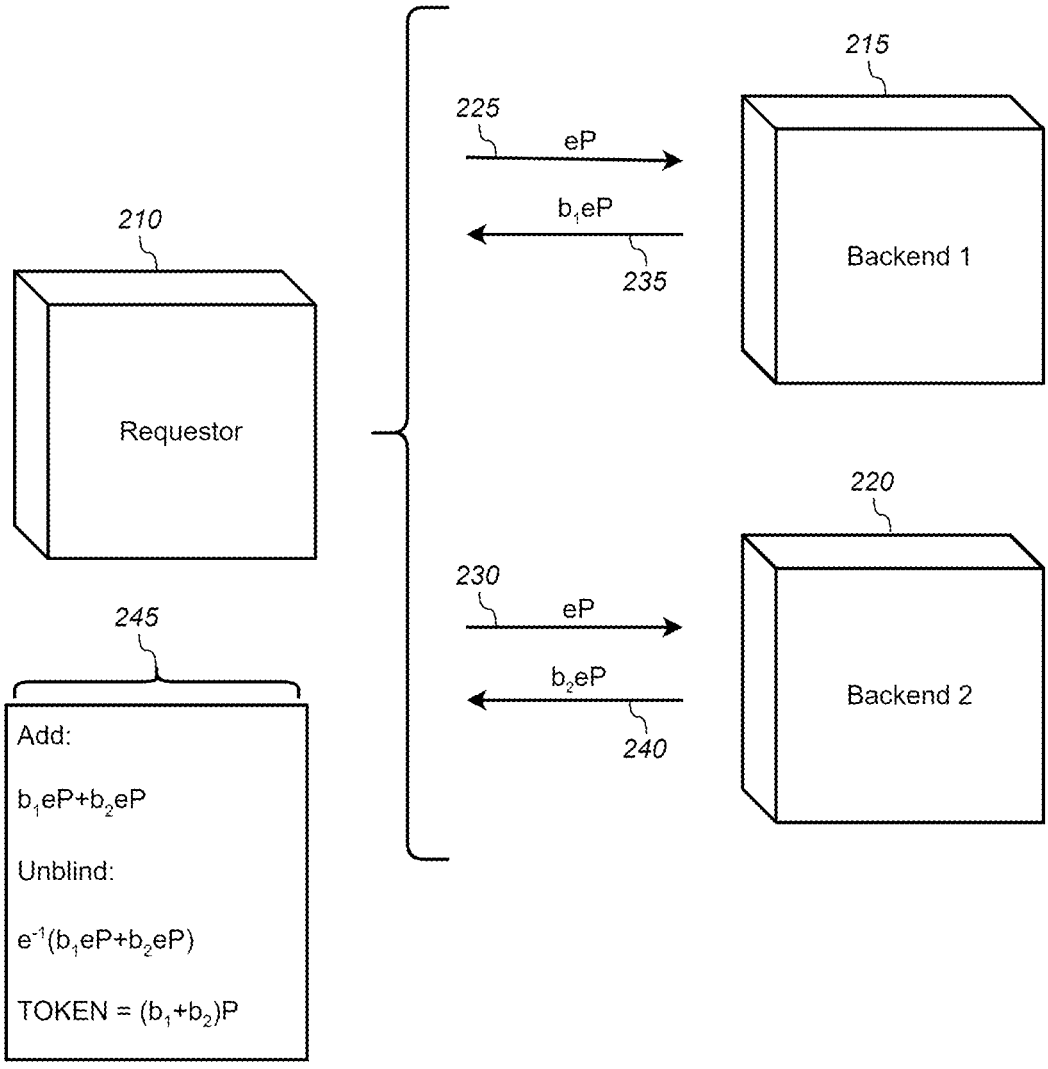

215
225
eP
b1eP
235
Backend 1
210
Requestor
220
230
eP
b2eP
240
Backend 2
245
Add:
b1eP+b2eP
Unblind:
e-1(b1eP+b2eP)
TOKEN = (b1+b2)P

FIG. 2

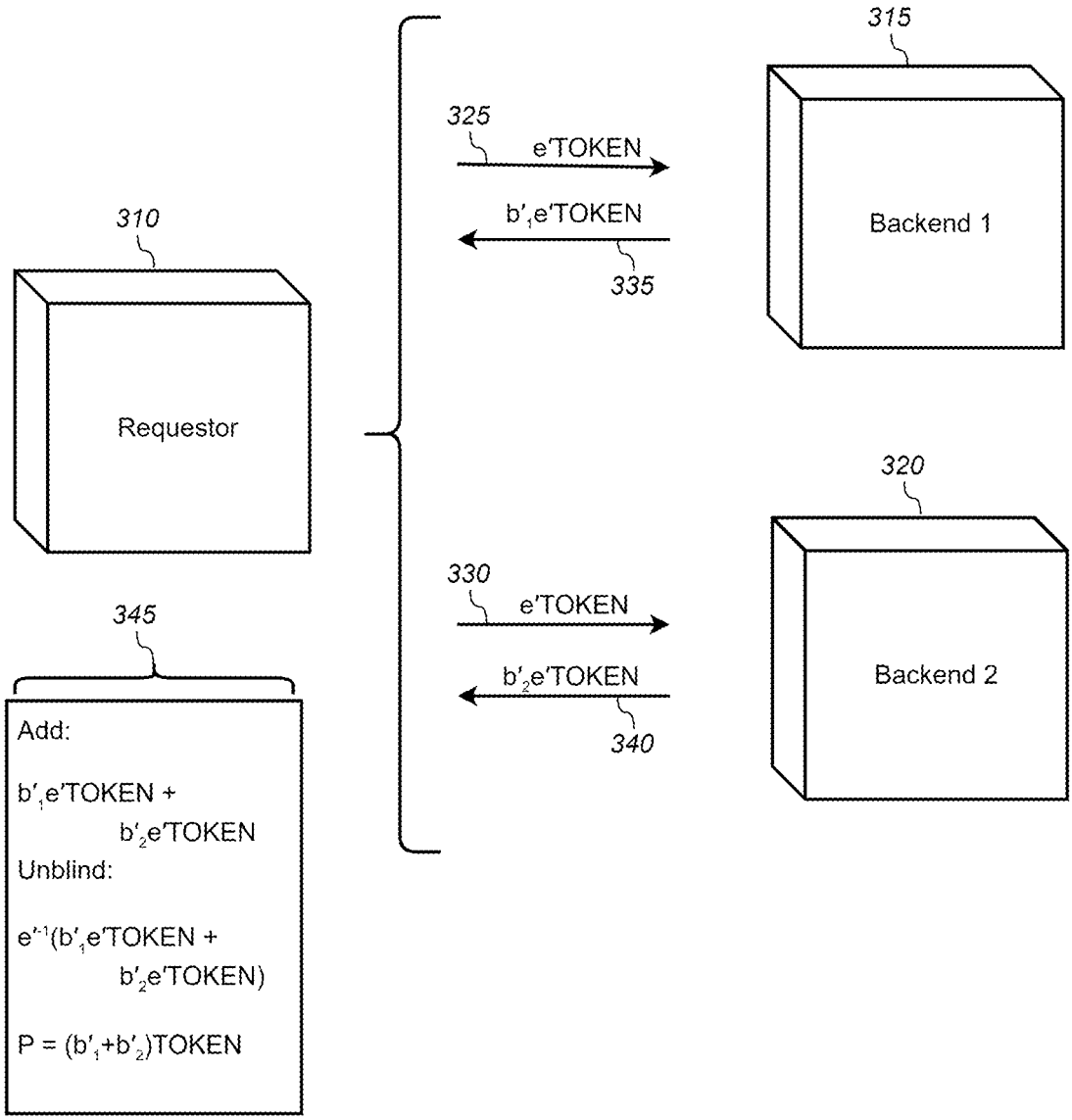

315
325
e'TOKEN
b'1e'TOKEN
335
Backend 1
310
Requestor
320
330
e'TOKEN
b'2e'TOKEN
340
Backend 2
345
Add:
b'1e'TOKEN +
b'2e'TOKEN
Unblind:
e'-1(b'1e'TOKEN +
b'2e'TOKEN)
P = (b'1+b'2)TOKEN

FIG. 3

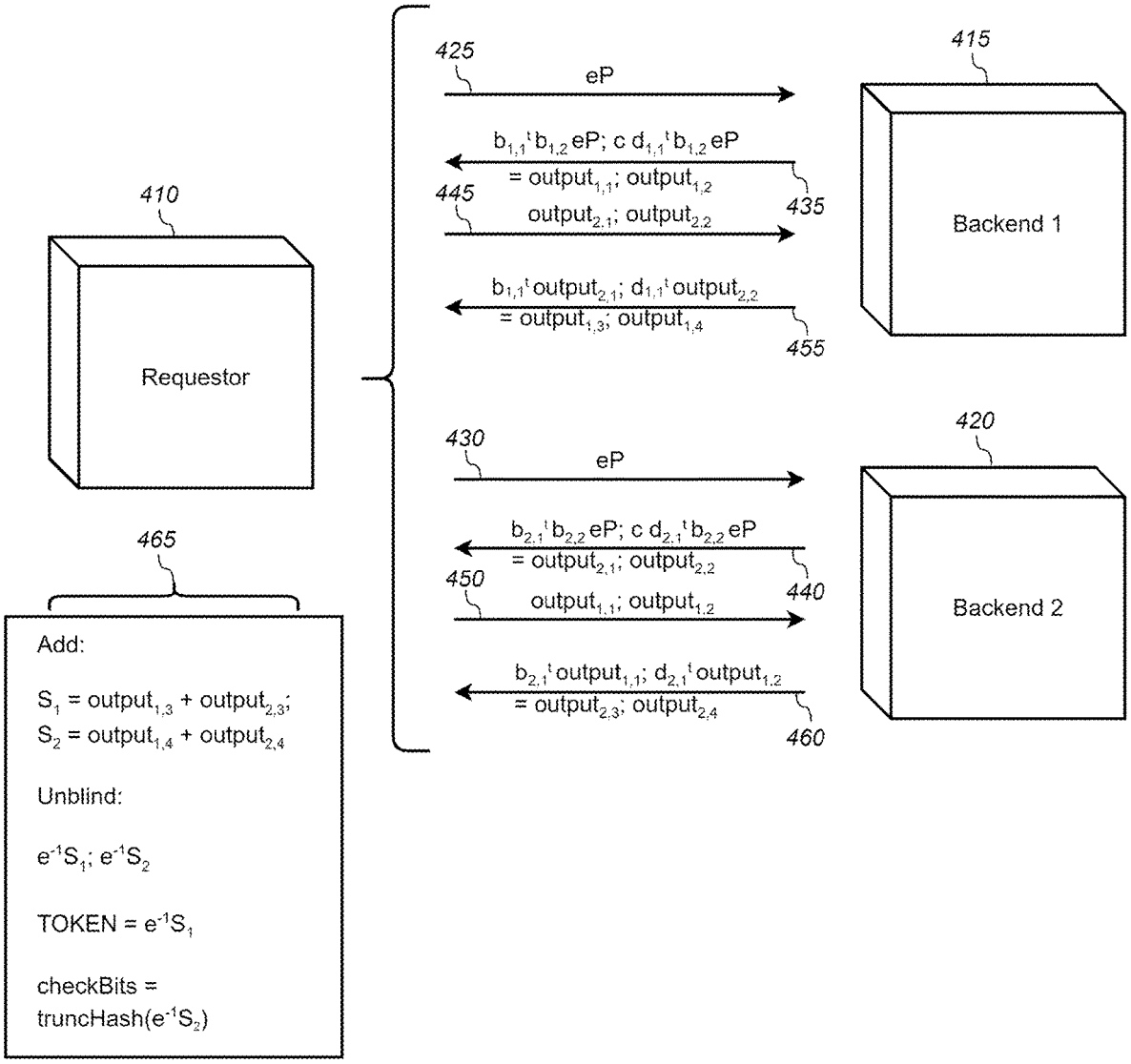

410
Requestor
415
Backend 1
420
Backend 2
425
eP
$b_{1,1}{}^t b_{1,2}$ eP; c $d_{1,1}{}^t b_{1,2}$ eP
= $output_{1,1}$; $output_{1,2}$
435
445
$output_{2,1}$; $output_{2,2}$
$b_{1,1}{}^t output_{2,1}$; $d_{1,1}{}^t output_{2,2}$
= $output_{1,3}$; $output_{1,4}$
455
430
eP
$b_{2,1}{}^t b_{2,2}$ eP; c $d_{2,1}{}^t b_{2,2}$ eP
= $output_{2,1}$; $output_{2,2}$
440
450
$output_{1,1}$; $output_{1,2}$
$b_{2,1}{}^t output_{1,1}$; $d_{2,1}{}^t output_{1,2}$
= $output_{2,3}$; $output_{2,4}$
460
465
Add:
S_1 = $output_{1,3}$ + $output_{2,3}$;
S_2 = $output_{1,4}$ + $output_{2,4}$
Unblind:
$e^{-1}S_1$; $e^{-1}S_2$
TOKEN = $e^{-1}S_1$
checkBits =
truncHash($e^{-1}S_2$)

FIG. 4

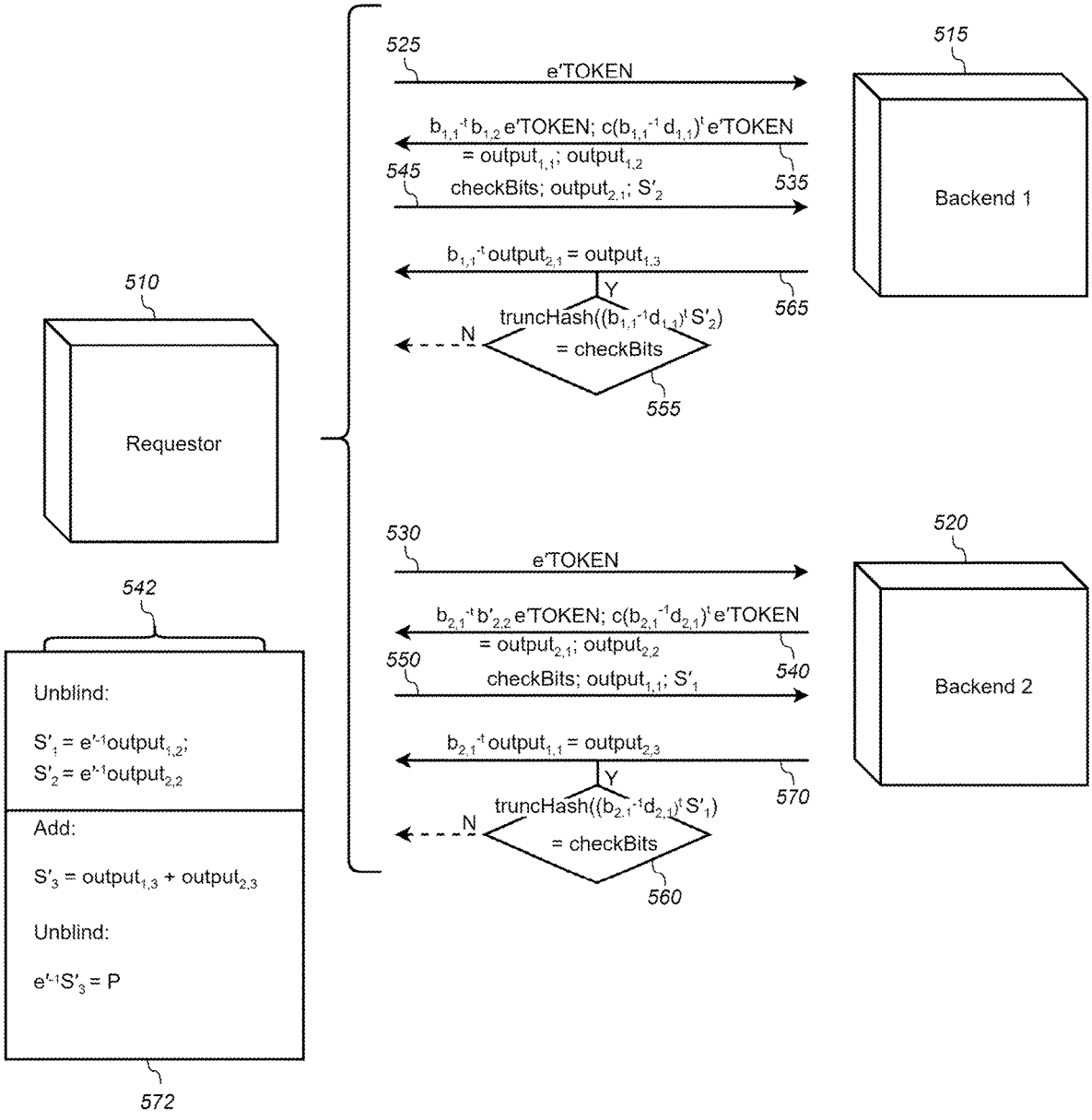

510
Requestor
515
Backend 1
520
Backend 2
525
e'TOKEN
$b_{1,1}^{-t} b_{1,2}$ e'TOKEN; $c(b_{1,1}^{-1} d_{1,1})^t$ e'TOKEN
= $output_{1,1}$; $output_{1,2}$
545
checkBits; $output_{2,1}$; S'_2
535
$b_{1,1}^{-t} output_{2,1} = output_{1,3}$
565
Y
N
truncHash($(b_{1,1}^{-1} d_{1,1})^t S'_2$)
= checkBits
555
530
e'TOKEN
$b_{2,1}^{-t} b'_{2,2}$ e'TOKEN; $c(b_{2,1}^{-1} d_{2,1})^t$ e'TOKEN
= $output_{2,1}$; $output_{2,2}$
550
checkBits; $output_{1,1}$; S'_1
540
$b_{2,1}^{-t} output_{1,1} = output_{2,3}$
570
Y
N
truncHash($(b_{2,1}^{-1} d_{2,1})^t S'_1$)
= checkBits
560
542
Unblind:
$S'_1 = e'^{-1} output_{1,2}$;
$S'_2 = e'^{-1} output_{2,2}$
Add:
$S'_3 = output_{1,3} + output_{2,3}$
Unblind:
$e'^{-1} S'_3 = P$
572

FIG. 5

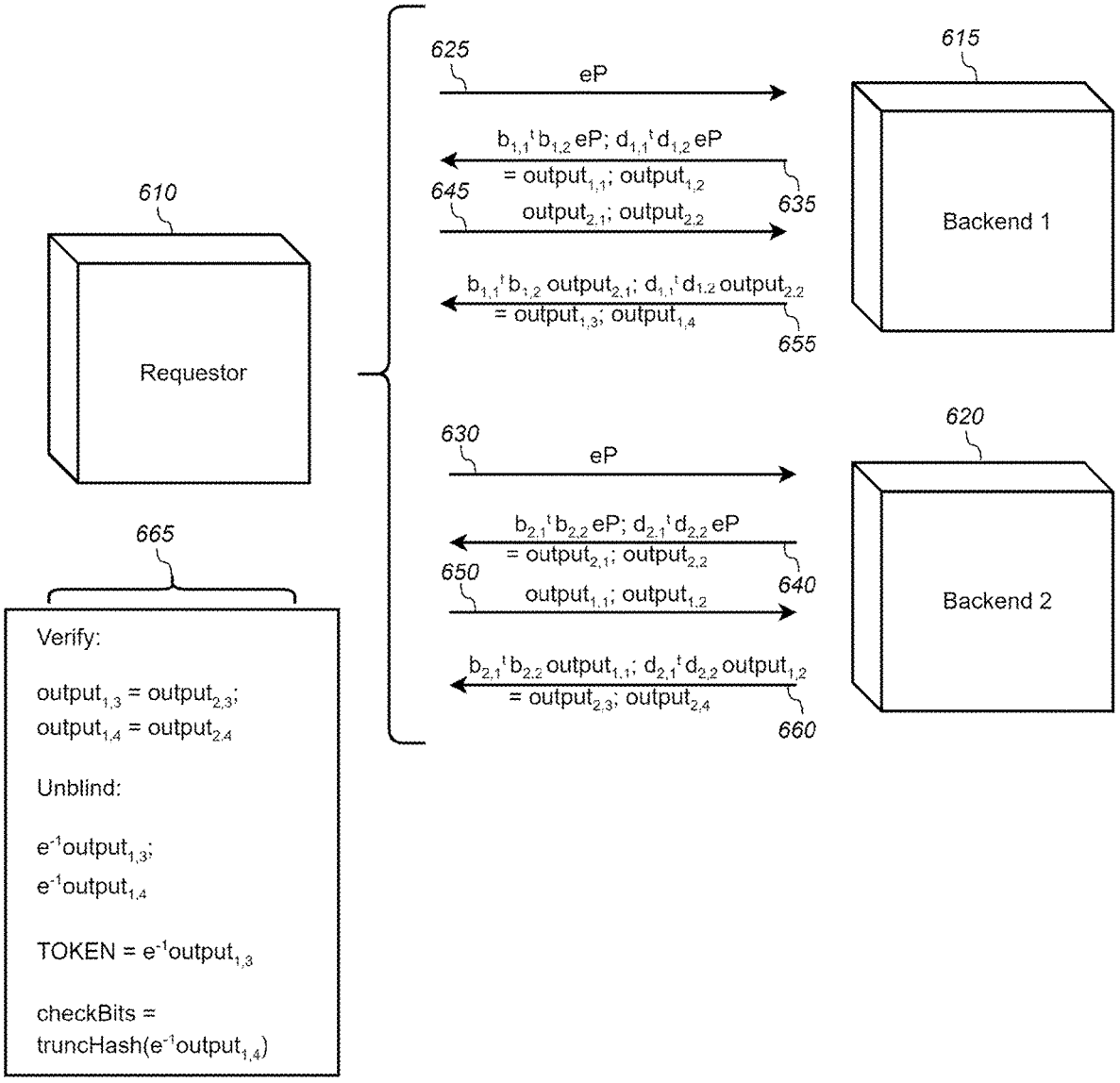

610
Requestor
665
Verify:
output1,3 = output2,3;
output1,4 = output2,4
Unblind:
e-1output1,3;
e-1output1,4
TOKEN = e-1output1,3
checkBits =
truncHash(e-1output1,4)
625
eP
615
Backend 1
b1,1tb1,2eP; d1,1td1,2eP
= output1,1; output1,2
645
output2,1; output2,2
635
b1,1tb1,2 output2,1; d1,1td1,2 output2,2
= output1,3; output1,4
655
630
eP
620
Backend 2
b2,1tb2,2eP; d2,1td2,2eP
= output2,1; output2,2
650
output1,1; output1,2
640
b2,1tb2,2 output1,1; d2,1td2,2 output1,2
= output2,3; output2,4
660

FIG. 6

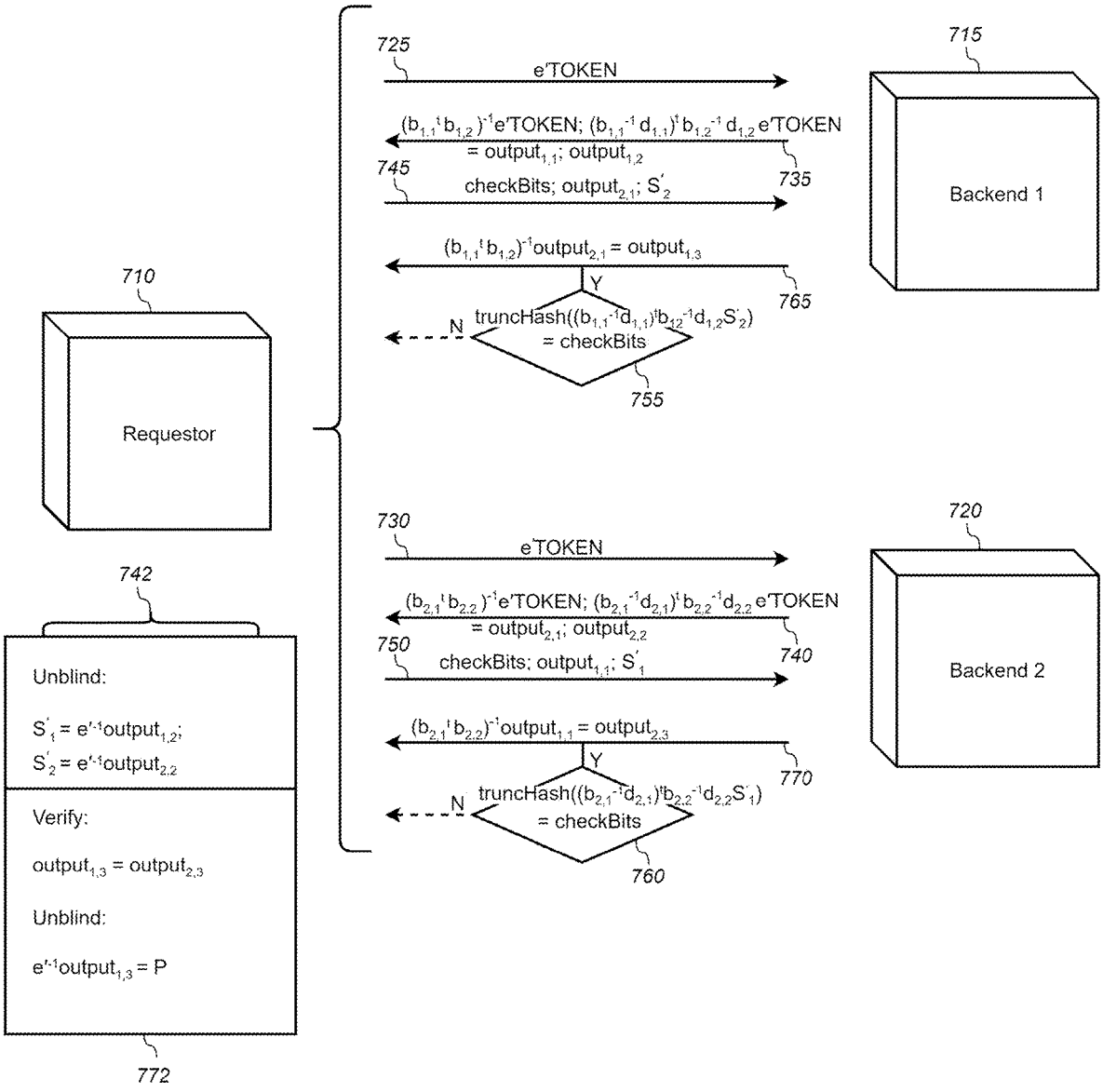

710
Requestor
715
Backend 1
720
Backend 2
725
e'TOKEN
(b1,1^t b1,2)^-1 e'TOKEN; (b1,1^-1 d1,1)^t b1,2^-1 d1,2 e'TOKEN
= output1,1; output1,2
735
745
checkBits; output2,1; S'2
(b1,1^t b1,2)^-1 output2,1 = output1,3
765
Y
N
truncHash((b1,1^-1 d1,1)^t b12^-1 d1,2 S'2)
= checkBits
755
730
e'TOKEN
(b2,1^t b2,2)^-1 e'TOKEN; (b2,1^-1 d2,1)^t b2,2^-1 d2,2 e'TOKEN
= output2,1; output2,2
740
750
checkBits; output1,1; S'1
(b2,1^t b2,2)^-1 output1,1 = output2,3
770
Y
N
truncHash((b2,1^-1 d2,1)^t b2,2^-1 d2,2 S'1)
= checkBits
760
742
Unblind:
S'1 = e'^-1 output1,2;
S'2 = e'^-1 output2,2
Verify:
output1,3 = output2,3
Unblind:
e'^-1 output1,3 = P
772

FIG. 7

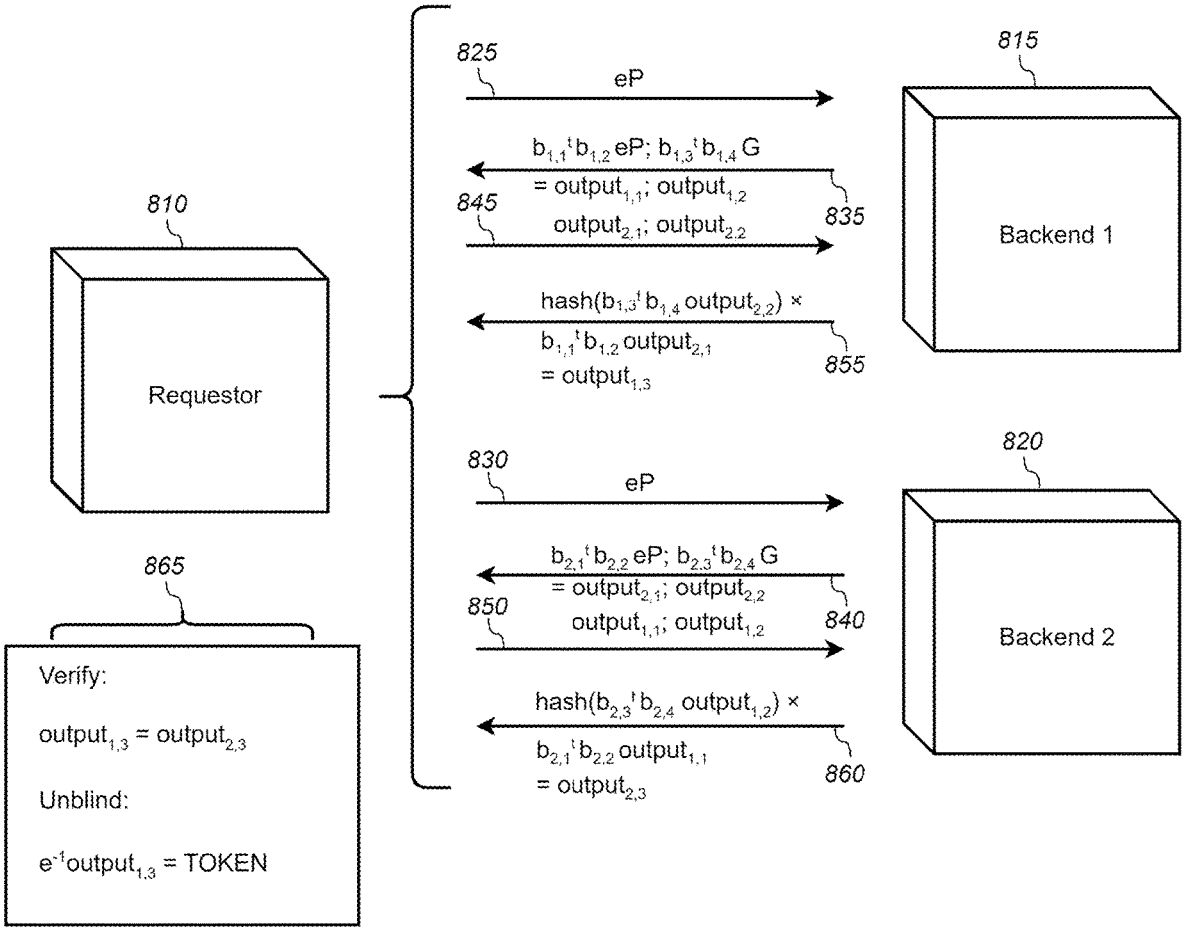

810
Requestor
865
Verify:
output1,3 = output2,3
Unblind:
e-1output1,3 = TOKEN
825
eP
815
Backend 1
b1,1tb1,2 eP; b1,3tb1,4 G
= output1,1; output1,2
845
output2,1; output2,2
835
hash(b1,3tb1,4 output2,2) ×
b1,1tb1,2 output2,1
= output1,3
855
830
eP
820
Backend 2
b2,1tb2,2 eP; b2,3tb2,4 G
= output2,1; output2,2
850
output1,1; output1,2
840
hash(b2,3tb2,4 output1,2) ×
b2,1tb2,2 output1,1
= output2,3
860

FIG. 8

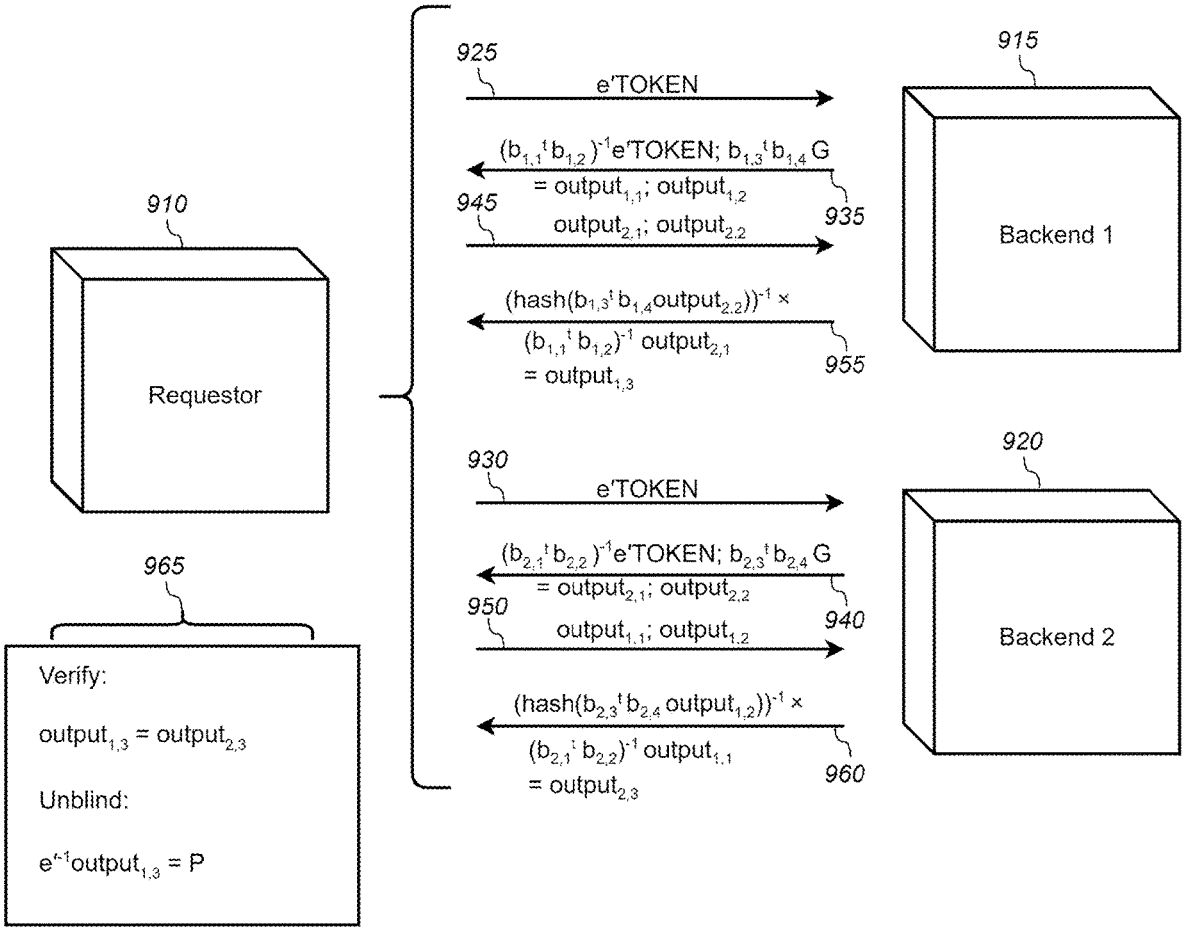

910
Requestor
965
Verify:
output1,3 = output2,3
Unblind:
e^-1 output1,3 = P
925
e'TOKEN
915
Backend 1
(b1,1^t b1,2)^-1 e'TOKEN; b1,3^t b1,4 G
= output1,1; output1,2
945
output2,1; output2,2
935
(hash(b1,3^t b1,4 output2,2))^-1 ×
(b1,1^t b1,2)^-1 output2,1
= output1,3
955
930
e'TOKEN
920
Backend 2
(b2,1^t b2,2)^-1 e'TOKEN; b2,3^t b2,4 G
= output2,1; output2,2
950
output1,1; output1,2
940
(hash(b2,3^t b2,4 output1,2))^-1 ×
(b2,1^t b2,2)^-1 output1,1
= output2,3
960

FIG. 9

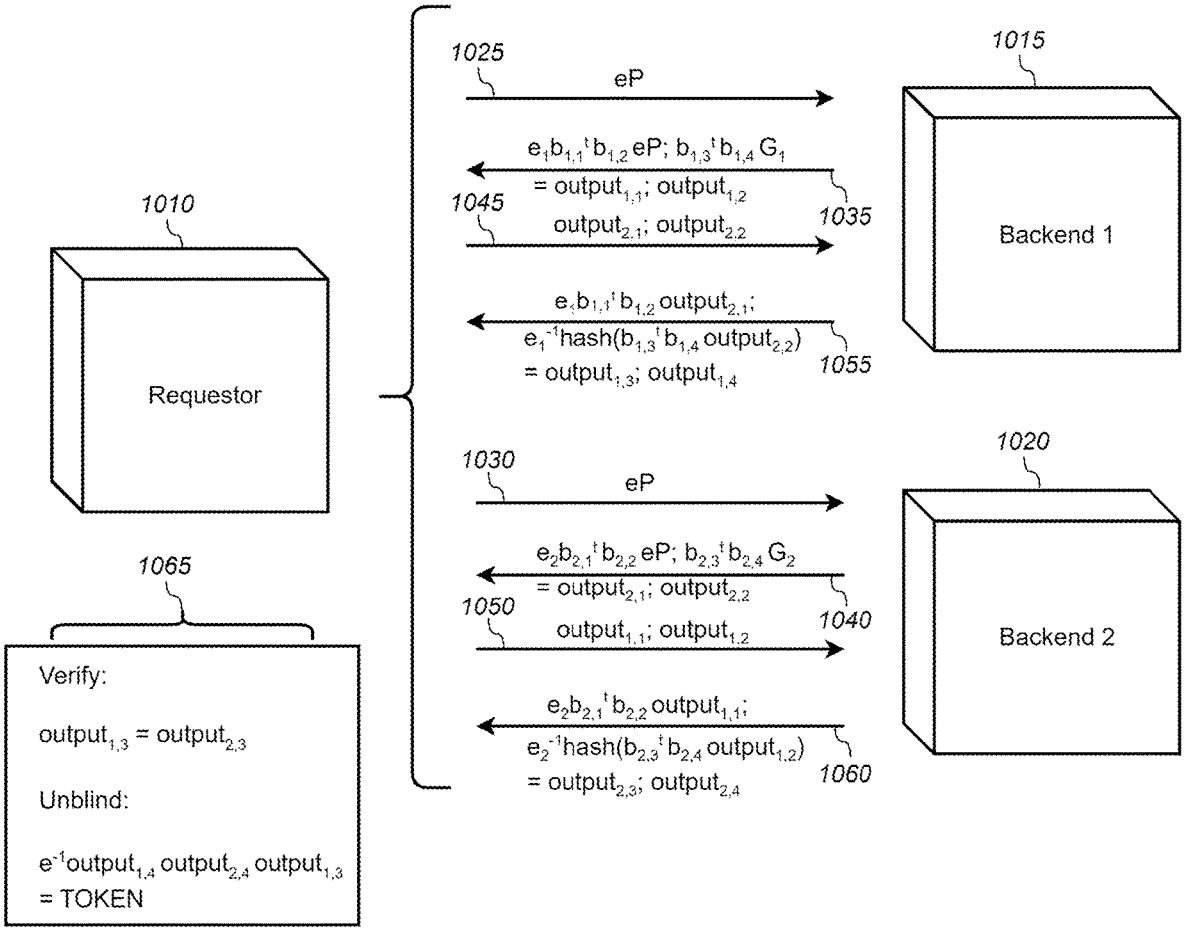

1010
Requestor
1065
Verify:
output1,3 = output2,3
Unblind:
e-1output1,4 output2,4 output1,3
= TOKEN
1025
eP
e1b1,1tb1,2 eP; b1,3tb1,4 G1
= output1,1; output1,2
1045
output2,1; output2,2
1035
e1b1,1tb1,2 output2,1;
e1-1hash(b1,3tb1,4 output2,2)
= output1,3; output1,4
1055
1015
Backend 1
1030
eP
e2b2,1tb2,2 eP; b2,3tb2,4 G2
= output2,1; output2,2
1050
output1,1; output1,2
1040
e2b2,1tb2,2 output1,1;
e2-1hash(b2,3tb2,4 output1,2)
= output2,3; output2,4
1060
1020
Backend 2

FIG. 10

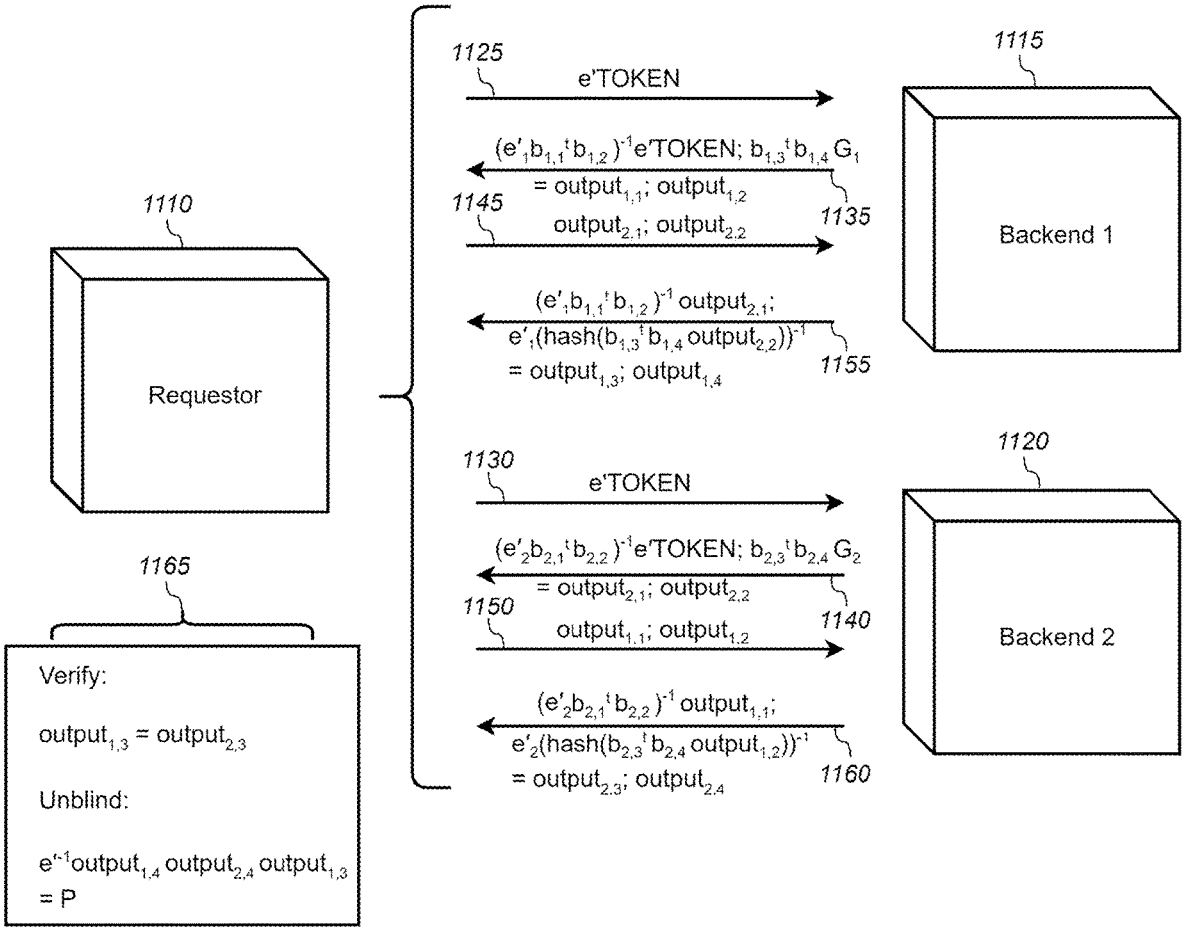

1110
Requestor
1165
Verify:
output1,3 = output2,3
Unblind:
e'-1output1,4 output2,4 output1,3
= P
1125
e'TOKEN
(e'1b1,1tb1,2)-1e'TOKEN; b1,3tb1,4G1
= output1,1; output1,2
1145
output2,1; output2,2
1135
(e'1b1,1tb1,2)-1 output2,1;
e'1(hash(b1,3tb1,4 output2,2))-1
= output1,3; output1,4
1155
1115
Backend 1
1130
e'TOKEN
(e'2b2,1tb2,2)-1e'TOKEN; b2,3tb2,4G2
= output2,1; output2,2
1150
output1,1; output1,2
1140
(e'2b2,1tb2,2)-1 output1,1;
e'2(hash(b2,3tb2,4 output1,2))-1
= output2,3; output2,4
1160
1120
Backend 2

FIG. 11

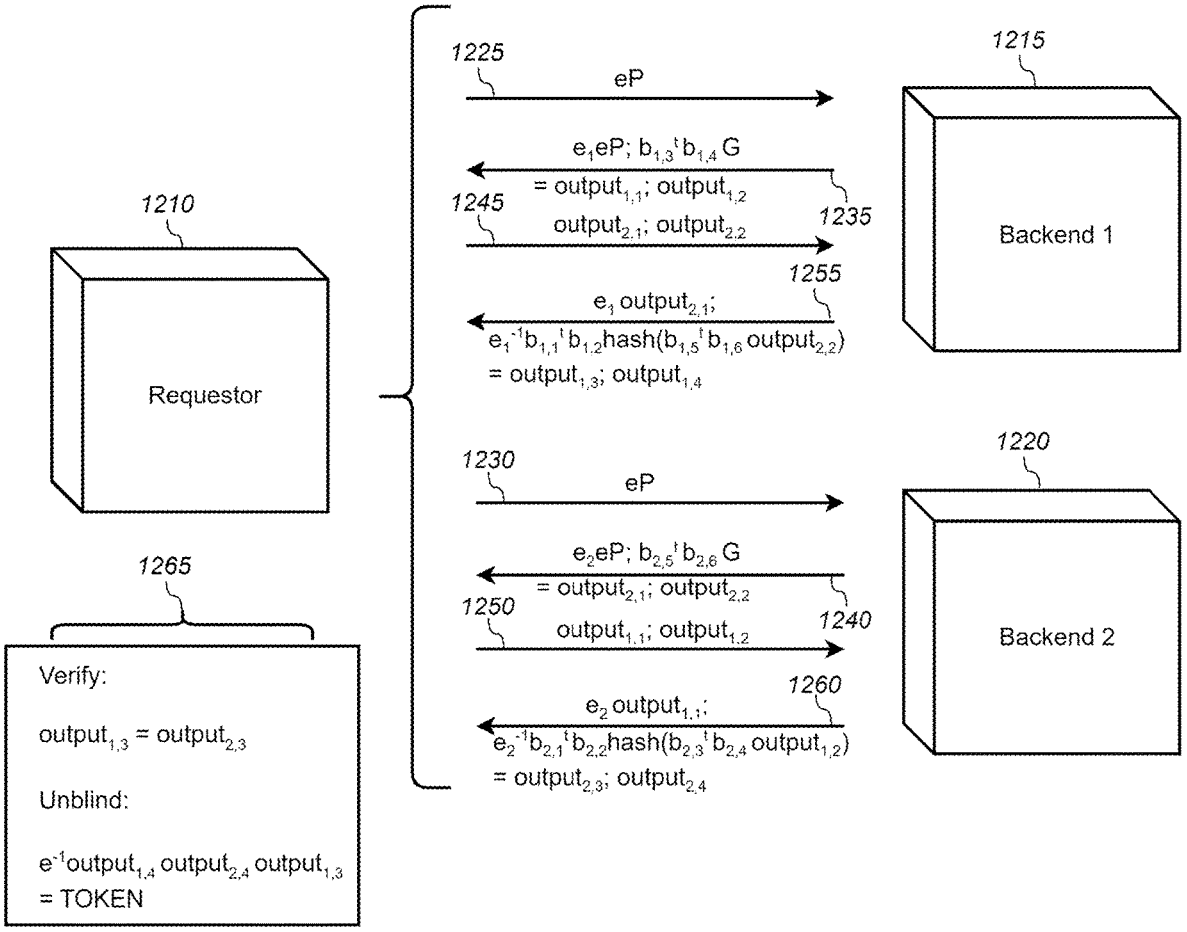

1210
Requestor
1215
Backend 1
1220
Backend 2
1225
eP
e_1eP; $b_{1,3}{}^t b_{1,4} G$
= $output_{1,1}$; $output_{1,2}$
1235
1245
$output_{2,1}$; $output_{2,2}$
1255
e_1 $output_{2,1}$;
$e_1{}^{-1} b_{1,1}{}^t b_{1,2} hash(b_{1,5}{}^t b_{1,6}$ $output_{2,2})$
= $output_{1,3}$; $output_{1,4}$
1230
eP
e_2eP; $b_{2,5}{}^t b_{2,6} G$
= $output_{2,1}$; $output_{2,2}$
1240
1250
$output_{1,1}$; $output_{1,2}$
1260
e_2 $output_{1,1}$;
$e_2{}^{-1} b_{2,1}{}^t b_{2,2} hash(b_{2,3}{}^t b_{2,4}$ $output_{1,2})$
= $output_{2,3}$; $output_{2,4}$
1265
Verify:
$output_{1,3}$ = $output_{2,3}$
Unblind:
$e^{-1} output_{1,4}$ $output_{2,4}$ $output_{1,3}$
= TOKEN

FIG. 12

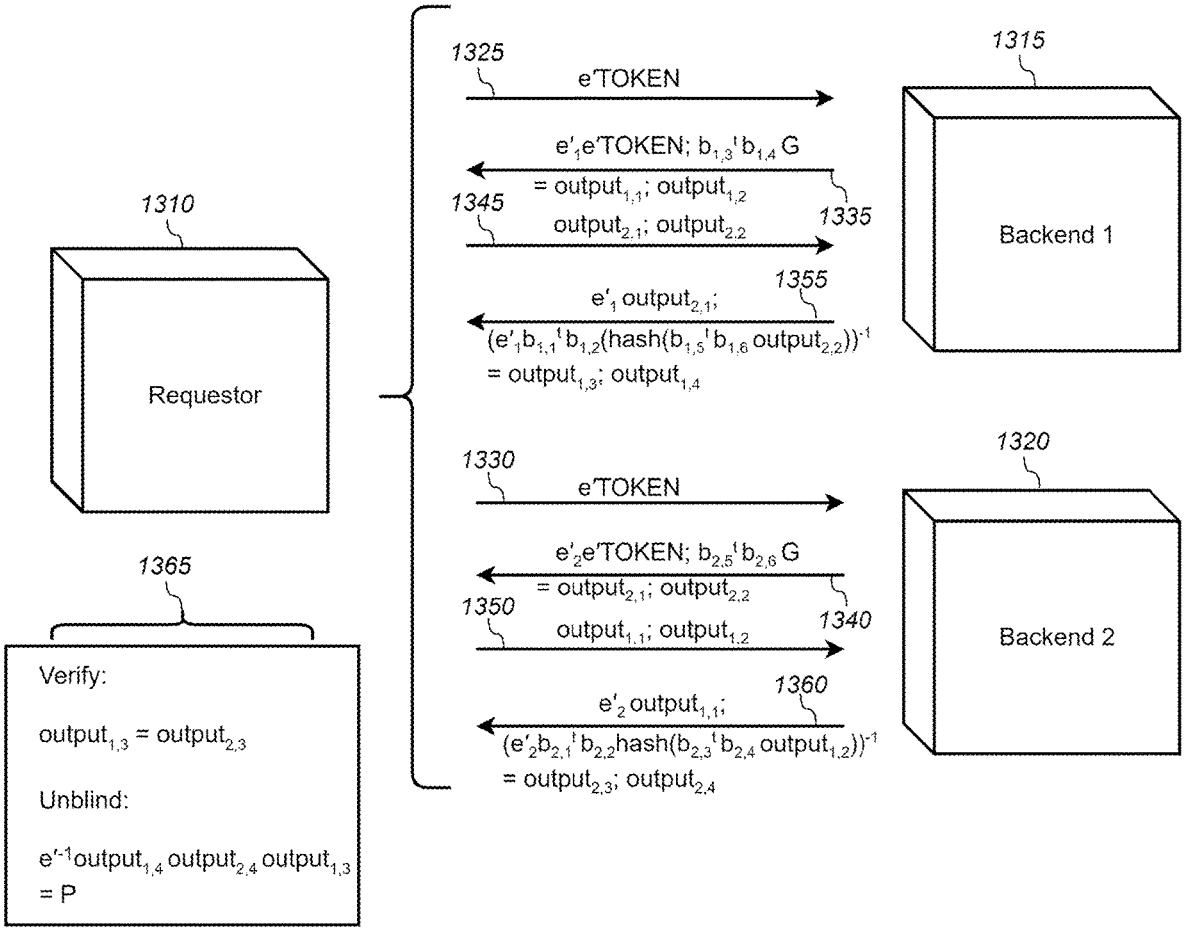

1310
Requestor
1315
Backend 1
1320
Backend 2
1325
e'TOKEN
e'1e'TOKEN; b1,3't b1,4 G
= output1,1; output1,2
1345
output2,1; output2,2
1335
1355
e'1 output2,1;
(e'1b1,1't b1,2(hash(b1,5't b1,6 output2,2))-1
= output1,3; output1,4
1330
e'TOKEN
e'2e'TOKEN; b2,5't b2,6 G
= output2,1; output2,2
1350
output1,1; output1,2
1340
1360
e'2 output1,1;
(e'2b2,1't b2,2hash(b2,3't b2,4 output1,2))-1
= output2,3; output2,4
1365
Verify:
output1,3 = output2,3
Unblind:
e'-1output1,4 output2,4 output1,3
= P

FIG. 13

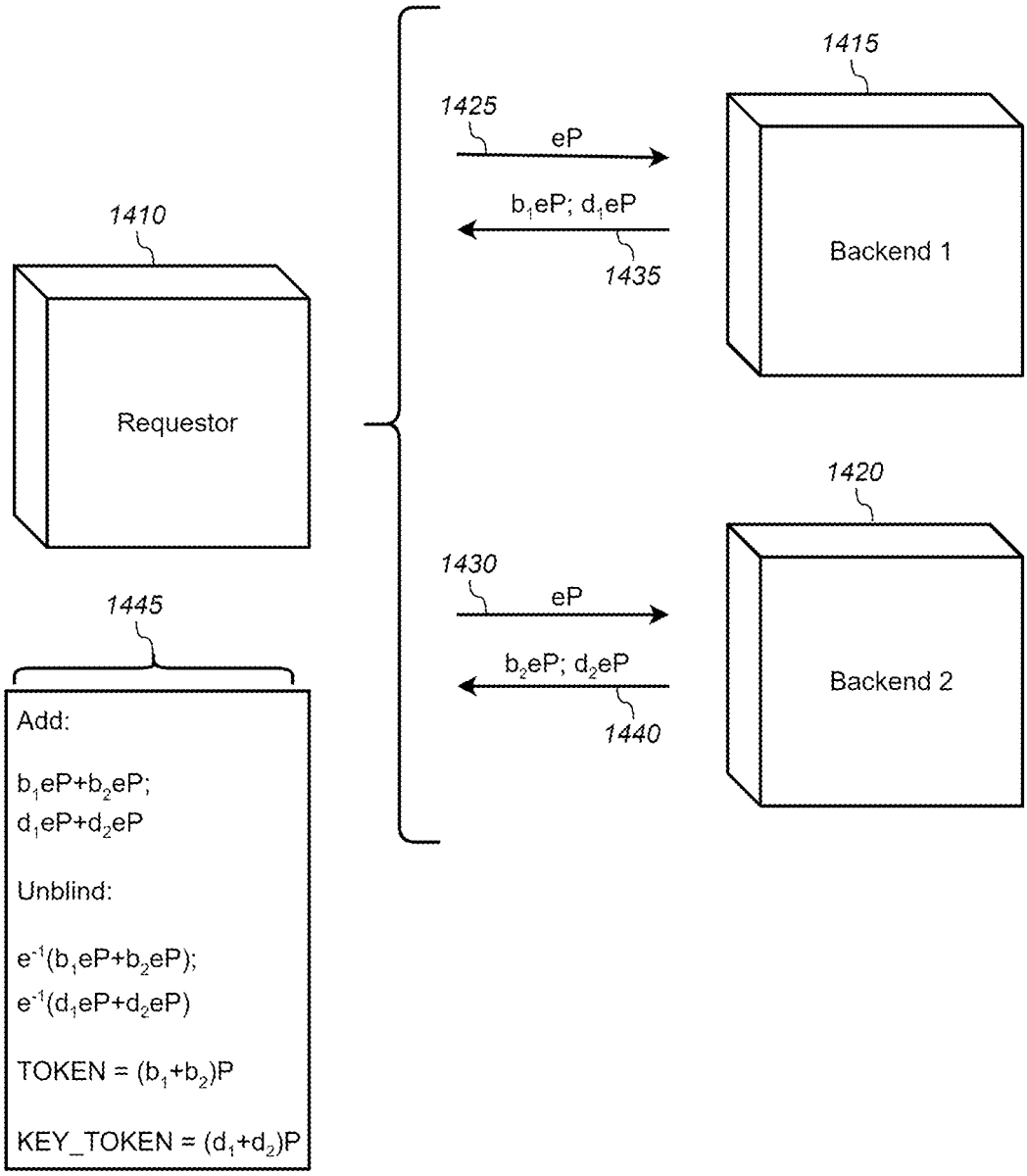

1415
1425
eP
b1eP; d1eP
1435
Backend 1
1410
Requestor
1420
1430
eP
b2eP; d2eP
1440
Backend 2
1445
Add:
b1eP+b2eP;
d1eP+d2eP
Unblind:
e-1(b1eP+b2eP);
e-1(d1eP+d2eP)
TOKEN = (b1+b2)P
KEY_TOKEN = (d1+d2)P

FIG. 14

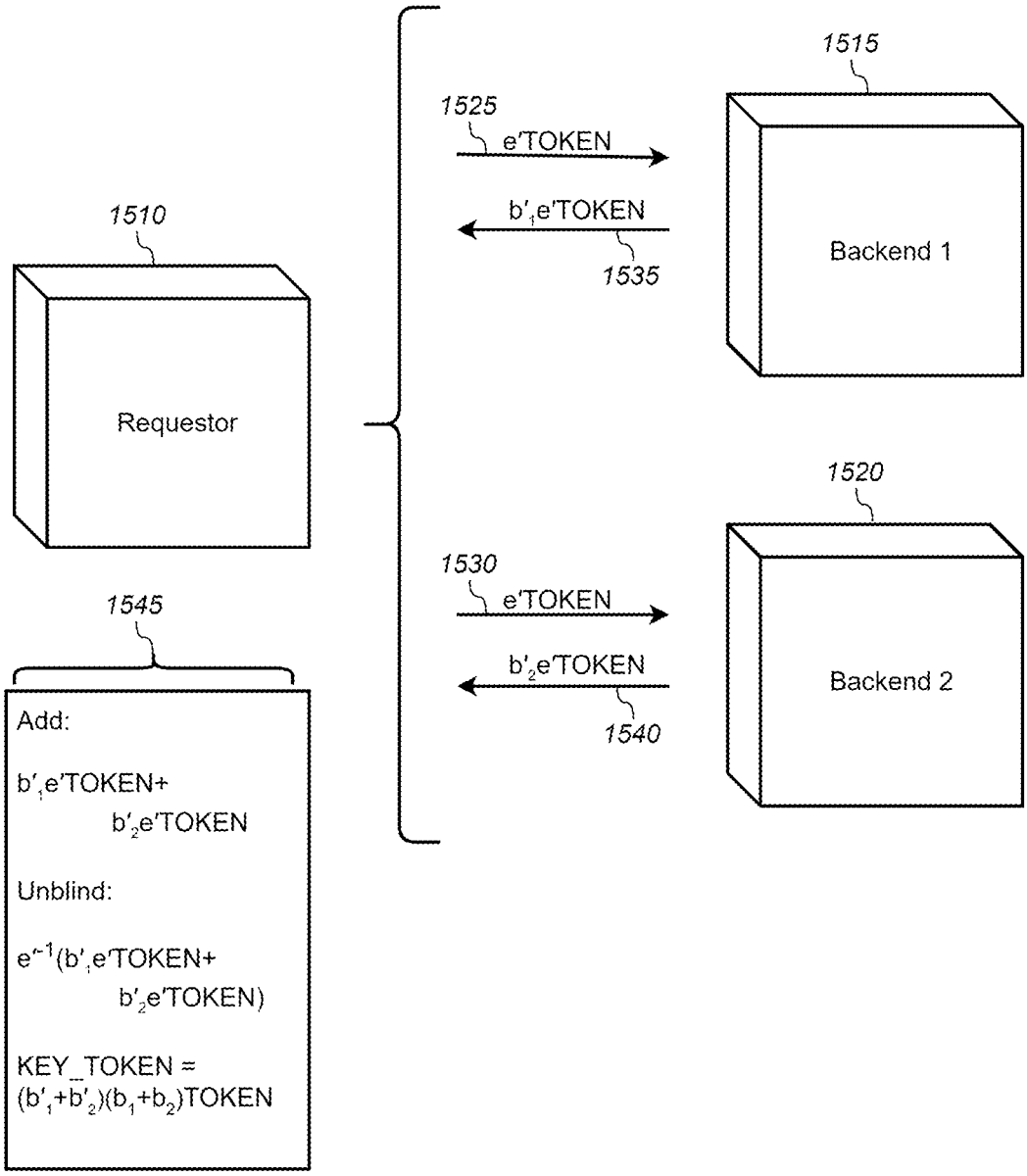

1515
1525
e'TOKEN
b'1e'TOKEN
1535
Backend 1
1510
Requestor
1520
1530
e'TOKEN
b'2e'TOKEN
1540
Backend 2
1545
Add:
b'1e'TOKEN+
b'2e'TOKEN
Unblind:
e'-1(b'1e'TOKEN+
b'2e'TOKEN)
KEY_TOKEN =
(b'1+b'2)(b1+b2)TOKEN

FIG. 15

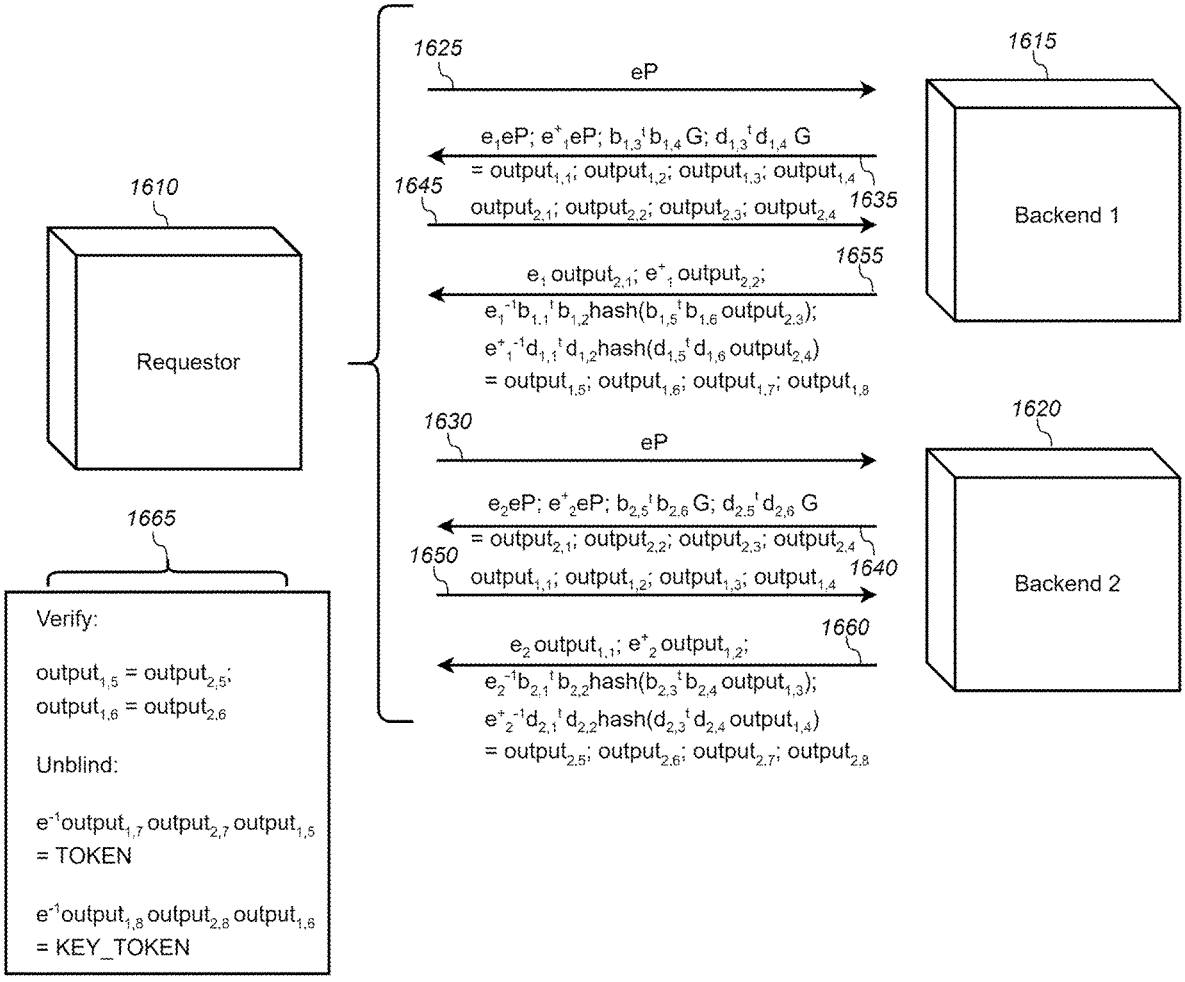

1610
Requestor
1615
Backend 1
1620
Backend 2
1625
eP
$e_1eP; e^+_1eP; b_{1,3}{}^t b_{1,4} G; d_{1,3}{}^t d_{1,4} G$
$= output_{1,1}; output_{1,2}; output_{1,3}; output_{1,4}$
1635
1645
$output_{2,1}; output_{2,2}; output_{2,3}; output_{2,4}$
1655
$e_1 output_{2,1}; e^+_1 output_{2,2};$
$e_1{}^{-1} b_{1,1}{}^t b_{1,2} hash(b_{1,5}{}^t b_{1,6} output_{2,3});$
$e^+_1{}^{-1} d_{1,1}{}^t d_{1,2} hash(d_{1,5}{}^t d_{1,6} output_{2,4})$
$= output_{1,5}; output_{1,6}; output_{1,7}; output_{1,8}$
1630
eP
$e_2eP; e^+_2eP; b_{2,5}{}^t b_{2,6} G; d_{2,5}{}^t d_{2,6} G$
$= output_{2,1}; output_{2,2}; output_{2,3}; output_{2,4}$
1650
1640
$output_{1,1}; output_{1,2}; output_{1,3}; output_{1,4}$
1660
$e_2 output_{1,1}; e^+_2 output_{1,2};$
$e_2{}^{-1} b_{2,1}{}^t b_{2,2} hash(b_{2,3}{}^t b_{2,4} output_{1,3});$
$e^+_2{}^{-1} d_{2,1}{}^t d_{2,2} hash(d_{2,3}{}^t d_{2,4} output_{1,4})$
$= output_{2,5}; output_{2,6}; output_{2,7}; output_{2,8}$
1665
Verify:
$output_{1,5} = output_{2,5};$
$output_{1,6} = output_{2,6}$
Unblind:
$e^{-1} output_{1,7} output_{2,7} output_{1,5}$
= TOKEN
$e^{-1} output_{1,8} output_{2,8} output_{1,6}$
= KEY_TOKEN

FIG. 16

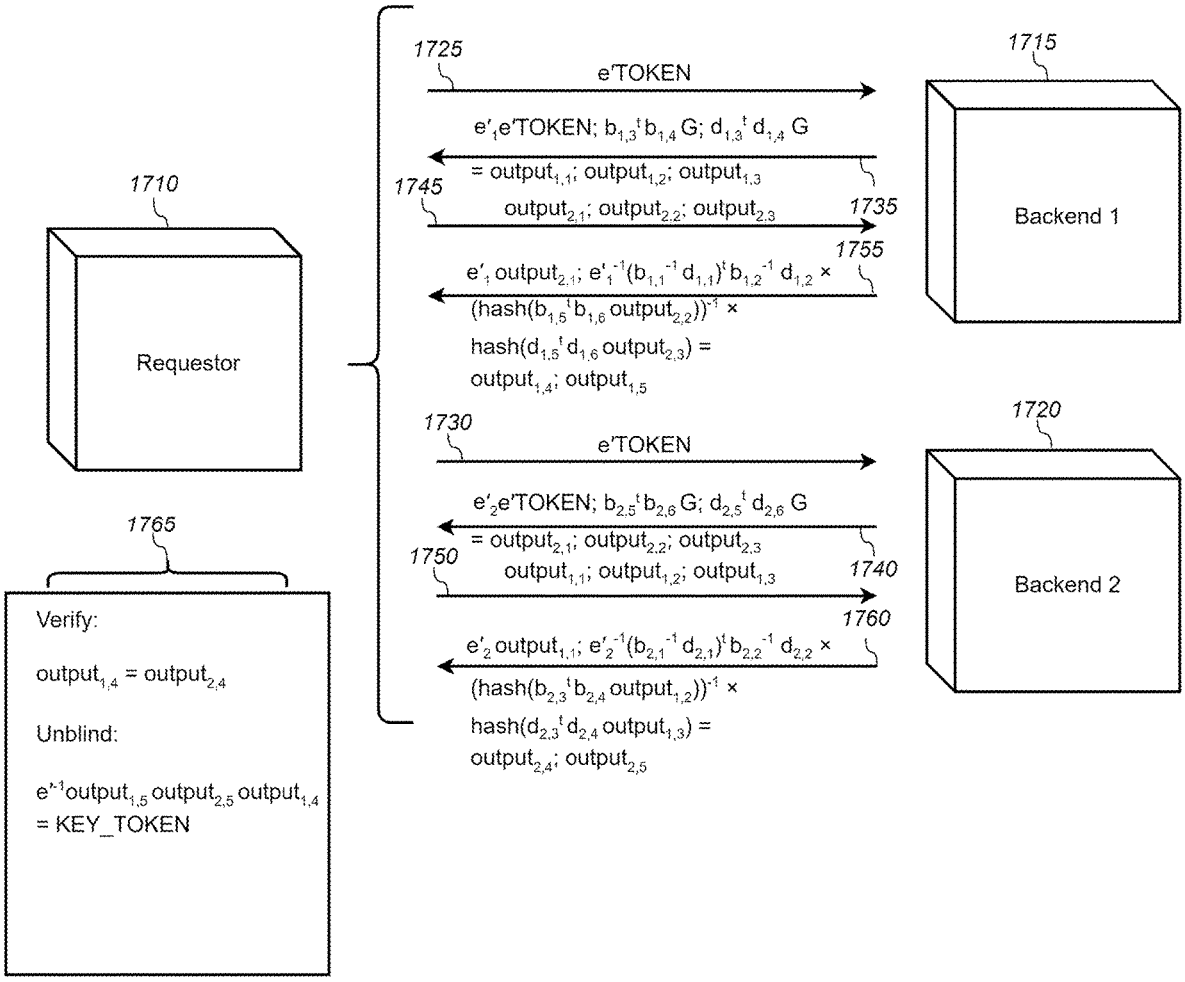

1710
Requestor
1715
Backend 1
1720
Backend 2
1725
e'TOKEN
e'1e'TOKEN; b1,3^t b1,4 G; d1,3^t d1,4 G
= output1,1; output1,2; output1,3
1745
output2,1; output2,2; output2,3
1735
1755
e'1 output2,1; e'1^-1(b1,1^-1 d1,1)^t b1,2^-1 d1,2 ×
(hash(b1,5^t b1,6 output2,2))^-1 ×
hash(d1,5^t d1,6 output2,3) =
output1,4; output1,5
1730
e'TOKEN
e'2e'TOKEN; b2,5^t b2,6 G; d2,5^t d2,6 G
= output2,1; output2,2; output2,3
1750
output1,1; output1,2; output1,3
1740
1760
e'2 output1,1; e'2^-1(b2,1^-1 d2,1)^t b2,2^-1 d2,2 ×
(hash(b2,3^t b2,4 output1,2))^-1 ×
hash(d2,3^t d2,4 output1,3) =
output2,4; output2,5
1765
Verify:
output1,4 = output2,4
Unblind:
e'^-1 output1,5 output2,5 output1,4
= KEY_TOKEN

FIG. 17

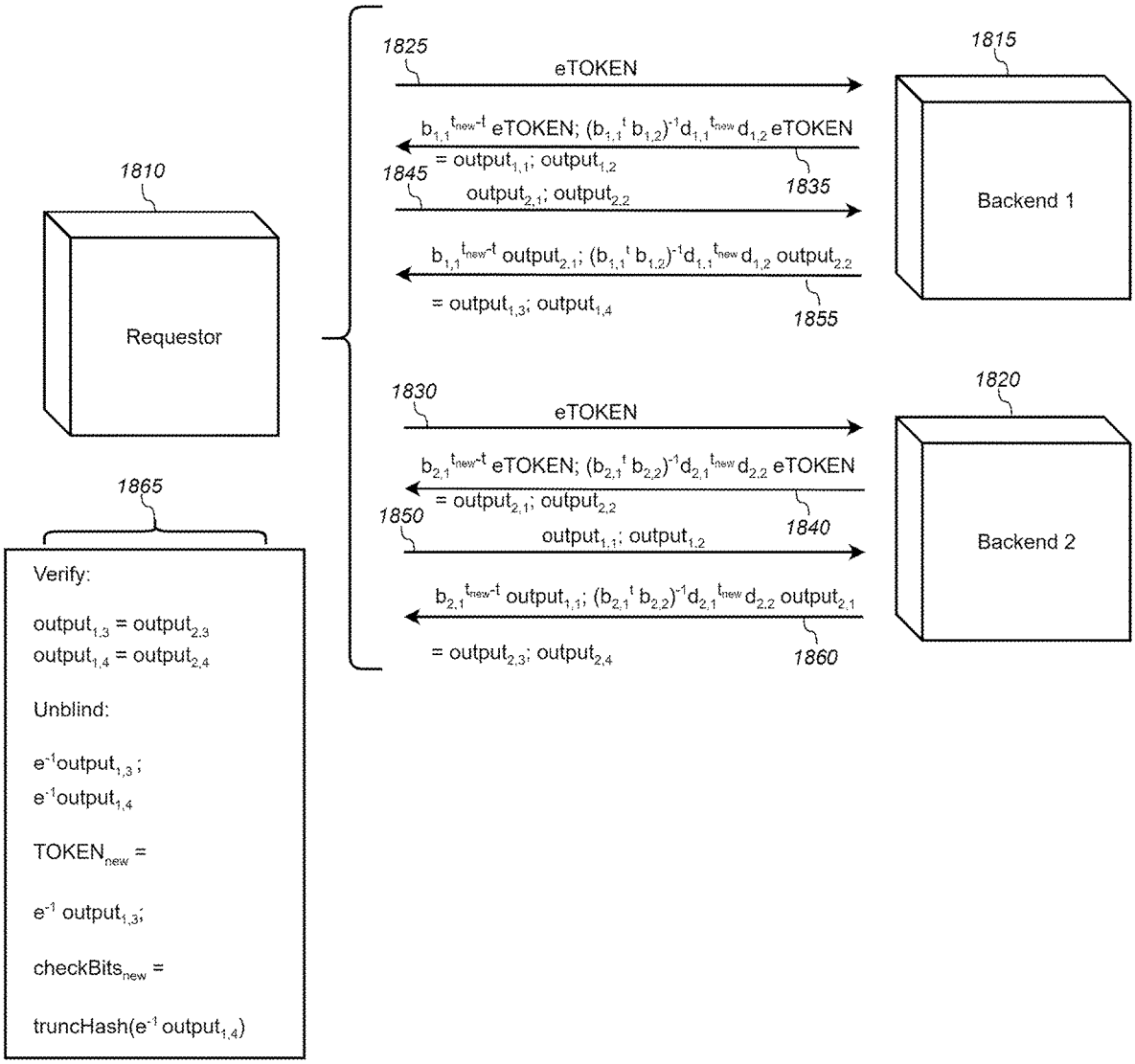

1810
Requestor
1865
Verify:
output1,3 = output2,3
output1,4 = output2,4
Unblind:
e-1output1,3 ;
e-1output1,4
TOKENnew =
e-1 output1,3;
checkBitsnew =
truncHash(e-1 output1,4)
1825
eTOKEN
b1,1 tnew-t eTOKEN; (b1,1t b1,2)-1d1,1 tnew d1,2 eTOKEN
= output1,1; output1,2
1845
output2,1; output2,2
b1,1 tnew-t output2,1; (b1,1t b1,2)-1d1,1 tnew d1,2 output2,2
= output1,3; output1,4
1855
1815
Backend 1
1830
eTOKEN
b2,1 tnew-t eTOKEN; (b2,1t b2,2)-1d2,1 tnew d2,2 eTOKEN
= output2,1; output2,2
1850
output1,1; output1,2
1840
b2,1 tnew-t output1,1; (b2,1t b2,2)-1d2,1 tnew d2,2 output2,1
= output2,3; output2,4
1860
1820
Backend 2

FIG. 18

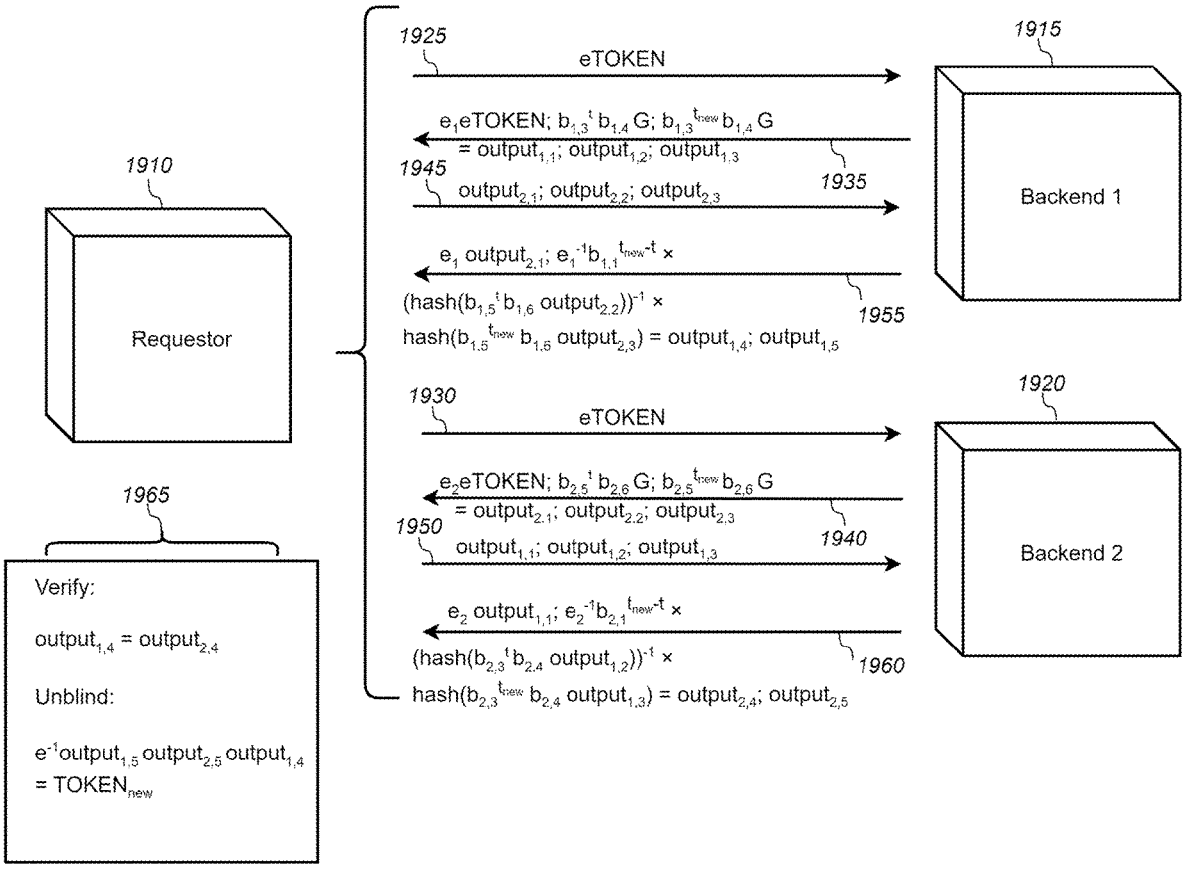

1910
Requestor
1915
Backend 1
1920
Backend 2
1925
eTOKEN
e_1eTOKEN; $b_{1,3}{}^{t} b_{1,4} G$; $b_{1,3}{}^{t_{new}} b_{1,4} G$
= $output_{1,1}$; $output_{1,2}$; $output_{1,3}$
1935
1945
$output_{2,1}$; $output_{2,2}$; $output_{2,3}$
e_1 $output_{2,1}$; $e_1{}^{-1} b_{1,1}{}^{t_{new}-t}$ ×
$(hash(b_{1,5}{}^{t} b_{1,6}\ output_{2,2}))^{-1}$ ×
$hash(b_{1,5}{}^{t_{new}} b_{1,6}\ output_{2,3}) = output_{1,4}; output_{1,5}$
1955
1930
eTOKEN
e_2eTOKEN; $b_{2,5}{}^{t} b_{2,6} G$; $b_{2,5}{}^{t_{new}} b_{2,6} G$
= $output_{2,1}$; $output_{2,2}$; $output_{2,3}$
1940
1950
$output_{1,1}$; $output_{1,2}$; $output_{1,3}$
e_2 $output_{1,1}$; $e_2{}^{-1} b_{2,1}{}^{t_{new}-t}$ ×
$(hash(b_{2,3}{}^{t} b_{2,4}\ output_{1,2}))^{-1}$ ×
$hash(b_{2,3}{}^{t_{new}} b_{2,4}\ output_{1,3}) = output_{2,4}; output_{2,5}$
1960
1965
Verify:
$output_{1,4} = output_{2,4}$
Unblind:
$e^{-1} output_{1,5}\ output_{2,5}\ output_{1,4}$
$= TOKEN_{new}$

FIG. 19

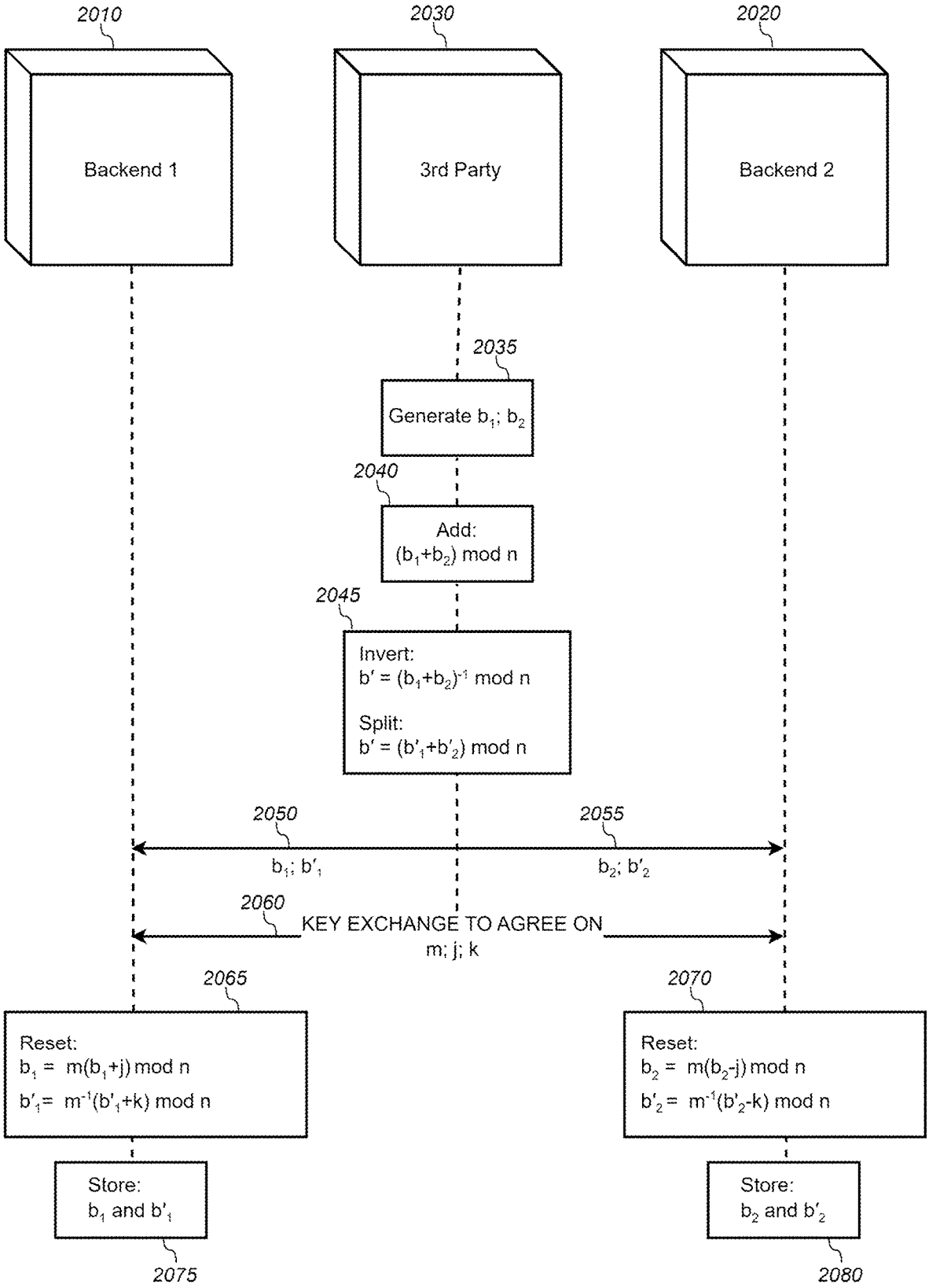

2010
2030
2020
Backend 1
3rd Party
Backend 2
2035
Generate b_1; b_2
2040
Add:
(b_1+b_2) mod n
2045
Invert:
$b' = (b_1+b_2)^{-1}$ mod n
Split:
$b' = (b'_1+b'_2)$ mod n
2050
2055
b_1; b'_1
b_2; b'_2
2060
KEY EXCHANGE TO AGREE ON
m; j; k
2065
2070
Reset:
$b_1 = m(b_1+j)$ mod n
$b'_1 = m^{-1}(b'_1+k)$ mod n
Reset:
$b_2 = m(b_2-j)$ mod n
$b'_2 = m^{-1}(b'_2-k)$ mod n
Store:
b_1 and b'_1
Store:
b_2 and b'_2
2075
2080

FIG. 20

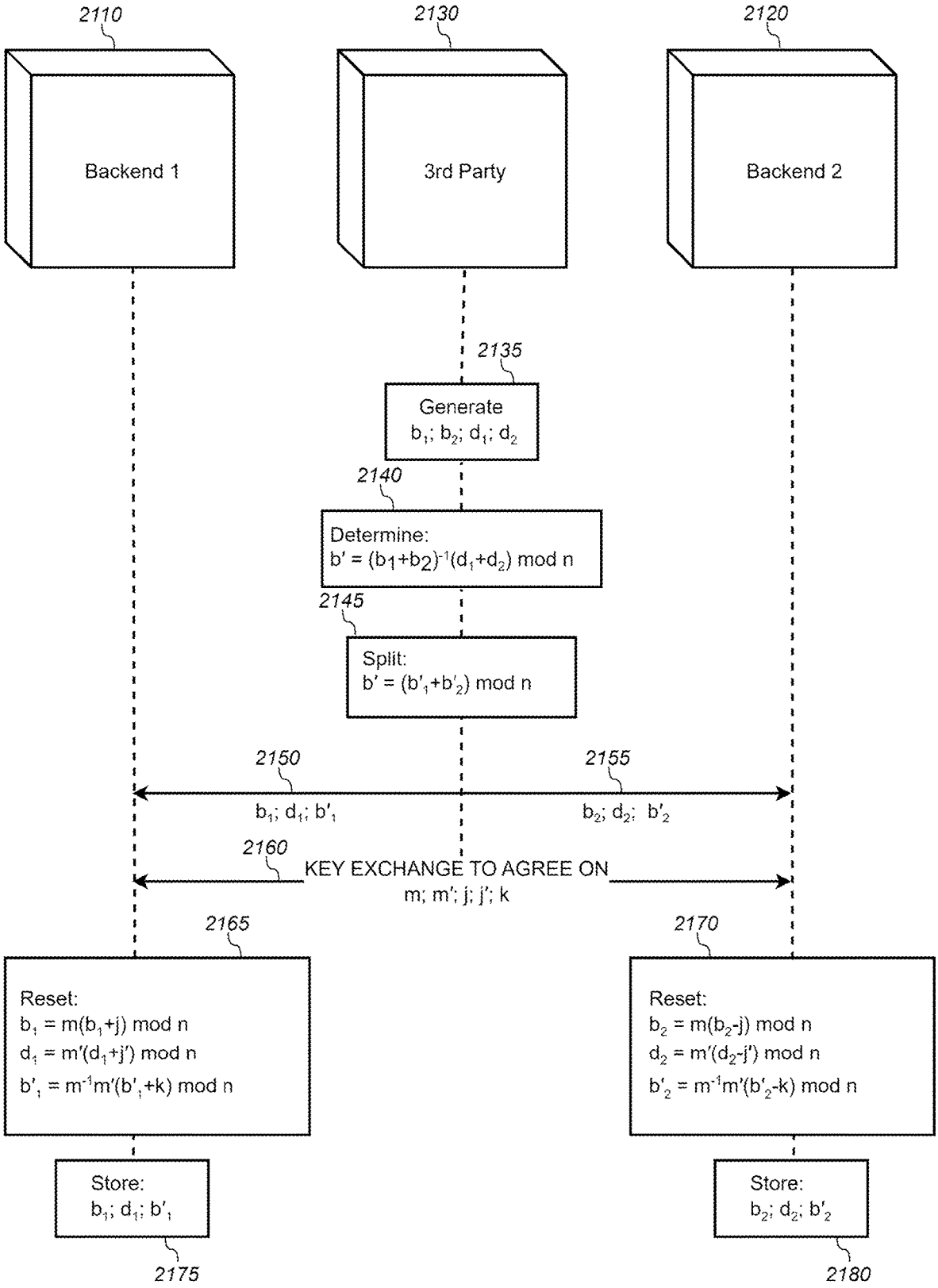

2110
2130
2120
Backend 1
3rd Party
Backend 2
2135
Generate
b_1; b_2; d_1; d_2
2140
Determine:
$b' = (b_1+b_2)^{-1}(d_1+d_2) \bmod n$
2145
Split:
$b' = (b'_1+b'_2) \bmod n$
2150
2155
b_1; d_1; b'_1
b_2; d_2; b'_2
2160
KEY EXCHANGE TO AGREE ON
m; m'; j; j'; k
2165
2170
Reset:
$b_1 = m(b_1+j) \bmod n$
$d_1 = m'(d_1+j') \bmod n$
$b'_1 = m^{-1}m'(b'_1+k) \bmod n$
Reset:
$b_2 = m(b_2-j) \bmod n$
$d_2 = m'(d_2-j') \bmod n$
$b'_2 = m^{-1}m'(b'_2-k) \bmod n$
Store:
b_1; d_1; b'_1
Store:
b_2; d_2; b'_2
2175
2180

FIG. 21

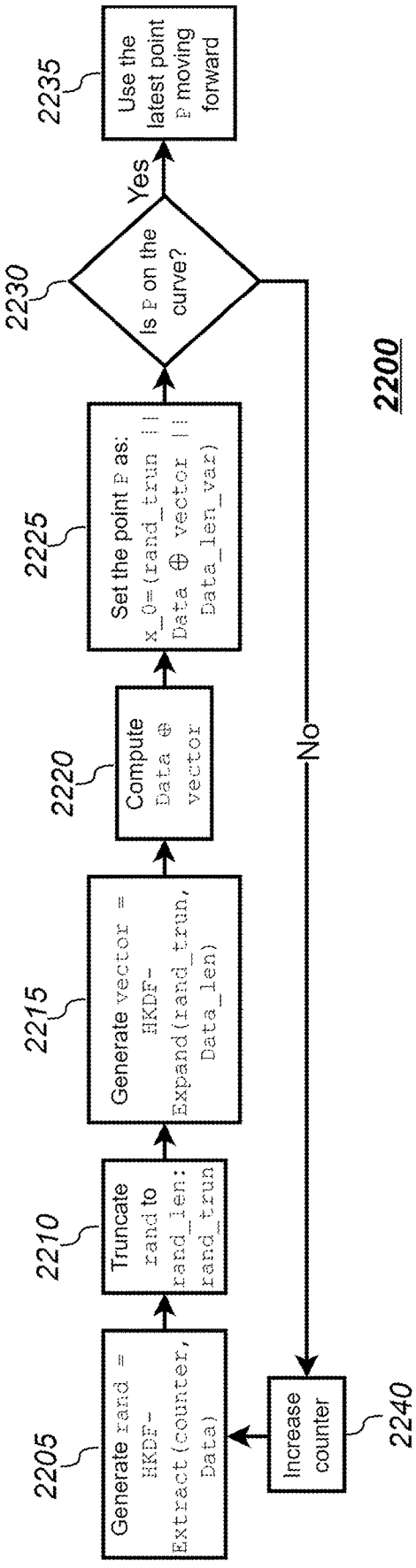

2205
Generate rand = HKDF-Extract(counter, Data)
2210
Truncate rand to rand_len: rand_trun
2215
Generate vector = HKDF-Expand(rand_trun, Data_len)
2220
Compute Data ⊕ vector
2225
Set the point P as: x_0=(rand_trun || Data ⊕ vector || Data_len_var)
2230
Is P on the curve?
Yes
No
2235
Use the latest point P moving forward
2240
Increase counter
2200

FIG. 22

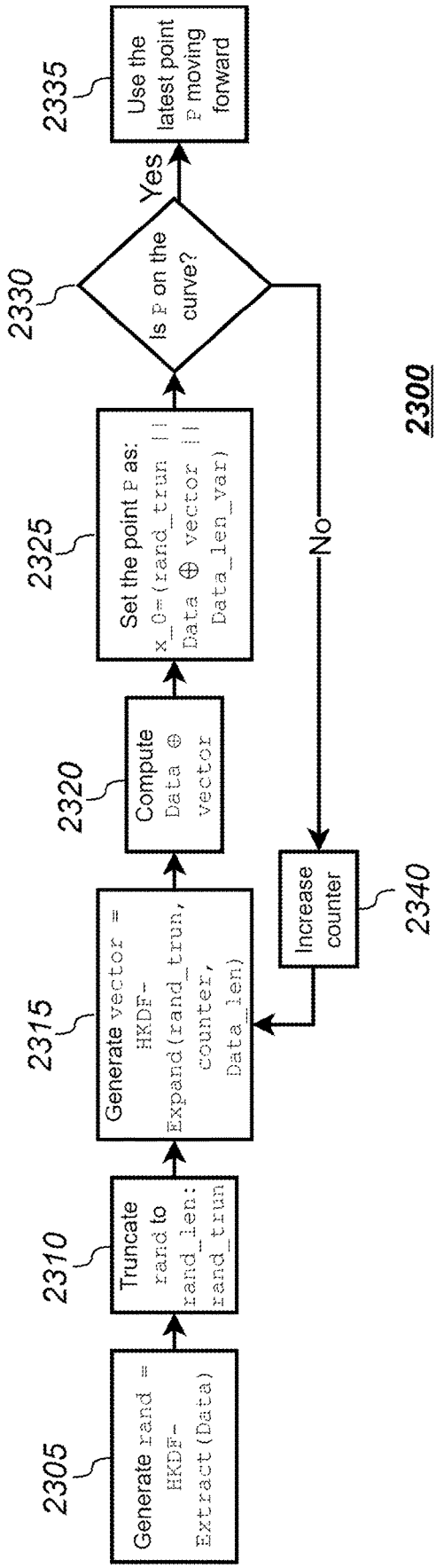

2305
Generate rand = HKDF-Extract(Data)
2310
Truncate rand to rand_len: rand_trun
2315
Generate vector = HKDF-Expand(rand_trun, counter, Data_len)
2320
Compute Data ⊕ vector
2325
Set the point P as: x_0=(rand_trun || Data ⊕ vector || Data_len_var)
2330
Is P on the curve?
Yes
2335
Use the latest point P moving forward
No
2340
Increase counter
2300

FIG. 23

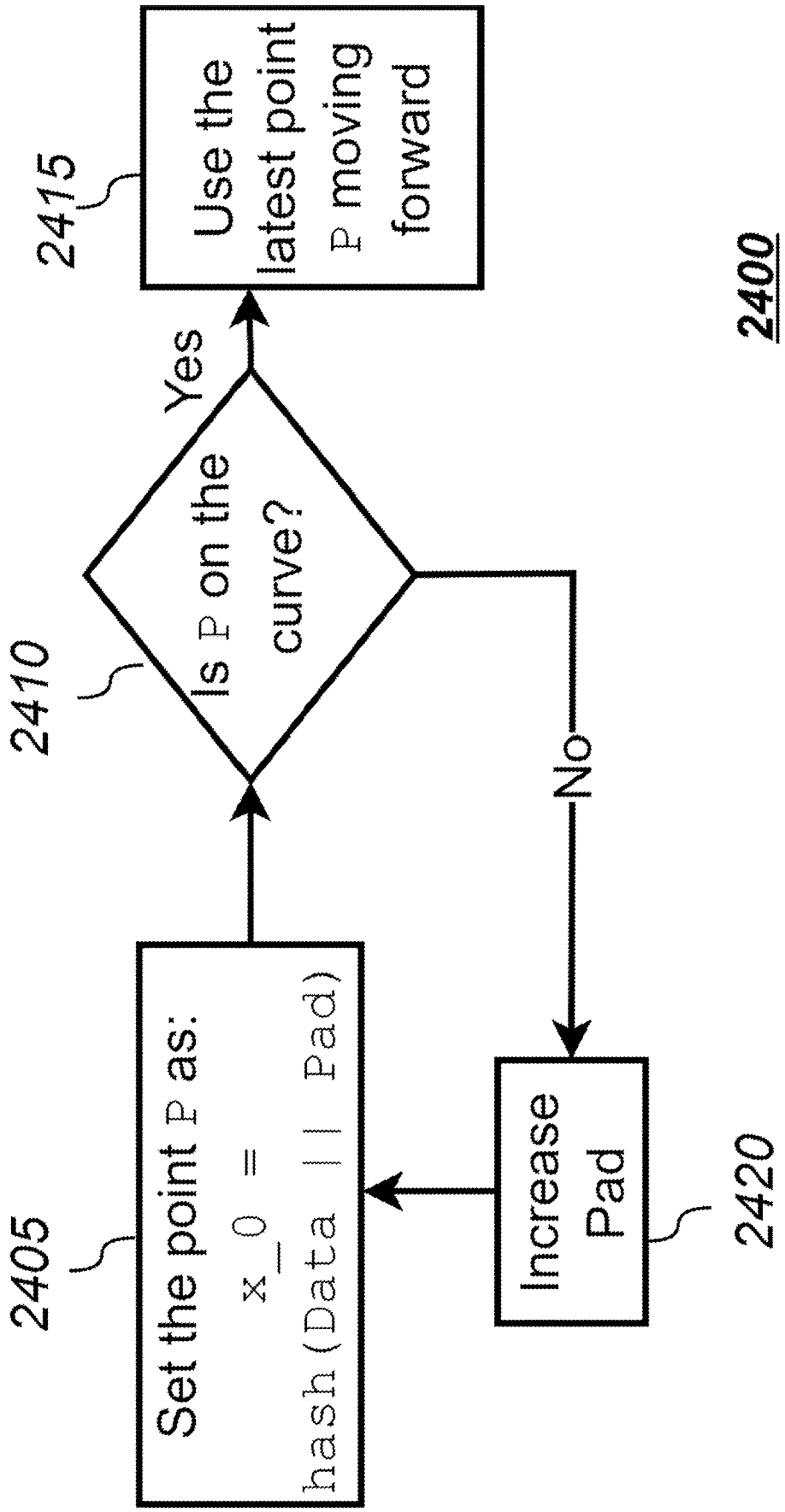

2400
2405
Set the point P as:
x_0 = hash(Data || Pad)
2410
Is P on the curve?
Yes
No
2415
Use the latest point P moving forward
2420
Increase Pad

FIG. 24

METHOD AND APPARATUS FOR REVERSIBLE TOKENIZATION WITH SUPPORT FOR EMBEDDABLE ROLE-BASED ACCESS CONTROL

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional application No. 63/393,734 filed Jul. 29, 2022, which is incorporated by reference in its entirety herein.

TECHNICAL FIELD

[0002] These teachings relate generally to accessing data and more particularly to the preservation of privacy.

BACKGROUND

[0003] It is known in the prior art to tokenize data via multiple processors such that the one or more secrets used by each processor to effect tokenization can be updated without requiring previously tokenized data to be retokenized to enable effective matching of tokenized data across instances of tokenization regardless of when tokenization occurred. It is also known to have a requestor of tokenization ephemerally blind the input data to hide its value during the tokenization process without affecting the finalized value of the resultant token. The applicant has determined that it can be desirable, however, to retain these properties while satisfying additional ones as explained below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. **1** comprises a flow diagram as configured in accordance with various embodiments of these teachings and that illustrates the architecture of Tokenization Processors and the topology of the communications. In this particular example, the enabling apparatus includes Tokenization Processors configured to effect tokenization, detokenization or token translation via a corresponding network;

[0005] FIG. **2** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable single-round tokenization involving a Requestor, a Backend 1 and a Backend 2. A reversible token is a final output, and its derivation involves addition and unblinding on the part of the Requestor. The transmissions depicted in FIG. **2** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0006] FIG. **3** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable single-round detokenization, intended to recover a representation of the Data that was tokenized as corresponding to FIG. **2** and involving a Requestor, a Backend 1 and a Backend 2. The transmissions depicted in FIG. **3** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0007] FIG. **4** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round tokenization involving a Requestor, a Backend 1 and a Backend 2. The final outputs comprise a reversible token and a cryptographic integrity token, and their derivation involves addition, unblinding and hashing on the part of the Requestor. The transmissions depicted in FIG. **4** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0008] FIG. **5** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round detokenization, intended to recover a representation of the Data that was tokenized as corresponding to FIG. **4** and involving a Requestor, a Backend 1 and a Backend 2. The transmissions depicted in FIG. **5** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0009] FIG. **6** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round tokenization involving a Requestor, a Backend 1 and a Backend 2. The final outputs comprise a reversible token and a cryptographic integrity token, and their derivation involves verification, unblinding and hashing on the part of the Requestor. The transmissions depicted in FIG. **6** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0010] FIG. **7** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round detokenization, intended to recover a representation of the Data that was tokenized as corresponding to FIG. **6** and involving a Requestor, a Backend 1 and a Backend 2. The transmissions depicted in FIG. **7** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0011] FIG. **8** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round tokenization involving a Requestor, a Backend 1 and a Backend 2. A reversible token is a final output, and its derivation involves verification and unblinding on the part of the Requestor. The transmissions depicted in FIG. **8** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0012] FIG. **9** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round detokenization, intended to recover a representation of the Data that was tokenized as corresponding to FIG. **8** and involving a Requestor, a Backend 1 and a Backend 2. The transmissions depicted in FIG. **9** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0013] FIG. **10** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round tokenization involving a Requestor, a Backend 1 and a Backend 2. A reversible token is a final output, and its derivation involves verification and unblinding on the part of the Requestor that follows unblinding on the part of Back-

end 1 and Backend 2. The transmissions depicted in FIG. **10** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0014] FIG. **11** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round detokenization, intended to recover a representation of the Data that was tokenized as corresponding to FIG. **10** and involving a Requestor, a Backend 1 and a Backend 2. The transmissions depicted in FIG. **11** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0015] FIG. **12** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round tokenization involving a Requestor, a Backend 1 and a Backend 2. A reversible token is a final output, and its derivation involves verification and unblinding on the part of the Requestor that follows unblinding on the part of Backend 1 and Backend 2. The transmissions depicted in FIG. **12** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0016] FIG. **13** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round detokenization, intended to recover a representation of the Data that was tokenized as corresponding to FIG. **12** and involving a Requestor, a Backend 1 and a Backend 2. The transmissions depicted in FIG. **13** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0017] FIG. **14** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round tokenization involving a Requestor, a Backend 1 and a Backend 2. Derivation of the final outputs involves addition and unblinding on the part of the Requestor, where these outputs comprise a key token usable to derive keying material and a token usable during detokenization to recover the key token. The processing of FIG. **14** is related to the direct tokenization of Data depicted in FIG. **2**. The transmissions depicted in FIG. **14** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0018] FIG. **15** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round detokenization, intended to recover the keying material as derived from the key token of FIG. **14** and involving a Requestor, a Backend 1 and a Backend 2. The transmissions depicted in FIG. **15** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0019] FIG. **16** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round tokenization involving a Requestor, a Backend 1 and a Backend 2. Derivation of the final outputs involves verification and unblinding on the part of the Requestor, where these outputs comprise a key token usable to derive keying material and a token usable during detokenization to recover the key token. The processing of FIG. **16** is related to the direct tokenization of Data depicted in FIG. **12**. The transmissions depicted in FIG. **16** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0020] FIG. **17** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round detokenization, intended to recover the keying material as derived from the key token of FIG. **16** and involving a Requestor, a Backend 1 and a Backend 2. The transmissions depicted in FIG. **17** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0021] FIG. **18** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round token translation involving a Requestor, a Backend 1 and a Backend 2. Derivation of the final outputs involves verification, unblinding and hashing on the part of the Requestor, where these outputs comprise a reversible token and a cryptographic integrity token. The processing of FIG. **18** is related to the tokenization depicted in FIG. **6**, where the scope t of FIG. **6** is converted to the scope t_{new} of FIG. **18**. The transmissions depicted in FIG. **18** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0022] FIG. **19** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates parallelizable two-round token translation involving a Requestor, a Backend 1 and a Backend 2. Derivation of a reversible token as a final output involves verification and unblinding on the part of the Requestor that follows unblinding on the part of Backend 1 and Backend 2. The processing of FIG. **19** is related to the tokenization depicted in FIG. **12**, where the scope t of FIG. **12** is converted to the scope t_{new} of FIG. **19**. The transmissions depicted in FIG. **19** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0023] FIG. **20** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates third-party setup of Backend 1 and Backend 2 and resetting and storage of tokenization processor secrets. The processing of FIG. **20** is compatible with the tokenization and detokenization of FIG. **2** and FIG. **3**, respectively, as well as compatible with the tokenization and detokenization of FIG. **4** and FIG. **5**, respectively. The transmissions depicted in FIG. **20** may include an overlay such as authenticated or non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0024] FIG. **21** comprises a flow chart with a signal flow diagram as configured in accordance with various embodiments of these teachings and that illustrates third-party setup of Backend 1 and Backend 2 and resetting and storage of tokenization processor secrets. The processing of FIG. **21** is compatible with the tokenization and detokenization of FIG. **14** and FIG. **15**, respectively. The transmissions depicted in FIG. **21** may include an overlay such as authenticated or

non-authenticated encryption that is subsequently decrypted, that is not explicitly shown;

[0025] FIG. **22** comprises a flow chart configured in accordance with various embodiments of these teachings and that illustrates generating a reversible elliptic curve point representation of Data that incorporates an optional integrity check.

[0026] FIG. **23** comprises a flow chart configured in accordance with various embodiments of these teachings and that illustrates, as an alternative flow to that depicted in FIG. **22**, generating a reversible elliptic curve point representation of Data that incorporates an optional integrity check.

[0027] FIG. **24** comprises a flow chart configured in accordance with various embodiments of these teachings and that illustrates generating a non-reversible elliptic curve point representation of Data for use in generating a token and key token.

DETAILED DESCRIPTION

[0028] Role-Based Access Control (RBAC) herein is actuated using scope that designates one or more attributes purportedly associated with a Requestor as submitted as part of a tokenization request and/or a detokenization request and/or a token translation request. Scope is used as a qualifying or disqualifying feature in responding to such requests. It is known to supplement Data to be tokenized with metadata that designates purported permissions or attributes of a tokenization Requestor, but that alone is insufficient to achieve the desired properties. A goal of the current invention is to embed scope-specific indicia (aka labels) as parameters into a TOKEN if the Requestor possesses permission to tokenize the source Data under the requested scope, and preferably to do so without need to observe the source Data. A further goal of the current invention is to take advantage of the scope-specific indicium that has been embedded into a TOKEN to render the underlying Data inaccessible without proving possession of that scope by the Requestor, and to preferably do so without need to observe the TOKEN. As a yet further goal, TOKENs should be endowed with a non-malleability property in that operating over morphed versions of TOKENs during tokenization and/or detokenization does not offer practically exploitable adversarial advantage. More specifically, attempts to tokenize a TOKEN or one or more morphed versions of such TOKEN and/or to detokenize a TOKEN or one or more morphed versions of such TOKEN by a Requestor or group of Requestors, where none of such Requestors individually possesses authorization to detokenize the original TOKEN, should render the responsive results as unsuitable to substantively recover the Data. A further property to be attained by the invention is that tokenization and detokenization operations are compatible with multiparty computation such that compromise of all but one of the Tokenization Processors that respond to a request for tokenization or detokenization or token translation is insufficient to substantively access the underlying Data. A yet further property is that the multiparty computation outputs remain invariant under resplitting of the collective secrets that are used for tokenization and/or detokenization and/or token translation computations, where such secrets are available compositely to the Tokenization Processors with one or more shares of such secrets held in each Tokenization Processor's associated memory and updated as a result of resplitting. Such resplitting results in a redistribution of tokenization processor secrets as updated tokenization processor secrets. A tokenization processor secret that is held in a specific Tokenization Processor's associated memory is said to be a tokenization processor secret of that Tokenization Processor. A yet further property is that given knowledge of $Data_A$ and a $TOKEN_A$ that is generated over $Data_A$ using known scope t_A, a $TOKEN_B$ that is generated over $Data_B$ using known scope t_B should be cryptographically indistinguishable [https://en.wikipedia.org/wiki/Ciphertext_indistinguishability] from a $TOKEN_C$ that is generated over $Data_A$ using known scope t_B, by any group of adversaries such that none of them possesses tokenization or detokenization permission using scope t_B, where scope $t_A \neq$ scope t_B and $Data_A \neq Data_B$. In addition, the method must retain its effectiveness in situations where the choices of Data that arise in practice are feasible to exhaust over, wherein no generally applicable solution can usefully supplement the Data with padding that is likely to remain inaccessible to adversaries. (If the values of such padding are shared across all entities that might request tokenization derived from the same Data, then the likelihood of these values remaining secret decreases significantly. If, alternatively, each Requestor supplements the Data with individually generated random padding, then TOKENs based on the same value of Data will fail to match or to be otherwise usefully comparable.)

[0029] Each processor is denoted herein as a Backend. The invention is presented primarily as involving two Backends, namely Backend 1 and Backend 2. However, the method is extensible to three or more Backends. The method is operable using only a single Backend, although at the expense of degraded security.

[0030] Role-Based Access Control for non-reversible tokens: This special case can be addressed using an extension of prior-art tokenization techniques that make use of a Translator/Coordinator (such as described in U.S. Pat. No. 11,374,910) in addition to Backends. Suppose there is a final tokenization operation comprised of HMAC using HMAC (Coordinator Key, scope label) as the scope-dependent HMAC key. Then one can use $(b_1+b_2)P$ as the HMAC preimage with the same values of b_1 and b_2 for all scopes without sacrificing scope isolation of the resultant tokens, where b_1 is a secret accessible by Backend 1, b_2 is a secret accessible by Backend 2, and P represents the Data to be tokenized. This is readily extensible to three or more Backends. P can be ephemerally blinded by a Requestor such that Backend 1 and Backend 2 access eP, and e is removed from $(b_1 eP+b_2 eP)$, by either the Requestor or by the Coordinator, using knowledge of the ephemeral value e. Rather than a single Coordinator applying HMAC, a threshold signature scheme can be applied. A threshold signature scheme can preferably invoke proactive redistribution/refresh of shares for increased resilience against compromise (e.g., https://dl.acm.org/doi/10.1145/3579375.3579389).

[0031] One high-level goal achieved by the current invention is to generate a token, via tokenization processing, that is representative of "Data" (which may comprise potentially sensitive information such as personally identifiable information), wherein such token is at least partially reversible, via detokenization processing, to (directly or indirectly) recover Data. Preferably, neither the token nor the tokenization/detokenization processing leaks Data in the absence of collusion between the (preferably two or more) Tokeni-

zation Processors involved in the token generation. The resultant tokens may be "deterministic" in that they are invariant for a given value of Data across participants as Requestors that request tokenization, or may be "non-deterministic" in that the resultant tokens differ across participants. The Data values may be "directly tokenized" in that the token is decrypted to directly recover the Data. Alternatively, Data may be "indirectly tokenized" in that the token is decrypted/inverted to recover a symmetric encryption key that is used, in turn, to decrypt ciphertext, as resulting in plaintext. The decryption of the ciphertext is not necessarily limited to recovery only of Data that was used in generation of the token. The plaintext that is thus recovered may include other information in addition to (or instead of) all or part of Data used to generate the token. The value of Data used to generate the token is not necessarily limited to or inclusive of sensitive data such as personally identifiable information. The recovery process may include potentially optional verification of the integrity of at least part of the recovered Data and/or other information.

[0032] A third-party server (also denoted as a 3^{rd} Party or third party within the sample embodiments) may be used to secure the setup procedure that enables provisioning of the Tokenization Processors, which may also be denoted as Backends. By one approach, such third-party server is implemented as a stand-alone or cloud-hosted enclave such as SGX-based or Amazon Nitro-based, respectively, to imbue trust into the system. Such an enclave may be hosted by a Tokenization Processor or may be hosted independently. Remote attestation (also known as cryptographic attestation) may be utilized to provide evidence of compliant protocol execution on the part of an enclave. Other methods such as witnessed use of a stand-alone device running vetted software wherein the device is locked away or destroyed or otherwise configured to delete memory of critical parameters may be invoked. As an alternative to making use of a third-party server that is considered trusted (to at least some preferably well-defined extent), an untrusted server may be used. More specifically, if the use of a third-party server does not include provision to assure non-availability of unauthorized access to critical parameters associated with its protocol execution, then preferably secure measures may be taken by one or more Tokenization Processors to assure the non-usefulness of such critical parameters relevant to generation of tokens and/or symmetric keys, and/or to recovery processing.

[0033] As previously noted, preferably, composite secrets held collectively across Tokenization Processors, can be resplit to effect updating without adversely affecting the usability of tokens that were generated using previous versions of each Tokenization Processor's individually-held tokenization processor secrets.

[0034] Third-party server operation can be limited to setup, such that no third-party server is necessarily involved in other operations, such as pertaining to tokenization, detokenization/recovery, resplit of composite secrets, or deletions or additions of Tokenization Processors.

[0035] Refresh of tokenization processor secrets, resulting via resplitting of composite secrets, can be accomplished through direct Tokenization Processor-to-Tokenization Processor communications or end-to-end secured via communications with an arbitrary/untrusted service.

[0036] Authentication and/or bidirectional freshness of communications between two parties can be assured via standard means, such as (a) one-time-use nonces incorporated into signed responses, or (b) dependency on ephemeral values such as incorporated into one-pass (static-ephemeral) Diffie-Hellman key establishment or ephemeral-ephemeral Diffie-Hellman key establishment, or (c) a combination of (a) and (b) such as one party signing a Diffie-Hellman ephemeral public key together with a nonce provided by the counterparty and interpreting the response from the counterparty as based on one or more values derived using a secret dependent on the Diffie-Hellman shared secret computed using the ephemeral private key and the counterparty Diffie-Hellman static public key, or each party signing an ephemeral public key for which they possess the corresponding ephemeral private key and basing ensuing communications on the Diffie-Hellman shared secret computed based at least in part on using knowledge of an ephemeral private key and a counterparty ephemeral public key.

[0037] Tokenization Processors can act in parallel relative to one another during tokenization and recovery operations. This aspect can be instantiated as based on U.S. Pat. No. 11,374,910, issued Jun. 28, 2022 and on a continuation thereof as U.S. Pat. No. 11,637,817, issued Apr. 25, 2023. Further, Tokenization Processors/Backends can be partitioned as described therein.

[0038] Both direct Data tokenization (i.e., the directly tokenized Data case) and tokenization of symmetric keys used to encrypt (and optionally authenticate) Data values (i.e., the indirectly tokenized Data case) are supported, where the choice of which to use may potentially be dependent on factors pertaining to characteristics such as bit length of Data values and/or constraints on size of tokens and/or accompanying ciphertext, if any.

[0039] In some embodiments, tokenization processing and detokenization processing are achievable using a single round for tokenization and a single round for detokenization, where detokenization results in direct Data recovery, or symmetric key recovery for indirect Data recovery such as via conversion of a token, say "TOKEN," to another token such as a "KEY_TOKEN."

[0040] Individual Tokenization Processors as well as combinations of Tokenization Processors that do not include all Tokenization Processors involved in the tokenization process are preferably blinded from access to Data even if aware of resultant tokens.

[0041] Both deterministic and non-deterministic tokenization sub-cases of the direct Data tokenization and indirect (symmetric key) tokenization cases are enabled, where deterministic refers to token values that are invariant across participants, also known as Requestors, requesting tokenization while non-deterministic allows for token values to differ from one participant/Requestor to another.

[0042] Non-deterministic tokenization can be implemented to assure uniqueness of token values if a given participant implements in that way, i.e., for a given tokenization Requestor/participant and Data value the resultant token is uniquely-valued. This still allows complete freedom in how random/pseudorandom inputs are selected the first time for each Data value.

[0043] Independently of application and strength of ephemeral blinding factors applied to representations of Data, Data bias within representations of Data is preferably distributed across input bits utilizing Data in the deterministic sub-case or concealed utilizing pseudo-randomness/randomness in the non-deterministic sub-case. The same

seeded deterministic random bit generator, if any, may potentially be used as contributing towards generation of ephemeral blinding factors as well as towards generation of pseudo-randomness used to conceal Data inputs (potentially together with an additional entropy source). Although the ephemeral blinding factor is removed prior to finalization of the token to enable reversibility without retention/transference of such ephemeral blinding factor (as well as to ensure independence of tokens from ephemeral blinding factors to enable the deterministic sub-case), the effect of flattening/concealment of the Data persists within the finalized token.

[0044] Access to ciphertext, and authentication tag (if any), is insufficient to enable feasible recovery of plaintext via exhaustive search of plaintext space, because the invention is implementable for some embodiments via

[0045] a) double-round tokenization and single-round recovery: symmetric key is generated from an intermediate token value (as a "KEY_TOKEN") a function of which intermediate token value is subjected to further tokenization, the result of which (as a "TOKEN") is reversible to enable the Tokenization Processors to provide for recovery of the symmetric key, or

[0046] b) single-round tokenization and single-round recovery: symmetric key is generated from an intermediate token value (as a "KEY_TOKEN") that is accompanied by a complementary token value (as a "TOKEN") wherein the complementary token value can be used to enable the Tokenization Processors to provide for recovery of the symmetric key.

[0047] Note that the remarks above regarding bias apply to both "TOKEN" and "KEY_TOKEN" values.

[0048] In the deterministic sub-case of Data-based tokenization of a symmetric key, the Data value(s) utilized in formulation of the symmetric key need not be identical to Data value(s) that are encrypted (and optionally authenticated) utilizing the resultant symmetric key.

[0049] Detokenization for Data recovery can be requested by authorized parties that may be independent of participants that requested tokenization.

[0050] Preferably, requests to Tokenization Processors are verifiable as originating with authorized Requestors, where Requestors of tokenization may be distinguishable from Requestors of detokenization.

[0051] The method is extensible to a plurality of Tokenization Processors greater than two, where additional Tokenization Processors may optionally be added after initial setup and deployment. Communication between Tokenization Processors can be secured using such techniques as key agreement utilizing standard pairwise Diffie-Hellman/elliptic curve Diffie-Hellman, or groupwise/group Diffie-Hellman.

[0052] Values that are agreed upon by Tokenization Processors can, for example, be based on individual contributed values and/or can be derived (e.g., via key derivation) based on Diffie-Hellman shared secrets.

[0053] Preferably, each Backend is programmed to delete values that are only needed transiently, such as additive resplitting factors and/or multiplicative blinding factors such as those applied following communication with a non-fully-trusted **3***r* d Party. Any ephemeral private keys, such as elliptic curve Diffie-Hellman keys, applied during key agreement operations, such as to generate shared secrets, should be deleted as well.

[0054] Preferably, each Backend is equipped with a non-replicable entropy source, rather than just relying on a purely deterministic random number generator.

[0055] These and other benefits may become clearer upon making a thorough review and study of the following detailed description. Referring now to the drawings, and in particular to FIG. **1**, an illustrative apparatus **100** that is compatible with many of these teachings will now be presented.

[0056] In this particular example, the enabling apparatus **100** includes one or more Tokenization Processors **101**. Such Tokenization Processors are configured to effect tokenization via one or more corresponding networks **105**. As will be described in more detail herein, such Tokenization Processors may operate on source data inputs that are ephemerally blinded.

[0057] In this illustrative example each of the Tokenization Processors **101** include a control circuit **102**. Being a "circuit," the control circuit **102** therefore comprises structure that includes at least one (and typically many) electrically-conductive paths (such as paths comprised of a conductive metal such as copper or silver) that convey electricity in an ordered manner, which path(s) will also typically include corresponding electrical components (both passive (such as resistors and capacitors) and active (such as any of a variety of semiconductor-based devices) as appropriate) to permit the circuit to effect the control aspect of these teachings.

[0058] Such a control circuit **102** can comprise a fixed-purpose hard-wired hardware platform (including but not limited to an application-specific integrated circuit (ASIC) (which is an integrated circuit that is customized by design for a particular use, rather than intended for general-purpose use), a field-programmable gate array (FPGA), and the like) or can comprise a partially or wholly-programmable hardware platform (including but not limited to microcontrollers, microprocessors, and the like). These architectural options for such structures are well known and understood in the art and require no further description here. This control circuit **102** is configured (for example, by using corresponding programming as will be well understood by those skilled in the art) to carry out one or more of the steps, actions, and/or functions described herein.

[0059] By one optional approach the control circuit **102** operably couples to a memory **103**. This memory **103** may be integral to the control circuit **102** or can be physically discrete (in whole or in part) from the control circuit **102** as desired. This memory **103** can also be local with respect to the control circuit **102** (where, for example, both share a common circuit board, chassis, power supply, and/or housing) or can be partially or wholly remote with respect to the control circuit **102** (where, for example, the memory **103** is physically located in another facility, metropolitan area, or even country as compared to the control circuit **102**).

[0060] In addition to storing other information as described herein, this memory **103** can serve, for example, to non-transitorily store the computer instructions that, when executed by the control circuit **102**, cause the control circuit **102** to behave as described herein. (As used herein, this reference to "non-transitorily" will be understood to refer to a non-ephemeral state for the stored contents (and hence excludes when the stored contents merely constitute signals or waves) rather than volatility of the storage media itself and hence includes both non-volatile memory (such as

read-only memory (ROM) as well as volatile memory (such as a dynamic random access memory (DRAM).)

[0061] In this example the control circuit **102** also operably couples to a network interface **104**. So configured the control circuit **102** can communicate with other elements (both within the apparatus and external thereto) via the network interface **104**. More particularly, the network interface **104** facilitates compatible communications via one or more networks **105**. Numerous examples are known in the art. A non-exhaustive listing would include Universal Serial 55 Bus (USB)-based interfaces, RS232-based interfaces, I.E.E.E. 1394 (aka Firewire)-based interfaces, Ethernet-based interfaces, any of a variety of so-called Wi-Fi™-based wireless interfaces, Bluetooth™-based wireless interfaces, cellular telephony-based wireless interfaces, Near Field Communications (NFC)-based wireless interfaces, standard telephone landline-based interfaces, cable modem-based interfaces, and digital subscriber line (DSL)-based interfaces. Such interfaces can be selectively employed to communicatively couple the control circuit **102** to another network element, to a local area network, or to any of a variety of wide area networks or extranets (such as, but not limited to, the Internet).

[0062] Relevant to the following description, so configured, each of the Tokenization Processors can compatibly communicate via the aforementioned protocol with any of a plurality of requesting network elements **106** (illustrated in FIG. **1** as a first network element through an Nth network element). As will be described in more detail below, such requesting network elements **106** act as Requestors.

[0063] Other apparatuses that may play a part in effecting the data-based activity in a given application setting include such elements as an initial data source **107** that does not act as a Requestor and/or a third party **108** that is involved in setup of one or more of the Tokenization Processors **101**.

[0064] Generalized Formulation (entailing 1 or 2 or 3 or more rounds of communication between Requestor and Backends to effect tokenization, and/or detokenization for recovery, and/or token translation): Note that differently identified parameters are not necessarily distinct from one another. Unless otherwise specifically noted, certain parameters may take on constant values across resplit intervals, although doing so may adversely affect security. Unless otherwise specifically noted, certain functions may take on constant values. Certain embodiments may incorporate additional functions and/or parameters not specifically depicted.

[0065] P represents the Data to be tokenized, and TOKEN represents the result of a successful tokenization request. t represents a scope (also known as a context) as a label that is associated with the request for tokenization or detokenization. Standard means, such as SAML assertions, can be used by each Backend to determine the validity of the Requestor's submitted scope.

[0066] In the specific embodiments presented, the operation between adjacent terms $f_i(\ )$ and $f_j(\ )$ is multiplication unless otherwise noted. If implemented using an elliptic curve, then P, G_1 and G_2 represent elliptic curve points and, unless otherwise noted, arithmetic (e.g., addition and/or multiplication and/or inversion of scalars) may be considered modulo n, the order of the elliptic curve point.

[0067] TOKEN=$f_3(\beta_{1,3}(t)\ \beta_{2,3}(t)\ \beta_{1,4}\ \beta_{2,4}\ G_1)\ f_4(\beta_{1,5}(t)\ \beta_{2,5}(t)\ \beta_{1,6}\ \beta_{2,6}\ G_2)\ f_1(\beta_{1,1}(t),\ \beta_{2,1}(t))\ f_2(\beta_{1,2},\ \beta_{2,2})$ P.

[0068] AUX TOKEN=$h(g_3(\delta_{1,3}(t)\ \delta_{2,3}(t)\ \delta_{1,4}\ \delta_{2,4}\ G_1)\ g_4(\delta_{1,5}(t)\ \delta_{2,5}(t)\ \delta_{1,6}\ \delta_{2,6}\ G_2),\ g_1(\delta_{1,1}(t),\ \delta_{2,1}(t))\ g_2(\delta_{1,2},\ \delta_{2,2})$ TOKEN).

[0069] G_1 and/or G_2, if any, can be fixed, or may be dependent on an AUX TOKEN if any is made available to Backends during detokenization (at the expense of 3 or more rounds during tokenization processing).

[0070] AUX_TOKEN may, e.g., comprise a cryptographic integrity token, denoted as checkBits, that is used as a condition of information release by Backends during detokenization, or may comprise a key token, denoted as KEY_TOKEN, that is used to derive keying material intended to encrypt and/or recover Data. In the latter case, such keying material may additionally or alternatively enable authentication of encrypted data and/or of additional data that is not encrypted. If there is no dependency on an AUX_TOKEN to enable derivation of keying material, then P is reversible to recover Data.

[0071] During tokenization, a Requestor may be supplied with both a TOKEN and KEY_TOKEN. In that case, the TOKEN may be retrieved from storage and submitted (in preferably blinded form) for detokenization that results in recovery of the corresponding KEY_TOKEN. Example embodiments of such TOKEN-KEY_TOKEN pairings are presented later within this specification.

[0072] There are at least three reasons to use KEY TOKENs, namely: (a) accommodate Data of length larger than that which fits within the bounds of standard elliptic curve points; (b) restrict the use of tokenization to keying material generation and recovery for compatibility with standard data encryption schemes, e.g., NIST format-preserving encryption, wherein ciphertext format that is consistent with plaintext format is said to be format-preserving [https://nvlpubs.nist.govinistpubs/SpecialPublications/NIST.SP.800-38Grl-draft.pdf]; and (c) hide release of information during detokenization from potential adversarial exploitation, wherein such information would otherwise be available to the Requestor if detokenization intended to recover P from TOKEN or blinded TOKEN were used instead. As an alternative to separating a tokenization-based key management scheme from standardized encryption of Data using one or more keys derivable via such key management scheme, the tokenization that is implementable from the current invention can be used directly to encrypt Data so as to meet certain format-preserving encryption requirements of the resultant ciphertext.

[0073] Example procedures to generate P from Data are presented later within this specification. There are two classes of such procedures, namely, designed to either: generate P from Data such that Data is recoverable via detokenization; or generate P from Data such that the corresponding TOKEN is usable during detokenization to recover KEY_TOKEN. As an example of the former that also meets certain format-preserving encryption requirements, consider tokenization of an elliptic curve point P that results in a TOKEN as an elliptic curve point with x-coordinate denoted as x_P. Suppose that the Data underlying P is chosen, for example, as representable as a 16-digit integer. Then write x_P as $x_P \bmod 10^{16}+k\ 10^{16}$, where k is a uniquely determined nonnegative integer. Then $x_P \bmod 10^{16}$, as extracted from x_P, can be considered as ciphertext that satisfies the format-preserving encryption requirement of mapping a 16-digit integer comprising Data as plaintext to a 16-digit integer as ciphertext, where Data is recoverable

via authorized detokenization from knowledge of the ciphertext and k. Suppose that an intermediary stores an encryption of the ciphertext under a key, KK, where the resultant encryption value is paired in storage with the corresponding value of k. Then a Requestor, armed with knowledge of KK, can supply the intermediary with the pair [EncryptKK (ciphertext), k] that corresponds to the TOKEN that resulted from tokenization of P as derived from Data. If there is a collision of the value of EncryptKK(ciphertext) against a previously stored pair [EncryptKK(ciphertext), k] with a different value of k, then the Pad—that along with Data comprises at least part of the value of P that is tokenized—is deterministically incremented and the resultant new value of P is submitted for tokenization. Under such deterministically incremented Pad procedure, the space of EncryptKK(ciphertext) will not be prematurely exhausted so as to cause failure to process retries.

[0074] There are three different components of Requestor processing of Backend outputs, dependent on specifics of TOKEN formulation (possibly in combination):

[0075] (1) Sum operation by Requestor of distinct second-round Backend outputs—Embodiments 1 and 2

[0076] (2) Checking for equality of second-round Backend outputs (where equality holds if both Backends act conformantly)—Embodiments 3 and 4

[0077] (3) Multiply operation by Requestor of distinct second-round Backend outputs—Embodiments 5 and 6

[0078] Embodiment 1: f_1=addition modulo n; f_2, f_3 and f_4 always return 1; $\beta_{1,1}(t)$ is a distinct value of Pi for each value of t, and $\beta_{2,1}(t)$ is a distinct value of b_2 for each value of t. The use of addition rather than multiplication for f_1 enables single-round tokenization and single-round detokenization for recovery. Embodiment 1 is particularly practical in the case of relatively few distinct scopes.

[0079] Embodiment 1 TOKEN: TOKEN=(b_1+b_2) P.

[0080] Brackets (as [ ]) below indicate inputs being acted upon. Note that such inputs are presented as their intended expressions, although these may differ under a cheating scenario. e indicates an ephemeral value that is generated by the Requestor and preferably withheld from both Backends.

[0081] Relevant to FIG. **2**, role-based access control can be enabled via cryptographic isolation of scopes from one another as based on assignment of distinct scope-specific tokenization processor secrets used for generation of reversible tokens, wherein each such scope-specific tokenization processor secret is updateable without affecting values of the reversible tokens that are generated jointly by at least two distinct tokenization processors. Specifically, in FIGS. **2**, b_1 and b_2, as used for tokenization by Backend 1 and Backend 2, respectively, can be distinct for each scope. Moreover, a Backend 1 and Backend 2 that possess values of b_1 and b_2, respectively, that correspond to certain scopes may be distinct from a Backend 1 and a Backend 2 that possess values of b_1 and b_2, respectively, that correspond to certain other scopes.

[0082] Referring now to FIG. **2**, stepping through tokenization processing, first the Requestor **210** transmits an ephemerally blinded representation of Data, i.e., eP, to Backend 1 **215** at **225** and transmits eP to Backend 2 **220** at **230**. Backend 1 **215** responds at **235** with b_1 [eP], and Backend 2 **220** responds at **240** with b_2 [eP]. At **245**, the Requestor **210** performs an addition operation and an unblinding operation to derive TOKEN=e^{-1}([b_1 eP]+[b_2 eP]).

[0083] Relevant to FIG. **3**, b'_1 and b'_2, as used for detokenization by Backend 1 and Backend 2, respectively, can be distinct for each scope. Scope-specific b'_1 and b'_2 can be updated without adversely affecting the capability for detokenization of tokens that were generated using previous versions of b_1 and b_2 that correspond to the same scope as do b'_1 and b'_2. Moreover, a Backend 1 and Backend 2 that possess values of b'_1 and b'_2, respectively, that correspond to certain scopes may be distinct from a Backend 1 and a Backend 2 that possess values of b'_1 and b'_2, respectively, that correspond to certain other scopes.

[0084] Referring now to FIG. **3**, stepping through detokenization processing, first the Requestor **310** transmits an ephemerally blinded representation of a token, i.e., e'TOKEN, to Backend 1 **315** at **325** and transmits e'TOKEN to Backend 2 **320** at **330**. Backend 1 **315** responds at **335** with b'_1 [e'TOKEN], and Backend 2 **320** responds at **340** with b'_2 [e'TOKEN], where $(b'_1+b'_2)$ (b_1+b_2)=1 mod n. At **345**, the Requestor **210** performs an addition operation and an unblinding operation to recover P=e'^{-1} ([b'_1 e'TOKEN]+[b'_2 e'TOKEN]).

[0085] The use of a third party to enable setup of parameters such as b'_1 and b'_2 is described subsequently within this specification. Such third party can be blinded from accessing useful information about the resultant parameter values. A similar setup procedure enables derivation of parameters the use of which enables re-derivation of KEY_TOKEN from TOKEN or blinded TOKEN where TOKEN incorporates an additive component such as (b_1+b_2) as a scalar multiple of P. In that case, b'_1 and b'_2 can be defined as satisfying: $(b'_1+b'_2)$ (b_1+b_2)=(d_1+d_2) mod n.

[0086] Embodiments 2-6 require a minimum of two-round tokenization and a minimum of two-round recovery, and are suitable for arbitrarily many scopes in that Backend-retained and -managed parameters are not scope-specific.

[0087] Embodiment 2: f_1=multiplication modulo n; f_2=addition modulo n; constant functions f_3 and f_4 always return 1; $\beta_{1,1}(t)=b_{1,1}^{\ t}$ and $\beta_{2,1}(t)=b_{2,1}^{\ t}$; $\beta_{1,2}=b_{1,2}$ and $\beta_{2,2}=b_{2,2}$.

[0088] h=truncated hash; g_1=multiplication modulo n; g_2=addition modulo n; constant functions g_3 and g_4 always return 1; $\delta_{1,1}(t)=d_{1,1}^{\ t}$ and $\delta_{2,1}(t)=d_{2,1}^{\ t}$; $\delta_{1,2}=d_{1,2}$ and $\delta_{2,2}=d_{2,2}$. AUX-TOKEN here is used as checkBits. Consider the case that $d_{1,2}=c\ b_{1,2}$ mod n and $d_{2,2}=c\ b_{2,2}$ mod n for a value of c available to both Backend 1 and Backend 2. truncHash denotes a truncated hash function, where length of truncated outputs may be set, for example, as uniform or as scope-specific.

[0089] Embodiment 2 TOKEN and checkBits: TOKEN=$(b_{1,1}\ b_{2,1})^r(b_{1,2}+b_{2,2})$P; checkBits=AUX_TOKEN=truncHashq($(d_{1,1}\ d_{2,1})^r c(b_{1,2}+b_{2,2})$P).

[0090] FIGS. **4-13** make use of subscripted "output" notation instead of the bracket ([ ]) notation used in their corresponding detailed description text. FIGS. **16-19** also make use of such "output" notation.

[0091] Relevant to FIG. **4**, FIG. **6**, FIG. **8**, FIG. **10**, FIG. **18**, and FIG. **19**, by one approach, one or more tokenization processors embed role-based access control scope parameters, for example denoted herein as t or t_{new}, into reversible tokens that are generated during tokenization or token translation. Further, the values of the thereby generated reversible tokens are not affected by changes in the tokenization processor secrets held individually by tokenization

processors wherein the changes are effected by resplitting of collectively held tokenization processor secrets.

[0092] Relevant to FIG. **4** and FIG. **6**, by one approach, at least a first tokenization processor generates a reversible token, denoted herein as TOKEN, and a cryptographic integrity token, denoted herein as checkBits. Moreover, relevant to FIG. **5** and FIG. **6**, during detokenization based, at least in part, on a purported blinded or unblinded TOKEN received from a requestor, at least a second tokenization processor attempts to match a purported checkBits value received from the requestor against a value that is recomputed by a third tokenization processor from the purported blinded or unblinded TOKEN, wherein there may be overlaps among the tokenization processors comprised by the at least a first tokenization processor, the at least a second tokenization processor and the at least a third tokenization processor.

[0093] Referring now to FIG. **4**, stepping through tokenization processing, first the Requestor **410** transmits eP to Backend 1 **415** at **425**, and transmits eP to Backend 2 **420** at **430**. Backend 1 **415** responds at **435** with $b_{1,1}{}^{t}\,b_{1,2}$ [eP] and $c\,d_{1,1}{}^{t}\,b_{1,2}$ [eP], and Backend 2 **420** responds with $b_{2,1}{}^{t}\,b_{2,2}$ [eP] and $c\,d_{2,1}{}^{t}\,b_{2,2}$ [eP] at **440**, thus completing round-one processing. Using $b_{2,1}{}^{t}\,b_{2,2}$ eP and $c\,d_{2,1}{}^{t}\,b_{2,2}$ eP received via **445**, Backend 1 **415** transmits $b_{1,1}{}^{t}\,[b_{2,1}{}^{t}\,b_{2,2}$ eP] and $d_{1,1}{}^{t}\,[c\,d_{2,1}{}^{t}\,b_{2,2}$ eP] to the Requestor **410** at **455**, thus completing its role in round-two processing. Similarly, using $b_{1,1}{}^{t}\,b_{1,2}$ eP and $c\,d_{1,1}{}^{t}\,b_{1,2}$ eP received via **450**, Backend 2 **420** transmits $b_{2,1}{}^{t}\,[b_{1,1}{}^{t}\,b_{1,2}$ eP] and $d_{2,1}{}^{t}\,[c\,d_{1,1}{}^{t}\,b_{1,2}$ eP] to the Requestor **410** at **460**, thus completing its role in round-two processing. At **465**, the Requestor **410** sums and unblinds the first output of **455** and the first output of **460** to derive $\text{TOKEN}=e^{-1}$ $([b_{1,1}{}^{t}\,b_{2,1}{}^{t}\,b_{2,2}$ eP]+$[b_{2,1}{}^{t}\,b_{1,1}{}^{t}\,b_{1,2}$ eP]). Also at **465**, the Requestor **410** sums and unblinds the second output of **455** and the second output of **460** followed by truncated hashing to form the AUX_TOKEN usable as a cryptographic integrity token by Backend 1 and Backend 2 in the processing of FIG. **5**, namely, $\text{checkBits}=\text{truncHash}(e^{-1}$ $([c\,d_{1,1}{}^{t}\,d_{2,1}{}^{t}\,b_{2,2}$ eP]+$[c\,d_{2,1}{}^{t}\,d_{1,1}{}^{t}\,b_{1,2}$ eP]).

[0094] Referring now to FIG. **5**, stepping through detokenization processing, first the Requestor **510** transmits e'TOKEN to Backend 1 **515** at **525**, and transmits e'TOKEN to Backend 2 **520** at **530**. Taking advantage of this relationship between tokenization processor secrets: $(b'_{1,2}+b'_{2,2})$ $(b_{1,2}+b_{2,2})=1 \bmod n$, Backend 1 **515** responds at **535** with $b_{1,1}{}^{-t}\,b'_{1,2}$ [e'TOKEN] and $c\,(b_{1,1}{}^{-1}\,d_{1,1})^{t}$ [e'TOKEN], and Backend 2 **520** responds at **540** with $b_{2,1}{}^{-t}\,b'_{2,2}$ [e'TOKEN] and $c\,(b_{2,1}{}^{-1}\,d_{2,1})^{t}$ [e'TOKEN], thus completing their role in round-one processing. $c\,(b_{1,1}{}^{-1}\,d_{1,1})^{t}$ e'TOKEN is exposed to the Requestor **510** so that it can unblind this value at **542** in order to be able to provide the result to Backend 2 **520** at **550**. Similarly, $c\,(b_{2,1}{}^{-1}\,d_{2,1})^{t}$ e'TOKEN is exposed to the Requestor **510** so that it can unblind this value at **542** in order to be able to provide the result to Backend 1 **515** at **545**. Also at **545**, the Requestor **510** provides Backend 1 **515** with checkBits, as was computed via the processing of FIG. **4**, and $b_{2,1}{}^{-t}\,b'_{2,2}$ e'TOKEN as was received from Backend 2 **520** at **540**. Similarly, also at **550**, the Requestor **510** provides Backend 2 **520** with checkBits, and $b_{1,1}{}^{-t}\,b'_{1,2}$ e'TOKEN as was received from Backend 1 **515** at **535**. At **555**, Backend 1 **515** computes $\text{truncHash}((b_{1,1}{}^{-1}\,d_{1,1})^{t}\,[c(b_{2,1}{}^{-1}\,d_{2,1})^{t}\,\text{TOKEN}])$, and verifies whether or not that value is equal to checkBits as received at **545**. If yes, then Backend 1 **515** transmits $b_{1,1}{}^{-t}\,[b_{2,1}{}^{-t}\,b'_{2,2}$ e'TOKEN] to the Requestor **510** at **565**. If no, then Backend 1 **515** aborts the response or sends an error message. Similarly, at **560**, Backend 2 **520** computes $\text{truncHash}((b_{2,1}{}^{-1}\,d_{2,1})^{t}\,[c(b_{1,1}{}^{-1}\,d_{1,1})^{t}\,\text{TOKEN}])$, and verifies whether that value is equal to checkBits as received at **550**. If yes, then Backend 2 **520** transmits $b_{2,1}{}^{-t}[b_{1,1}{}^{-t}\,b'_{1,2}$ e'TOKEN] to the Requestor **510** at **570**. If no, then Backend 2 **520** aborts the response or sends an error message. This completes the role of Backend 1 **515** and Backend 2 **520** in round-two processing. At **572**, the Requestor **510** adds the outputs if provided by Backend 1 **515** at **565** and by Backend 2 **520** at **570**, respectively, followed by unblinding to recover P as the representation of Data. That is, $P=e'-1$ $([b_{1,1}{}^{-t}\,b_{2,1}{}^{-t}\,b'_{2,2}$ e'TOKEN]+$[b_{2,1}{}^{-t}\,b_{1,1}{}^{-t}\,b'_{1,2}$ e'TOKEN]).

[0095] A goal of the use of addition rather than multiplication for f_2 is to cause bad Requestor inputs that fail checkBits integrity verification during detokenization to be rejected by conformant Backend(s), thus preventing effective recovery via summing if at least one Backend is conformant (where recovery here does not necessarily imply recovery of P if a Requestor is acting illegitimately). However, if ephemerally blinded TOKENs are expected to be provided to Backends during detokenization (as depicted above for Embodiment 2), then a Requestor acting illegitimately can ignore first-round blinded Backend outputs that are intended for use in reformulating checkBits and instead provide unblinded inputs for second-round Backend processing that correspond to a previous legitimate checkBits calculation for an unrelated TOKEN. This subterfuge forces the checkBits integrity verification to pass during second-round processing even though such inputs are unrelated to the TOKEN currently being detokenized. If both Backends are currently operating conformantly, then such attack can be thwarted via the use of end-to-end authenticated encryption combined with fresh randomization of the first-round blinded Backend outputs that are intended for use in reformulating checkBits. To effect a binding process, the authenticated encryption is preferably applied to the randomizing factors needed to remove the effect of the randomization as well as to the first-round Backend-generated values used by the opposite Backends during the second round of detokenization to generate the values to be released if checkBits verification passes. A simplified embodiment that is purely multiplicative, thus lending itself to checking for equality of second-round Backend outputs by a Requestor that is acting legitimately, is presented as Embodiment 3. This is followed by Embodiment 3 detokenization augmented with the introduction of the above-mentioned randomizing factors.

[0096] In both Embodiment 2 and Embodiment 3, alternatively to having the Requestor unblind first-round blinded Backend outputs during detokenization to enable verification of checkBits, detokenization can be performed over TOKENs that are not ephemerally blinded by the Requestor. In that case, end-to-end authentication (with or without encryption) can be used to prevent the specific attack of effective undetectable substitution of the parts of first-round Backend outputs by a Requestor that are used for checkBits reformulation by the Backends during second-round processing. In Embodiment 3 under submission by the Requestor of TOKENs that are not ephemerally blinded, to prevent either Backend from unilaterally recovering P from such TOKEN during detokenization, each Backend can ephemerally blind the part of its first-round output that is used by the opposite Backend during second-round process-

ing to enable recovered P to be provided to a Requestor that acts legitimately. Each Backend can provide their ephemeral blinding factor (or its inverse) to the Requestor privately as part of its second-round Backend output, so that this ephemeral blinding factor can be inverted out by the Requestor towards recovery of P (where the Requestor applies the inverse ephemeral blinding factor associated with a Backend to a part of the opposite Backend's second-round output).

[0097] To thwart successful "mirroring," the authenticated encryption (or authentication-only, e.g., HMAC) keys derived by each Backend (e.g., from hash(previous resplit parameter(s))) should preferably also be a function of Backend identity, so that the key used for encryption by Backend 1 and for decryption by Backend 2 differs from that used for encryption by Backend 2 and for decryption by Backend 1 (although both Backend 1 and Backend 2 can derive both keys).

[0098] Embodiment 3: f_1=multiplication modulo n; f_2=multiplication modulo n; constant functions f_3 and f_4 always return 1; $\beta_{1,1}(t)=b_{1,1}{}^t$, and $\beta_{2,1}(t)=b_{2,1}{}^t$; $\beta_{1,2}=b_{1,2}$ and $\beta_{2,2}=b_{2,2}$.

[0099] h=truncated hash; g_1=multiplication modulo n; g_2=multiplication modulo n; constant functions g_3 and g_4 always return 1; $\delta_{1,1}(t)=d_{1,1}{}^t$ and $\delta_{2,2}(t)=d_{2,1}{}^t$; $\delta_{1,2}=d_{1,2}$ and $\delta_{2,2}=d_{2,2}$.

[0100] Embodiment 3 TOKEN and checkBits: TOKEN=$(b_{1,1}\ b_{2,1})^t\ b_{1,2}\ b_{2,2}$ P; checkBits=AUX_TOKEN=truncHash $((d_{1,1}\ d_{2,1})^t\ d_{1,2}\ d_{2,2}$ P).

[0101] Referring now to FIG. **6**, stepping through tokenization processing, first the Requestor **610** transmits eP to Backend 1 **615** at **625**, and transmits eP to Backend 2 **620** at **630**. Backend 1 **615** responds at **635** with $b_{1,1}{}^t\ b_{1,2}$ [eP] and $d_{1,1}{}^t\ d_{1,2}$ [eP], and Backend 2 **620** responds with $b_{2,1}{}^t\ b_{2,2}$ [eP] and $d_{2,1}{}^t\ d_{2,2}$ [eP] at **640**, thus completing their round-one processing. Using $b_{2,1}{}^t\ b_{2,2}$ eP and $d_{2,1}{}^t\ d_{2,2}$ eP received via **645**, Backend 1 **615** transmits $b_{1,1}{}^t\ b_{1,2}[b_{2,1}{}^t\ b_{2,2}$ eP] and $d_{1,1}{}^t\ d_{1,2}[d_{2,1}{}^t\ d_{2,2}$ eP] to the Requestor **610** at **655**, thus completing its role in round-two processing. Similarly, using $b_{1,1}{}^t\ b_{1,2}$ eP and $d_{1,1}{}^t\ d_{1,2}$ eP received via **650**, Backend 2 **620** transmits $b_{2,1}{}^t\ b_{2,2}[b_{1,1}{}^t\ b_{1,2}$ eP] and $d_{2,1}{}^t\ d_{2,2}[d_{1,1}{}^t\ d_{1,2}$ eP] to the Requestor **610** at **660**, thus completing its role in round-two processing. At **665**, the Requestor **610** verifies equality of the first output of **655** and the first output of **660**, and the second output of **655** and the second output of **660**, respectively. Also at **665**, the Requestor **610** unblinds the first output of **655** to derive TOKEN=e^{-1} $[b_{1,1}{}^t\ b_{2,1}{}^t\ b_{1,2}\ b_{2,2}$ eP]. The Requestor **610** also unblinds the second output of **655**, followed by truncated hashing to form the AUX_TOKEN usable as a cryptographic integrity token by Backend 1 **715** and Backend 2 **720** in the processing of FIG. **7**, namely, checkBits=truncHash(e^{-1} $[d_{1,1}{}^t\ d_{2,1}{}^t\ d_{1,2}\ d_{2,2}$ eP]).

[0102] Referring now to FIG. **7**, stepping through detokenization processing, first the Requestor **710** transmits e'TOKEN to Backend 1 **715** at **725**, and transmits e'TOKEN to Backend 2 **720** at **730**. Backend 1 **715** responds at **735** with $(b_{1,1}{}^t\ b_{1,2})^{-1}$ [e'TOKEN] and $(b_{1,1}{}^{-1}\ d_{1,1})^t\ b_{1,2}{}^{-1}\ d_{1,2}$ [e'TOKEN], and Backend 2 **720** responds at **740** with $(b_{2,1}{}^t\ b_{2,2})^{-1}$ [e'TOKEN] and $(b_{2,1}{}^{-1}\ d_{2,1})^t\ b_{2,2}{}^{-1}\ d_{2,2}$ [e'TOKEN], thus completing their role in round-one processing. $(b_{1,1}{}^{-1}\ d_{1,1})^t\ b_{1,2}\ d_{1,2}$ e'TOKEN is exposed to the Requestor **710** so that it can unblind this value at **742** in order to be able to provide the result to Backend 2 **720** at **750**. Similarly, $(b_{2,1}{}^{-1}\ d_{2,1})^t\ b_{2,2}{}^{-1}\ d_{2,2}$ e'TOKEN is exposed to the Requestor **710** so that it can unblind this value at **742** in order to be able to provide the result to Backend 1 **715** at **745**. Also at **745**, the Requestor **710** provides Backend 1 **715** with checkBits, as was computed via the processing of FIGS. **6**, and $(b_{2,1}{}^t\ b_{2,2})^{-1}$ e'TOKEN as was received from Backend 2 **720** at **740**. Similarly, also at **750**, the Requestor **710** provides Backend 2 **720** with checkBits, and $(b_{1,1}{}^t\ b_{1,2})^{-1}$ e'TOKEN as was received from Backend 1 **715** at **735**. At **755**, Backend 1 **715** computes truncHash($(b_{1,1}{}^{-1}\ b_{1,1})^t\ b_{1,2}{}^{-1}\ d_{1,2}$ $[(b_{2,1}{}^{-1}\ d_{2,1})^t\ b_{2,2}{}^{-1}\ d_{2,2}$ TOKEN]), and verifies whether or not that value is equal to checkBits as received at **745**. If yes, then Backend 1 **715** transmits $(b_{1,1}{}^t\ b_{1,2})^{-1}$ $[(b_{2,1}{}^t\ b_{2,2})^{-1}$ e'TOKEN] to the Requestor at **765**. If no, then Backend 1 **715** aborts the response or sends an error message. Similarly, at **760**, Backend 2 **720** computes truncHash($(b_{2,1}{}^{-1}\ d_{2,1})^t$ $b_{2,2}{}^{-1}\ d_{2,2}$ $[(b_{1,1}{}^{-1}\ d_{1,1})^t\ b_{1,2}{}^{-1}\ d_{1,2}$ TOKEN]), and verifies whether that value is equal to checkBits as received at **750**. If yes, then Backend 2 **720** transmits $(b_{2,1}{}^t\ b_{2,2})^{-1}$ $[(b_{1,1}{}^t$ $b_{1,2})^{-1}$ e'TOKEN] to the Requestor at **770**. If no, then Backend 2 **720** aborts the response or sends an error message. This completes the role of Backend 1 **715** and Backend 2 **720** in round-two processing. At **772**, the Requestor **710** verifies equality of the output of **765** and the output of **770**, followed by unblinding of the output of **765** to recover P as the representation of Data. That is, P=e'^{-1} $[(b_{1,1}{}^t\ b_{1,2})^{-1}$ $(b_{2,1}{}^t$ $b_{2,2})^{-1}$ e'TOKEN].

[0103] Augmenting detokenization with $rand_1$ generated by Backend 1 and $rand_2$ generated by Backend 2:

[0104] Detokenization round-one Backend processing:

[0105] Backend 1: $(b_{1,1}{}^t\ b_{1,2})^{-1}$ [e'TOKEN] and $rand_1$—provided privately via end-to-end authenticated encryption to Backend 2 (although passing opaquely through Requestor); $rand_1\ b_{1,1}{}^{-1}\ d_{1,1})^t\ b_{1,2}{}^{-1}\ d_{1,2}$ [e'TOKEN]

[0106] Backend 2: $(b_{2,1}{}^t\ b_{2,2})^{-1}$ [e'TOKEN] and $rand_2$—provided privately via end-to-end authenticated encryption to Backend 1 (although passing opaquely through Requestor); $rand_2\ (b_{2,1}{}^{-1}\ d_{2,1})^t\ b_{2,2}{}^{-1}\ d_{2,2}$ [e'TOKEN]

[0107] Detokenization round-two Backend processing:

[0108] Backend 1: $(b_{1,1}{}^t\ b_{1,2})^{-1}$ $[(b_{2,1}{}^t\ b_{2,2})^{-1}$ e'TOKEN]; $(rand_2{}^{-1}\ (b_{1,1}{}^{-1}\ d_{1,1})^t\ b_{1,2}{}^{-1}\ d_{1,2})$ mod n $[(b_{2,1}{}^{-1}$ $d_{2,1})^t\ b_{2,2}{}^{-1}\ d_{2,2}$ TOKEN] (using $[e'^{-1}(rand_2\ (b_{2,1}{}^{-1}$ $d_{2,1})^t\ b_{2,2}{}^{-1}\ d_{2,2}$ e'TOKEN)] and end-to-end encrypted $rand_2$ (or $rand_2{}^{-1}$ mod n) provided by Requestor); Verify that truncHash($(b_{1,1}{}^{-1}\ d_{1,1})^t\ b_{1,2}{}^{-1}\ d_{1,2}$ $[(b_{2,1}{}^{-1}$ $d_{2,1})^t\ b_{2,2}{}^{-1}\ d_{2,2}$ TOKEN])=checkBits as condition of releasing $(b_{1,1}{}^t\ [(b_{2,1}{}^t\ b_{2,2})^{-1}$ e'TOKEN] to Requestor

[0109] Backend 2: $(b_{2,1}{}^t\ b_{2,2})^{-1}$ $[(b_{1,1}{}^t\ b_{1,2})^{-1}$ e'TOKEN]; $(rand_1{}^{-1}\ (b_{2,1}{}^{-1}\ b_{2,2}{}^{-1}\ d_{2,2})$ mod n $[(b_{1,1}{}^{-1}\ d_{1,1})^t$ $b_{1,2}{}^{-1}\ d_{1,2}$ TOKEN] (using $[e'^{-1}(rand_1\ (b_{1,1}{}^{-1}\ d_{1,1})^t$ $b_{1,2}{}^{-1}\ d_{1,2}$ e'TOKEN)] and end-to-end encrypted $rand_1$ (or $rand_1{}^{-1}$ mod n) provided by Requestor); Verify that truncHash($(b_{2,1}{}^{-1}\ d_{2,1})^t\ b_{2,2}{}^{-1}\ d_{2,2}[(b_{1,1}{}^{-1}\ d_{1,1})^t\ b_{1,2}{}^{-1}$ $d_{1,2}$ TOKEN])=checkBits as condition of releasing $(b_{2,1}{}^t\ b_{2,2})^{-1}$ $[(b_{1,1}{}^t\ b_{1,2})^{-1}$ e'TOKEN] to Requestor

[0110] Detokenization final Requestor processing: Verify that $[(b_{1,1}{}^t\ b_{1,2})^{-1}$ $(b_{2,1}{}^t\ b_{2,2})^{-1}$ e'TOKEN] received from Backend 1=$[(b_{2,1}{}^t\ b_{2,2})^{-1}$ $(b_{1,1}{}^t\ b_{1,2})^{-1}$ e'TOKEN] received from Backend 2. Recover P=$e'^{-1}[(b_{1,1}{}^t\ (b_{2,1}{}^t\ b_{2,2})^{-1}$ e'TOKEN].

[0111] As an alternative to Backend 1 suppressing the release of $(b_{2,1}{}^t\ b_{2,2})^{-1}$ $[(b_{1,1}{}^t\ b_{1,2})^{-1}$ e'TOKEN] to the Requestor in the event that checkBits verification fails, and to Backend 2 suppressing the release of $(b_{2,1}{}^t\ b_{2,2})^{-1}$ $[(b_{1,1}{}^t$

$b_{1,2})^{-1}$ e'TOKEN] to the Requestor in the event that checkBits verification fails, Backend 1 can release a modified version that incorporates or substitutes the value of one or more $b_{1,j}$ values, and Backend 2 can release the corresponding modified version that incorporates or substitutes the value of one or more $b_{2,j}$ values. Since $(b_{1,j}\ b_{2,j})$ mod n remains constant through resplit intervals, then a Requestor acting adversely will not detect an inequality in the received values or a difference across resplit intervals, if $b_{1,j}$ and $b_{2,j}$ are used in a consistent formulation and only as the product $(b_{1,j}\ b_{2,j})$ mod n. Parallel computations such as these can also be used in other embodiments that entail one or more checks conducted by the Backends, as an alternative to aborting computation and/or transmitting an error message.

[0112] Unlike Embodiment 2, in Embodiment 3, the second-round computation by each Backend that enables recovery of P in the legitimate Requestor case is identical to that in the first-round computation. End-to-end encryption (whether authenticated or not) of that part of the first-round computation can thwart the specific attack in which a Requestor (that is unilaterally attempting attack) requests first-round detokenization processing twice instead of requesting first-round detokenization processing followed by requesting second-round detokenization processing.

[0113] Unlike Embodiments 2 and 3, Embodiments 4-6 (as well as Embodiment 1) do not expose any aspects of non-blinded TOKENs to either of the Backends and do not entail augmenting the TOKEN by an element such as checkBits, as an AUX_TOKEN, that is stored in addition to the TOKEN to enable detokenization processing by the Backends.

[0114] Embodiment 4: f_1=multiplication modulo n; f_2=multiplication modulo n; f_3=hash; constant function f_4 always returns 1; $\beta_{1,1}(t)=b_{1,1}\ t$, and $\beta_{2,1}(t)=b_{2,1}{}^t$; $\beta_{1,2}=b_{1,2}$ and $\beta_{2,2}=b_{2,2}$; $\beta_{1,3}(t)=b_{1,3}{}^t$; $\beta_{2,3}(t)=b_{2,3}{}^t$; $\beta_{1,4}=b_{1,4}$, $\beta_{2,4}=b_{2,4}$; G_1=G. Setting $f_3(x)$=hash(x) is an example. Another example is to set $f_3(x)$=(hash(0||x)||hash(1||x)) mod n. This holds analogously for Embodiment 5 and Embodiment 6 presented later with respect to functions f_3 and f_4.

[0115] Embodiment 4 TOKEN: TOKEN=$(b_{1,1}\ b_{2,1})^t\ b_{1,2}\ b_{2,2}$ hash$((b_{1,3}\ b_{2,3})^t\ b_{1,4}\ b_{2,4}\ G)$ P.

[0116] Referring now to FIG. **8**, stepping through tokenization processing, first the Requestor **810** transmits eP to Backend 1 **815** at **825**, and transmits eP to Backend 2 **820** at **830**. Backend 1 **815** responds at **835** with $b_{1,1}{}^t\ b_{1,2}$ [eP] and $b_{1,3}{}^t\ b_{1,4}$ G, and Backend 2 **820** responds with $b_{2,1}{}^t\ b_{2,2}$ [eP] and $b_{2,3}{}^t\ b_{2,4}$ G at **840**, thus completing their round-one processing. Using $b_{2,1}{}^t\ b_{2,2}$ eP and $b_{2,3}{}^t\ b_{2,4}$ G received via **845**, Backend 1 **815** transmits hash$(b_{1,3}{}^t\ b_{1,4}\ [b_{2,3}{}^t\ b_{2,4}\ G])\ b_{1,2}\ [b_{2,1}{}^t\ b_{2,2}$ eP] to the Requestor **810** at **855**, thus completing its role in round-two processing. Similarly, using $b_{1,1}{}^t\ b_{1,2}$ eP and $b_{1,3}{}^t\ b_{1,4}$ G received via **850**, Backend 2 **820** transmits hash$(b_{2,3}{}^t\ b_{2,4}\ [b_{1,3}{}^t\ b_{1,4}\ G])\ b_{2,1}{}^t\ b_{2,2}\ [b_{1,1}{}^t\ b_{1,2}$ eP] to the Requestor **810** at **860**, thus completing its role in round-two processing. At **865**, the Requestor **810** verifies equality of the output of **855** and the output of **860**, and unblinds the output of **855** to derive TOKEN=e^{-1} [hash$(b_{1,3}{}^t\ b_{1,4}\ b_{2,3}{}^t\ b_{2,4}\ G)\ b_{1,1}{}^t\ b_{1,2}\ b_{2,1}{}^t\ b_{2,2}$ eP].

[0117] Referring now to FIG. **9**, stepping through detokenization processing, first the Requestor **910** transmits e'TOKEN to Backend 1 **915** at **925**, and transmits e'TOKEN to Backend 2 **920** at **930**. Backend 1 **915** responds at **935** with $(b_{1,1}{}^t\ b_{1,2})^{-1}$ [e'TOKEN] and $b_{1,3}{}^t\ b_{1,4}$ G, and Backend 2 **920** responds at **940** with $(b_{2,1}{}^t\ b_{2,2})^{-1}$ [e'TOKEN] and $b_{2,3}{}^t\ b_{2,4}$ G, thus completing their role in round-one processing. Using $(b_{2,1}{}^t\ b_{2,2})^{-1}$ e'TOKEN and $b_{2,3}{}^t\ b_{2,4}$ G received via **945**, Backend 1 **915** transmits (hash$(b_{1,3}{}^t\ b_{1,4}\ [b_{2,3}{}^t\ b_{2,4}\ G]))^{-1}$ mod n $[(b_{2,1}{}^t\ b_{2,2})^{-1}$ e'TOKEN] to the Requestor **910** at **955**, thus completing its role in round-two processing. Using $(b_{1,1}{}^t\ b_{1,2})^{-1}$ e'TOKEN and $b_{1,3}{}^t\ b_{1,4}$ G received via **950**, Backend 2 **920** transmits (hash$(b_{2,3}{}^t\ b_{2,4}\ [b_{1,3}{}^t\ b_{1,4}\ G]))^{-1}$ mod n $(b_{2,1}{}^t\ b_{2,2})^{-1}\ [(b_{1,1}{}^t\ b_{1,2}))^{-1}$ e'TOKEN] to the Requestor **910** at **960**, thus completing its role in round-two processing. At **965**, the Requestor **910** verifies equality of the output of **955** and the output of **960**. The Requestor **910** unblinds the output of **955**, resulting in recovery of P=e'^{-1} [(hash$(b_{1,3}{}^t\ b_{1,4}\ b_{2,3}{}^t\ b_{2,4}\ G))^{-1}$ mod n $(b_{1,1}{}^t\ b_{1,2})^{-1}\ (b_{2,1}{}^t\ b_{2,2})^{-1}$ e'TOKEN].

[0118] Like Embodiment 3, Embodiment 4 has the Backends perform, at least in part, similar computations during the two rounds. Any adverse consequences of such similarity as potentially exploitable by illegitimately acting Requestors (such as pertaining to a lack of end-to-end encryption or release of such encryption key by a non-conformant Backend, thus enabling bypass of the second round by a Requestor during certain adversarial operations) are not relevant to Embodiment 5 and Embodiment 6.

[0119] Alternative Embodiment 4:

[0120] f_1=multiplication modulo n; f_2=multiplication modulo n; constant function f_3 always return 1; f_4=identity function; the operation between f_4 and f_1 is elliptic curve point addition; $\beta_{1,1}(t)=b_{1,1}{}^t$, and $\beta_{2,1}(t)=b_{2,1}{}^t$, $\beta_{1,2}=b_{1,2}$ and $\beta_{2,2}=b_{2,2}$; $\beta_{1,5}(t)=b_{1,5}{}^t$; $\beta_{2,5}(t)=b_{2,5}{}^t$; $\beta_{1,6}=b_{1,6}$; $\beta_{2,6}=b_{2,6}$; G_2=G.

[0121] Alternative Embodiment 4 TOKEN: TOKEN=$(b_{1,1}\ b_{2,1})^t\ b_{1,2}\ b_{2,2}\ P+(b_{1,5}\ b_{2,5})^t\ b_{1,6}\ b_{2,6}\ G$.

[0122] Alternative Embodiment 4, if implemented under 2-round tokenization that does not allow for enabling P-dependent G or t within the additive modifier $(b_{1,5}\ b_{2,5})^t\ b_{1,6}\ b_{2,6}$ G, can be attacked as follows (which is why a 3-round tokenization example of Alternative Embodiment 4 will be presented subsequently): The t-dependent additive modifier $(b_{1,5}\ b_{2,5})^t\ b_{1,6}\ b_{2,6}$ G, denoted as m_t, can be extracted by a Requestor that requests tokenization of any two elliptic curve points P_1 and P_2, where P_2 is chosen as aP_1 for a known integer value of $a\neq 1$: $aTOKEN_1=a\ (b_{1,1}\ b_{2,1})^t\ b_{1,2}\ b_{2,2}\ P_1+a\ (b_{1,5}\ b_{2,5})^t\ b_{1,6}\ b_{2,6}$ G, and $TOKEN_2=(b_{1,1}\ b_{2,1})^t\ b_{1,2}\ b_{2,2}\ a\ P_1+(b_{1,5}\ b_{2,5})^t\ b_{1,6}\ b_{2,6}$ G together imply that $(a-1)^{-1}$ mod n $(aTOKEN_1-TOKEN_2)=m_t$.

[0123] 3-round tokenization example of Alternative Embodiment 4:

[0124] Note that t* is a function oft via the formulation of AUX_TOKEN, and G=Gcheck (as defined below):

[0125] TOKEN=$(\beta_{1,1}\ b_{2,1})^{t*}\ b_{1,2}\ b_{2,2}\ P+(b_{1,5}\ b_{2,5})^{t*}\ b_{1,6}\ b_{2,6}$ Gcheck; checkBits=AUX_TOKEN=truncHash$((d_{1,1}\ d_{2,1})^t\ d_{1,2}\ d_{2,2}\ P)$.

[0126] As an example of t* where n is prime: t*=(hash (0||AUX_TOKEN)||hash(1||AUX_TOKEN)) mod n−1, where || denotes concatenation.

[0127] As an example formulation of Gcheck: Let Gcheck x-coordinate=hash(AUX TOKEN||Pad) where Pad is deterministically generated as the smallest nonnegative integer such that hash(AUX TOKEN||Pad) is an x-coordinate of a point on the elliptic curve and hash(AUX TOKEN||Pad)<p, where the elliptic curve is defined over the prime field GF(p). The y-coordinate is preferably chosen unambiguously as one of the two possible values that correspond to the x-coordinate per the equation of the elliptic curve.

[0128] Tokenization round-one Backend processing:

[0129] Backend 1: $d_{1,1}{}^{t}\,d_{1,2}$ [eP]—provide to Requestor

[0130] Backend 2: $d_{2,1}{}^{t}\,d_{2,2}$ [eP]—provide to Requestor

[0131] Tokenization round-two Backend processing:

[0132] Backend 1: $d_{1,1}{}^{t}\,d_{1,2}$ [$d_{2,1}{}^{t}\,d_{2,2}$ P] (using [e^{-1}($d_{2,1}{}^{t}$ $d_{2,2}$ eP)] provided by Requestor); checkBits=truncHash ($d_{1,1}{}^{t}\,d_{1,2}$ [$d_{2,1}{}^{t}\,d_{2,2}$ P])—provide to Requestor; derive t* and Gcheck; $b_{1,5}{}^{t^*}$ $b_{1,6}$ Gcheck—provide to Requestor; $b_{1,1}{}^{t^*}$ $b_{1,2}$ [eP]

[0133] Backend 2: $d_{2,1}{}^{t}\,d_{2,2}$ [$d_{1,1}{}^{t}\,d_{1,2}$ P] (using [e^{-1}($d_{1,1}{}^{t}$ $d_{1,2}$ eP)] provided by Requestor); checkBits=truncHash ($d_{2,1}{}^{t}\,d_{2,2}$ [$d_{1,1}{}^{t}\,d_{1,2}$ P])—provide to Requestor; derive t* and Gcheck; $b_{2,5}{}^{t^*}$ $b_{2,6}$ Gcheck—provide to Requestor; $b_{2,1}{}^{t^*}$ $b_{2,2}$ [eP]

[0134] Tokenization round-three Backend processing (if [checkBits] provided to Requestor by Backend 1=[checkBits] provided to Requestor by Backend 2):

[0135] Backend 1: $b_{1,1}{}^{t^*}$ $b_{1,2}$ [$b_{2,1}{}^{t^*}$ $b_{2,2}$ eP]; $b_{1,5}{}^{t^*}$ $b_{1,6}$ [$b_{2,5}{}^{t^*}$ $b_{2,6}$ eGcheck] (using [e($b_{2,5}{}^{t^*}$ $b_{2,6}$ Gcheck)] provided by Requestor); $b_{1,1}{}^{t^*}$ $b_{1,2}$ [$b_{2,1}{}^{t^*}$ $b_{2,2}$ eP]+$b_{1,5}{}^{t^*}$ $b_{1,6}$ [e $b_{2,5}{}^{t^*}$ $b_{2,6}$ Gcheck]-provide to Requestor

[0136] Backend 2: $b_{2,1}{}^{t^*}$ $b_{2,2}$ [$b_{1,1}{}^{t^*}$ $b_{1,2}$ eP]; $b_{2,5}{}^{t^*}$ $b_{2,6}$ [$b_{1,5}{}^{t^*}$ $b_{1,6}$ eGcheck] (using [e($b_{1,5}{}^{t^*}$ $b_{1,6}$ Gcheck)] provided by Requestor); $b_{2,1}{}^{t^*}$ $b_{2,2}$ [$b_{1,1}{}^{t^*}$ $b_{1,2}$ eP]+$b_{2,5}{}^{t^*}$ $b_{2,6}$ [e $b_{1,5}{}^{t^*}$ $b_{1,6}$ Gcheck]-provide to Requestor

[0137] Tokenization final Requestor processing: Verify that [$b_{1,1}{}^{t^*}$ $b_{1,2}$ $b_{2,1}{}^{t^*}$ $b_{2,2}$ eP+$b_{1,5}{}^{t^*}$ $b_{1,6}$ e $b_{2,5}{}^{t^*}$ $b_{2,6}$ Gcheck] received from Backend 1=[$b_{2,1}{}^{t^*}$ $b_{2,2}$ $b_{1,1}{}^{t^*}$ $b_{1,2}$ eP+$b_{2,5}{}^{t^*}$ $b_{2,6}$ e $b_{1,5}{}^{t^*}$ $b_{1,6}$ Gcheck] received from Backend 2. Derive TOKEN=e^{-1} [$b_{1,1}{}^{t^*}$ $b_{1,2}$ $b_{2,1}{}^{t^*}$ $b_{2,2}$ eP+$b_{1,5}{}^{t^*}$ $b_{1,6}$ e $b_{2,5}{}^{t^*}$ $b_{2,6}$ Gcheck].

[0138] Detokenization round-one Backend processing:

[0139] Backend 1: derive t* and Gcheck from [checkBits] provided by Requestor; $(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ [e'TOKEN]; $(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ $b_{1,5}{}^{t^*}$ $b_{1,6}$ [e'Gcheck]; $d_{1,1}{}^{t}\,d_{1,2}$ $(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ [e'TOKEN]-provide to Requestor; $d_{1,1}{}^{t}\,d_{1,2}$ $(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ $b_{1,5}{}^{t^*}$ $b_{1,6}$ [Gcheck]

[0140] Backend 2: derive t* and Gcheck from [checkBits] provided by Requestor; $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ [e'TOKEN]; $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ $b_{2,5}{}^{t^*}$ $b_{2,6}$ [e'Gcheck]; $d_{2,1}{}^{t}\,d_{2,2}$ $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ [e'TOKEN]-provide to Requestor; $d_{2,1}{}^{t}\,d_{2,2}$ $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ $b_{2,5}{}^{t^*}$ $b_{2,6}$ [Gcheck]

[0141] Detokenization round-two Backend processing:

[0142] Backend 1: $(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ [$(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ e'TOKEN]; $(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}b_{1,5}{}^{t^*}\,b_{1,6}$ [$(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ $b_{2,5}{}^{t^*}$ $b_{2,6}$ e'Gcheck]; $d_{1,1}{}^{t}\,d_{1,2}$ $(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ [$d_{2,1}{}^{t}\,d_{2,2}$ $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ TOKEN] (using [$d_{2,1}{}^{t}\,d_{2,2}$ $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ e'TOKEN] provided by Requestor); $d_{1,1}{}^{t}\,d_{1,2}$ $(b_{1,1}{}^{t^*}\,b_{1,2})_{-1}$ $b_{1,5}{}^{t^*}\,b_{1,6}$ [$d_{2,1}{}^{t}\,d_{2,2}$ $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ $b_{2,5}{}^{t^*}\,b_{2,6}$ Gcheck]; Verify that truncHash($d_{1,1}{}^{t}\,d_{1,2}$ $(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ [$d_{2,1}{}^{t}\,d_{2,2}$ $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ TOKEN]—$d_{1,1}{}^{t}\,d_{1,2}$ $(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ $b_{1,5}{}^{t^*}\,b_{1,6}$ [$d_{2,1}{}^{t}\,d_{2,2}$ $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ $b_{2,5}{}^{t^*}\,b_{2,6}$ Gcheck])=[checkBits] as condition of releasing $(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ [$(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ e'TOKEN]—$(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ $b_{1,5}{}^{t^*}\,b_{1,6}$ [$(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ $b_{2,5}{}^{t^*}\,b_{2,6}$ e'Gcheck] to Requestor

[0143] Backend 2: $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ [$(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ e'TOKEN]; $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}b_{2,5}{}^{t^*}\,b_{2,6}$ [$(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ $b_{1,5}{}^{t^*}\,b_{1,6}$ e'Gcheck]; $d_{2,1}{}^{t}\,d_{2,2}$ $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ [$d_{1,1}{}^{t}\,d_{1,2}$ $(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ TOKEN] (using [$d_{1,1}{}^{t}\,d_{1,2}$ $(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ e'TOKEN] provided by Requestor); $d_{2,1}{}^{t}\,d_{2,2}$ $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ $b_{2,5}{}^{t^*}\,b_{2,6}$ [$d_{1,1}{}^{t}\,d_{1,2}$ $(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ $b_{1,5}{}^{t^*}\,b_{1,6}$ Gcheck]; Verify that truncHash($d_{2,1}{}^{t}\,d_{2,2}$ $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ [$d_{1,1}{}^{t}\,d_{1,2}$ $(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ TOKEN]—$d_{2,1}{}^{t}\,d_{2,2}$ $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ $b_{2,5}{}^{t^*}\,b_{2,6}$ [$d_{1,1}{}^{t}\,d_{1,2}$ $(b_{1,1}{}^{t}\,b_{1,2})^{-1}$ $b_{1,5}{}^{t^*}\,b_{1,6}$ Gcheck])=[checkBits] as condition of releasing $(b_{2,1}{}^{t^*}\,b_{2,2})$ **1** [$(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ e'TOKEN]—$(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}b_{2,5}$ t* $b_{2,6}$ [$(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ $b_{1,5}{}^{t^*}$ $b_{1,6}$ e'Gcheck] to Requestor

[0144] Detokenization final Requestor processing: Verify that [$(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ e'TOKEN—$(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ $b_{1,5}{}^{t^*}\,b_{1,6}$ $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}b_{2,5}{}^{t^*}\,b_{2,6}$ e'Gcheck] received from Backend 1=[$(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ e'TOKEN—$(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ $b_{2,5}{}^{t^*}$ $b_{2,6}$ $(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ $b_{1,5}{}^{t^*}\,b_{1,6}$ e'Gcheck] received from Backend 2. Recover P=e'$^{-1}$[$(b_{1,1}{}^{t^*}\,b_{2,2})^{-1}$ $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}$ e'TOKEN—$(b_{1,1}{}^{t^*}\,b_{1,2})^{-1}$ $b_{1,5}{}^{t^*}\,b_{1,6}$ $(b_{2,1}{}^{t^*}\,b_{2,2})^{-1}b_{2,5}{}^{t^*}\,b_{2,6}$ e'Gcheck].

[0145] Unlike Embodiment 4 and Alternative Embodiment 4, the TOKENs of Embodiment 5 and 6 each incorporate two rather than one multiplicative modifier, where G_1 and G_2 are generated independently of each other for use within Embodiment 5, and where G_1=G_2 in Embodiment 6. The use of two distinct multiplicative modifiers within the computation of each TOKEN, where the intent is that each Backend does not have access to the multiplicative modifiers of the opposite Backend, implies that each of the two Backends would have to eventually be compromised to totally remove the combined effect of the modifiers. Analogously to the case of detokenization of non-blinded TOKENs under Embodiment 3, Embodiments 5 and 6 make use of ephemeral blinding factors generated independently by each of the Backends, even though here detokenization involves blinded Tokens. However, under Embodiments 5 and 6, Backends preferably use such ephemeral blinding factors during both tokenization and detokenization and do not ultimately reveal the ephemeral blinding factors to Requestors. Even though here the ephemeral blinding factors are not provided as first- or second-round outputs to Requestors, these values still traverse across the first and second rounds. Preferably, each Backend utilizes the ephemeral blinding factors during second-round computations to prevent both the opposite Backend and the Requestor (acting independently or collusively) from accessing the multiplicative modifiers that the Backend is responsible for using and safeguarding. Each Backend incorporates such a multiplicative modifier into a TOKEN during tokenization and attempts to remove such a multiplicative modifier during detokenization. Whether or not such removal is successful depends on the legitimacy or not of purported blinded TOKENs submitted by Requestors. Preferably, multiplicative modifiers are scope dependent.

[0146] After presenting Embodiment 5 and Embodiment 6, two mechanisms intended towards assuring traversal of Backend-generated ephemeral blinding factors across first and second rounds are described, where: (i) the first entails, in part, "boomeranging" of randomly generated values between the first and second rounds; and (ii) the second utilizes deterministic generation during the first round and deterministic re-generation during the second round.

[0147] Embodiment 5: f_1=multiplication modulo n; f_2=multiplication modulo n; f_3=hash; f_4=hash; $\beta_{1,1}(t)=b_{1,1}{}^{t}$, and $\beta_{2,1}(t)=b_{2,1}$ t; $\beta_{1,2}=b_{1,2}$ and $\beta_{2,2}=b_{2,2}$; $\beta_{1,3}(t)=b_{1,3}{}^{t}$; $\beta_{2,3}(t)=b_{2,3}{}^{t}$; $\beta_{1,4}=b_{1,4}$; $\beta_{2,4}=b_{2,4}$; $\beta_{1,5}(t)=b_{1,3}{}^{t}$; $\beta_{2,5}(t)=b_{2,3}{}^{t}$; $\beta_{1,6}=b_{1,4}$; $\beta_{2,6}=b_{2,4}$.

[0148] Embodiment 5 TOKEN: TOKEN=$(b_{1,1}\,b_{2,1})^{t}$ $b_{1,2}$ $b_{2,2}$ hash($(b_{1,3}\,b_{2,3})^{t}$ $(b_{1,4}\,b_{2,4})$ hash($(b_{1,3}\,b_{2,3})^{t}$ $(b_{1,4}\,b_{2,4})$ G_2) P.

[0149] In Embodiment 5 as well as Embodiment 6 considered next, the hash function of f_3 need not be the same as the hash function of f_4.

[0150] In both Embodiment 5 and Embodiment 6: e_1 and e_2 denote the ephemeral blinding factors of Backend 1 and Backend 2, respectively, as used during tokenization; e'_1 and e'_2 denote the ephemeral blinding factors of Backend 1 and Backend 2, respectively, as used during detokenization.

[0151] In both Embodiment 5 and Embodiment 6: the removal by each Backend of the effect of its ephemeral blinding factor requires the Requestor to initiate running round **2**, as is the case for both tokenization and detokenization.

[0152] In both Embodiment 5 and Embodiment 6: at least one second-round output differs in its value between each of the Backends independently of any difference in values between the ephemeral blinding factors, as is the case for both tokenization and detokenization.

[0153] Relevant to FIG. **10** and FIG. **12**, by one approach, a Requestor combines at least three values comprising a first value, a second value and a third value, as part of its processing to derive a TOKEN, wherein: the first value involves at least ephemeral blinding by the requestor of Data that is further ephemerally blinded by a first tokenization processor and by a second tokenization processor; the second value involves at least the ephemeral blinding by the first tokenization processor and tokenization processor secrets of both the first tokenization processor and the second tokenization processor, and a scope label denoted as t, but not the Data and not the ephemeral blinding by the requestor; the third value, which is distinct from the second value, involves at least the ephemeral blinding by the second tokenization processor and tokenization processor secrets of both the first tokenization processor and the second tokenization processor that may be the same or different than the tokenization processor secrets involved in the second value, and the scope label denoted as t, but not the Data and not the ephemeral blinding by the requestor.

[0154] Referring now to FIG. **10**, stepping through tokenization processing, first the Requestor **1010** transmits eP to Backend 1 **1015** at **1025**, and transmits eP to Backend 2 **1020** at **1030**. Backend 1 **1015** responds at **1035** with $e_1\ b_{1,1}{}^t\ b_{1,2}$ [eP] and $b_{1,3}{}^t\ b_{1,4}\ G_1$, and Backend 2 **1020** responds with $e_2\ b_{2,1}{}^t\ b_{2,2}$ [eP] and $b_{2,3}{}^t\ b_{2,4}\ G_2$ at **1040**, thus completing round-one processing. Using $e_2\ b_{2,1}{}^t\ b_{2,2}$ eP and $b_{2,3}{}^t\ b_{2,4}\ G_2$ received via **1045**, Backend 1 **1015** transmits $e_1\ b_{1,1}{}^t\ b_{1,2}$ [$e_2\ b_{2,1}{}^t\ b_{2,2}$ eP] and $(e_1{}^{-1}\ \text{hash}(b_{1,3}{}^t\ b_{1,4}\ [b_{2,3}{}^t\ b_{2,4}\ G_2]))$ mod n to the Requestor **1010** at **1055**, thus completing its role in round-two processing. Similarly, using $e_1\ b_{1,1}{}^t\ b_{1,2}$ eP and $b_{1,3}{}^t\ b_{1,4}\ G_1$ received via **1050**, Backend 2 **1020** transmits $e_2\ b_{2,1}{}^t\ b_{2,2}$ [$e_1\ b_{1,1}{}^t\ b_{1,2}$ eP] and $(e_2{}^{-1}\ \text{hash}(b_{2,3}{}^t\ b_{2,4}\ [b_{1,3}{}^t\ b_{1,4}\ G_1]))$ mod n to the Requestor **1010** at **1060**, thus completing its role in round-two processing. At **1065**, the Requestor **1010** verifies equality of the first output of **1055** and the first output of **1060**. Also at **1055**, the Requestor **1010** computes the product of: the second output of **1055**, the second output of **1060** and the first output of **1055**. Finally at **1065**, the Requestor **1010** unblinds the resultant product to derive $\text{TOKEN}=e^{-1}\ [(e_1{}^{-1}\ \text{hash}(b_{1,3}{}^t\ b_{1,4}\ b_{2,3}{}^t\ b_{2,4}\ G_2))\ \text{mod n}]\ (e_2{}^{-1}\ \text{hash}(b_{2,3}{}^t\ b_{2,4}\ b_{1,3}{}^t\ b_{1,4}\ G_1))\ \text{mod n}]\ [e_1\ b_{1,1}{}^t\ b_{1,2}\ e_2\ b_{2,1}{}^t\ b_{2,2}$ eP].

[0155] Referring now to FIG. **11**, stepping through detokenization processing, first the Requestor **1110** transmits e'TOKEN to Backend 1 **1115** at **1125**, and transmits e'TOKEN to Backend 2 **1120** at **1130**. Backend 1 **1115** responds at **1135** with $(e'_1\ [b_{1,1}{}^t\ b_{1,2})^{-1}$ e'TOKEN] and $b_{1,3}{}^t\ b_{1,4}\ G_1$, and Backend 2 **1120** responds at **1140** with $(e'_2\ b_{2,1}{}^t\ b_{2,2})^{-1}$ [e'TOKEN] and $b_{2,3}{}^t\ b_{2,4}\ G_2$, thus completing their role in round-one processing. Using $(e'_2\ b_{2,1}{}^t\ b_{2,2})^{-1}$ e'TOKEN and $b_{2,3}{}^t\ b_{2,4}\ G_2$ received via **1145**, Backend 1 **1115** transmits $(e'_1\ b_{1,1}{}^t\ b_{1,2})^{-1}$ $[(e'_2\ b_{2,1}{}^t\ b_{2,2})^{-1}$ e'TOKEN] and $(e'_1(\text{hash}(b_{1,3}{}^t\ b_{1,4}\ [b_{2,3}{}^t\ b_{2,4}\ G_2]))^{-1})$ mod n to the Requestor **1110** at **1155**, thus completing its role in round-two processing. Using $(e'_1\ b_{1,1}{}^t\ b_{1,2})^{-1}$ [e'TOKEN] and $b_{1,3}{}^t\ b_{1,4}\ G_1$ received via **1150**, Backend 2 **1120** transmits $(e'_2\ b_{2,1}{}^t\ b_{2,2})_{-1}$ $[(e'_1\ b_{1,1}{}^t\ b_{1,2})^{-1}$ e'TOKEN] and $(e'_2\ (\text{hash}(b_{2,3}{}^t\ b_{2,4}\ [b_{1,3}{}^t\ b_{1,4}\ G_1]))^{-1})$ mod n to the Requestor **1110** at **1160**, thus completing its role in round-two processing. At **1165**, the Requestor **1110** verifies equality of the first output of **1155** and the first output of **1160**. Also at **1165**, the Requestor **1110** computes the product of: the second output of **1155**, the second output of **1160** and the first output of **1155**. Finally at **1165**, the Requestor **1110** unblinds the resultant product to derive $P=e'^{-1}$ $[(e'_1\ (\text{hash}(b_{1,3}{}^t\ b_{1,4}\ b_{2,3}{}^t\ b_{2,4}\ G_2))^{-1})\ \text{mod n}]\ [(e'_2\ (\text{hash}(b_{2,3}{}^t\ b_{2,4}\ b_{1,3}{}^t\ b_{1,4}\ G_1))^{-1})\ \text{mod n}]\ [(e'_1\ b_{1,1}{}^t\ b_{1,2})^{-1}\ (e'_2\ b_{2,1}{}^t\ b_{2,2})^{-1}$ e'TOKEN].

[0156] Embodiment 5 can be exploited by a non-conformant Backend unless appropriate safeguards are taken to: (1) prevent a Backend from fooling the other Backend to compute the multiplicative modifier (as part of its second-round output) that the adversarial Backend knows, by effectively switching the use of G_1 vs. G_2; and (2) prevent a Backend from fooling the other Backend to provide it with the multiplicative modifier that the unwitting victim Backend correctly uses in computing part of its second-round output.

[0157] As an example of countermeasure (1): Suppose Backend 1 provides Backend 2 with a fresh value of $bb_{1,1}\ G_2$ at the onset of each parameter resplit period; suppose Backend 2 provides Backend 1 with a fresh value of $bb_{2,1}\ G_1$ at the onset of each resplit period. During both tokenization and recovery, Backend 1 forms $\text{hash}(b_{1,3}{}^t\ b_{1,4}\ b_{2,3}{}^t\ b_{2,4}\ G_2)$ as: $\text{hash}((b_{1,3}{}^t\ b_{1,4}\text{-}bb_{1,1})\ [(b_{2,3})^t\ b_{2,4}\ G_2)]+[(b_{2,3})^t\ b_{2,4}\ bb_{1,1}\ G_2])$ rather than as $\text{hash}(b_{1,3}{}^t\ b_{1,4}\ [b_{2,3}{}^t\ b_{2,4}\ G_2])$, where Backend 2 generates $(b_{2,3})^t\ b_{2,4}\ [bb_{1,1}\ G_2]$ as well as $(b_{2,3})^t\ b_{2,4}\ G_2$ during first-round computation. Computation by Backend 2 to form $\text{hash}(b_{2,3}{}^t\ b_{2,4}\ b_{1,3}{}^t\ b_{1,4}\ G_1)$ is done analogously. But if Backend 1 provides Backend 2 with $bb_{1,1}\ G_1$ instead of $bb_{1,1}\ G_2$, then $[(b_{2,3})^t\ b_{2,4}\ bb_{1,1}\ G_1]$ as received from unwitting Backend 2 by Backend 1 would enable Backend 1 to generate $\text{hash}(b_{2,3}{}^t\ b_{2,4}\ b_{1,3}{}^t\ b_{1,4}\ G_1)$ as $b_{1,3}{}^t\ b_{1,4}\ [(b_{2,3})^t\ b_{2,4}\ bb_{1,1}\ G_1]$ (where the analogous attack would entail Backend 2 providing Backend 1 with $bb_{2,1}\ G_2$ instead of $bb_{2,1}\ G_1$, and Backend 2 generating $\text{hash}(b_{1,3}{}^t\ b_{1,4}\ b_{2,3}{}^t\ b_{2,4}\ G_2)$ as $b_{2,3}{}^t\ b_{2,4}\ [(b_{1,3})^t\ b_{1,4}\ bb_{2,1}\ G_2]$. To mitigate against that:

[0158] As an example of countermeasure (2): Suppose Backend 1 also provides Backend 2 with a fresh value of $bb_{1,2}\ G_1$ at the onset of each parameter resplit period; suppose Backend 2 also provides Backend 1 with a fresh value of $bb_{2,2}\ G_2$ at the onset of each resplit period. Then as a condition of continuing round two computation, Backend 1 verifies that $bb_{1,2}\ [bb_{2,1}\ G_1]=[bb_{2,1}\ bb_{1,2}\ G_1]$; analogously, as a condition of continuing round two computation, Backend 2 verifies that $bb_{2,2}\ [bb_{1,1}\ G_2]=[bb_{1,1}\ bb_{2,2}\ G_2]$.

[0159] In lieu of providing countermeasures such as these as safeguards, one can consider Embodiment 6 below as an alternative.

[0160] Embodiment 6: f_1=multiplication modulo n; f_2=multiplication modulo n; f_3=hash; f_4=hash; $\beta_{1,1}(t)=b_{1,1}{}^t$, and $\beta_{2,1}(t)=b_{2,1}{}^t$; $\beta_{1,2}=b_{1,2}$ and $\beta_{2,2}=b_{2,2}$; $\beta_{1,3}(t)=b_{1,3}{}^t\ \beta_{2,3}(t)$

$=b_{2,3}^{t}$; $\beta_{1,4}=b_{1,4}$; $\beta_{2,4}=b_{2,4}$; $\beta_{1,5}(t)=b_{1,5}^{t}$; $\beta_{2,5}(t)=b_{2,5}^{t}$; $\beta_{1,6}=b_{1,6}$; $\beta_{2,6}=b_{2,6}$; $G_1=G_2=G$.

[0161] Embodiment 6 TOKEN: TOKEN=$(b_{1,1}\ b_{2,1})^t\ b_{1,2}\ b_{2,2}$ hash$((b_{1,3}\ b_{2,3})^t\ b_{1,4}\ b_{2,4}\ G)$ hash$((b_{1,5}\ b_{2,5})^t\ b_{1,6}\ b_{2,6}\ G)$ P.

[0162] Embodiment 6 is characterized, in part, by having each Backend withhold the use of at least some of its preferably secret parameters until the second round of both tokenization and detokenization.

[0163] Referring now to FIG. **12**, stepping through tokenization processing, first the Requestor **1210** transmits eP to Backend 1 **1215** at **1225**, and transmits eP to Backend 2 **1220** at **1230**. Backend 1 **1215** responds at **1235** with e_1 [eP] and $b_{1,3}^{t}\ b_{1,4}$ G, and Backend 2 **1220** responds with e_2 [eP] and $b_{2,5}^{t}\ b_{2,6}$ G at **1240**, thus completing round-one processing. Using e_2eP and $b_{2,5}^{t}\ b_{2,6}$ G received via **1245**, Backend 1 **1215** transmits e_1[e_2 eP] and $(e_1^{-1}\ b_{1,1}^{t}\ b_{1,2}$ hash$(b_{1,5}^{t}\ b_{1,6}$ [$b_{2,5}^{t}\ b_{2,6}$ G])) mod n to the Requestor **1210** at **1255**, thus completing its role in round-two processing. Similarly, using e_1eP and $b_{1,3}^{t}\ b_{1,4}$ G received via **1250**, Backend 2 **1220** transmits e_2[e_1 eP] and $(e_2^{-1}\ b_{2,1}^{t}\ b_{2,2}$ hash$(b_{2,3}^{t}\ b_{2,4}$ [$b_{1,3}^{t}\ b_{1,4}$ G])) mod n to the Requestor **1210** at **1260**, thus completing its role in round-two processing. At **1265**, the Requestor **1210** verifies equality of the first output of **1255** and the first output of **1260**. Also at **1255**, the Requestor **1210** computes the product of: the second output of **1255**, the second output of **1260** and the first output of **1255**. Finally at **1265**, the Requestor **1210** unblinds the resultant product to derive TOKEN=e^{-1}[$(e_1^{-1}\ b_{1,1}^{t}\ b_{1,2}$ hash$(b_{1,5}^{t}\ b_{1,6}\ b_{2,5}^{t}\ b_{2,6}\ G))$ mod n] [$e_2^{-1}\ b_{2,1}^{t}\ b_{2,2}$ hash$(b_{2,3}^{t}\ b_{2,2}\ b_{1,3}^{t}\ b_{1,4}\ G))$ mod n] [$e_1\ e_2$ eP].

[0164] Referring now to FIG. **13**, stepping through detokenization processing, first the Requestor **1310** transmits e'TOKEN to Backend 1 **1315** at **1325**, and transmits e'TOKEN to Backend 2 **1320** at **1330**. Backend 1 **1315** responds at **1335** with e'_1 [e'TOKEN] and $b_{1,3}^{t}\ b_{1,4}$ G, and Backend 2 **1320** responds at **1340** with e'_2 [e'TOKEN] and $b_{2,5}^{t}\ b_{2,6}$ G, thus completing their role in round-one processing. Using e'_2 e'TOKEN and $b_{2,5}^{t}\ b_{2,6}$ G received via **1345**, Backend 1 **1315** transmits e'_1 [e'_2 e'TOKEN] and $(e'_1\ b_{1,1}^{t}\ b_{1,2}$ hash$(b_{1,5}^{t}\ b_{1,6}$ [$b_{2,5}^{t}\ b_{2,6}$ G]))$^{-1}$ mod n to the Requestor **1310** at **1355**, thus completing its role in round-two processing. Using e'_1 e'TOKEN and $b_{1,3}^{t}\ b_{1,4}$ G received via **1350**, Backend 2 **1320** transmits e'_2 [e'_1 e'TOKEN] and $(e'_2\ b_{2,1}^{t}\ b_{2,2}$ hash$(b_{2,3}^{t}\ b_{2,4}$ [$b_{1,3}^{t}\ b_{1,4}$ G]))$^{-1}$ mod n to the Requestor **1310** at **1360**, thus completing its role in round-two processing. At **1365**, the Requestor **1310** verifies equality of the first output of **1355** and the first output of **1360**. Also at **1365**, the Requestor **1310** computes the product of: the second output of **1355**, the second output of **1360** and the first output of **1355**. Finally at **1365**, the Requestor **1310** unblinds the resultant product to derive P=e'^{-1} [$e'_1\ b_{1,1}^{t}\ b_{1,2}$ hash$(b_{1,5}^{t}\ b_{1,6}\ b_{2,5}^{t}\ b_{2,6}\ G))^{-1}$ mod n] [$(e'_2\ b_{2,1}^{t}\ b_{2,2}$ hash$(b_{2,3}^{t}\ b_{2,4}\ b_{1,3}^{t}\ b_{1,4}\ G))^{-1}$ mod n] [$e'_1\ e'_2$ e'TOKEN].

[0165] Detokenization round-one Backend processing:

[0166] Backend 1: e'_1 [e'TOKEN]; $b_{1,3}^{t}\ b_{1,4}$ G

[0167] Backend 2: e'_2 [e'TOKEN]; $b_{2,5}^{t}\ b_{2,6}$ G

Detokenization round-two Backend processing:

[0168] Backend 1: e'_1 [e'_2 e'TOKEN]—provide to Requestor; $b_{1,5}^{t}\ b_{1,6}$ [$b_{2,5}^{t}\ b_{2,6}$ G]; $(e'_1\ b_{1,1}^{t}\ b_{1,2}$ hash$(b_{1,5}^{t}\ b_{1,6}$ [$b_{2,5}^{t}\ b_{2,6}$ G]))$^{-1}$ mod n—provide to Requestor

[0169] Backend 2: e'_2 [e'_1 e'TOKEN]—provide to Requestor; $b_{2,3}^{t}\ b_{2,4}$ [$b_{1,3}^{t}\ b_{1,4}$ G]; $(e'_2 b_{2,1}^{t}\ b_{2,2}$ hash$(b_{2,3}^{t}\ b_{2,4}$ [$b_{1,3}^{t}\ b_{1,4}$ G]))$^{-1}$ mod n—provide to Requestor

[0170] Detokenization final Requestor processing: Verify that [$e'_1\ e'_2$ e'TOKEN] received from Backend 1=[$e'_2\ e'_1$ e'TOKEN] received from Backend 2. Recover P=e'^{-1} [$(e'_1\ b_{1,1}^{t}\ b_{1,2}$ hash$(b_{1,5}^{t}\ b_{1,6}\ b_{2,5}^{t}\ b_{2,6}\ G))^{-1}$ mod n] [$(e'_2 b_{2,1}^{t}\ b_{2,2}$ hash$(b_{2,3}^{t}\ b_{2,4}\ b_{1,3}^{t}\ b_{1,4}\ G))^{-1}$ mod n] [$e'_1\ e'_2$ e'TOKEN].

[0171] Optional Add-On to Embodiment 6:

[0172] Within Embodiment 6 as well as other embodiments involving two or more rounds, the following assurance mechanism can be used if the Requestor supplies both Backends with the same eP, where the intent is that each Backend can verify whether the opposite Backend has operated within the first round, at least in part, by applying a scalar multiple known to it to eP:

[0173] For example, the Requestor supplies eP, ee_1 and ee_2 eP to Backend 1, and eP, ee_2 and eel eP to Backend 2, where information about ee_1 other than ee_1 eP is not supplied to Backend 2 and information about ee_2 other than ee_2 eP is not supplied to Backend 1. Backend 1 aborts performance of round-two computation upon [$Point_{2,1}$] if ee_1 [$Point_{2,1}$] [$Point_{2,2}$] for received values [$Point_{2,1}$] and [$Point_{2,2}$]. Analogously, Backend 2 aborts performance of round-two computation upon [$Point_{1,1}$] if ee_2 [$Point_{1,1}$] [$Point_{1,2}$] for received values [$Point_{1,1}$] and [$Point_{1,2}$]. The corresponding optional add-on for detokenization can be applied, whether or not the optional tokenization add-on has been applied during tokenization that resulted in the TOKEN values used during detokenization. The Requestor supplies e'TOKEN, ee'_1 and ee'_2 e'TOKEN to Backend 1, and e'TOKEN, ee'_2 and ee'_1 e'TOKEN to Backend 2. Note that there is a degree of similarity between this example of the optional add-on technique and the earlier-presented example of countermeasure (2).

[0174] Multiplex Extension/Alternative Embodiment 6:

[0175] Multiple TOKENs may be generated via a single run of the tokenization protocol if [eP] received from the Requestor by Backend 1 and Backend 2 for first-round processing is replaced by a sequence [eP_1, eP_2, . . . , eP_m] for some integer m greater than 1. More generally, in lieu of enabling the Requestor to verify that [$e_1\ e_2\ eP_1$, $e_1\ e_2\ eP_2$, . . . , $e_1\ e_2\ eP_m$]=[$e_2\ e_1\ eP_1$, $e_2\ e_1\ eP_2$, . . . , $e_2\ e_1\ eP_m$], the Requestor can distribute [eP_1, eP_k] for some non-negative integer k (where [eP_1, . . . , eP_0] is vacuous) to one of the Backends for it to act upon and return a result, and distribute [eP_{k+1}, . . . , eP_m] to the other Backend for it to act upon and return a result, for some positive integer m. Detokenization can be addressed analogously (using [e'$TOKEN_1$, . . . , e'$TOKEN_k$] and [e'$TOKEN_{k+1}$, . . . , e'$TOKEN_m$]), independently of if/how this technique was applied during tokenization.

[0176] Two mechanisms intended towards assuring traversal of Backend-generated ephemeral blinding factors across first and second rounds:

[0177] (i): In this example embodiment, hash-based message authentication code (HMAC) and encryption (Enc) keys are deterministically derived from each Backend's current Pohlig-Hellman values using a preferably NIST-approved key derivation function (KDF). Each Backend's HMAC keys for tokenization and detokenization are computationally independent of each other. This is also true of the symmetric Enc keys. When an HMAC value is generated, it is placed in that Backend's non-volatile storage and is deleted from that storage if/when that value is returned to it within the second round of the corresponding tokenization/detokenization. If a putative HMAC value returned to a

Backend does not appear in that Backend's storage, that Backend preferably aborts that round's computation. If a putative HMAC value returned to a Backend fails to verify over the inserted arguments (including those obtained by decrypting a received value putatively resulting from encryption using the Enc key), that Backend preferably aborts that round's computation. Each Backend's storage of HMAC values is erased upon onset of a new resplit interval. With regard to Embodiment 5 and Embodiment 6, arguments that are inserted for HMAC value computation can include, in particular, the purportedly current value of the ephemeral blinding factor e_1 or e_2, respectively.

[0178] (ii): Rather than the Backends sending HMAC values and/or Enc values and evaluating received values purported to be HMAC values and/or Enc values, values that need to traverse across multiple rounds can be derived via deterministic computation. As an example, Backend 1 generates e_1 as HKDF-Expand(K_1, info=[requestorID, t, eP], L) mod n [HKDF-Expand(K2, info=[requestorID, t, eP], L) mod n], where K_1 is a Pohlig-Hellman parameter-derived key derivation key. K_1 can be derived using HKDF-Extract. Alternatively, generation of K_1 and/or e_1 can utilize KMAC. Within the expansion, eP can be represented as the octet string comprising the x-coordinate of the point. HKDF-Expand generates L octets as output, where L is preferably at least 8 greater than the octet-length of n to reduce bias of e_1. The same key derivation key K_1 can be used for both tokenization and detokenization, e.g., if strings signifying "tokenization" and "detokenization" are added as respective arguments of HKDF-Expand or KMAC. The analogous formulation for detokenization is e_1=HKDF-Expand(K_1, info=[requestorID, t, e'TOKEN], L) mod n. A reference for Hash-based Key Derivation Function (HKDF) is https://doi.org/10.17487/RFC5869. A reference for KECCAK Message Authentication Code (KMAC) is https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-185.pdf.

[0179] Relevant to FIG. **14** and FIG. **16**, by one approach, at least one tokenization processor is used to generate a TOKEN and a KEY_TOKEN upon a request from a Requestor.

[0180] Referring now to FIG. **14**, stepping through a TOKEN-plus-KEY_TOKEN version of tokenization processing as an alternative to Embodiment 1, first the Requestor **1410** transmits an ephemerally blinded representation of Data, i.e., eP, to Backend 1 **1415** at **1425** and transmits eP to Backend 2 **1420** at **1430**. Backend 1 **1415** responds at **1435** with b_1 [eP] and d_1 [eP], and Backend 2 **220** responds at **240** with b_2 [eP] and d_2 [eP]. At **1445**, the Requestor **1410** performs two addition operations and two unblinding operations to derive TOKEN=e^{-1}([b_1 eP]+[b_2 eP])=(b_1+b_2)P and KEY_TOKEN=e^{-1}([d_1 eP]+[d_2 eP])=(d_1+d_2)P, respectively.

[0181] Relevant to FIG. **15** and FIG. **17**, by one approach, at least one tokenization processor is used to attempt recovery of a KEY_TOKEN from a purported TOKEN received from a Requestor that may or may not be the same as a Requestor that requested generation of the KEY_TOKEN. The tokenization processors that attempt recovery of the KEY_TOKEN may overlap with the tokenization processors that generated the TOKEN. The purported TOKEN may be submitted by the Requestor in blinded form as depicted FIG. **15** and FIG. **17**.

[0182] Referring now to FIG. **15**, stepping through a TOKEN-to-KEY_TOKEN version of detokenization processing as an alternative to Embodiment 1, first the Requestor **1510** transmits e'TOKEN, to Backend 1 **1515** at **1525** and transmits e'TOKEN to Backend 2 **1520** at **1530**. Backend 1 **1515** responds at **1535** with b'_1 [e'TOKEN], and Backend 2 **1520** responds at **1540** with b'_2 [e'TOKEN], where (b_1+b_2) (b'_1+b'_2)=(d_1+d_2) mod n. At **1445**, the Requestor **1410** performs an addition operation over the output of **1535** and the output of **1540** followed by an unblinding operation over the resultant sum to derive KEY_TOKEN=(b'_1+b'_2) (b_1+b_2)TOKEN=(d_1+d_2)P.

[0183] Referring now to FIG. **16**, stepping through a TOKEN-plus-KEY_TOKEN version of tokenization processing as an alternative to Embodiment 6, first the Requestor **1610** transmits eP to Backend 1 **1615** at **1625**, and transmits eP to Backend 2 **1620** at **1630**. Backend 1 **1615** responds at **1635** with e_1 [eP], e^+_1 [eP], $b_{1,3}{}^t$ $b_{1,4}$ G and $d_{1,3}{}^t$ $d_{1,4}$ G, and Backend 2 **1620** responds with e_2 [eP], e^+_2 [eP], $b_{2,5}{}^t$ $b_{2,6}$ G and $d_{2,5}{}^t$ $d_{2,6}$ G at **1640**, where e_1 and e^+_1 are ephemeral blinding factors generated by Backend 1 **1615** and e_2 and e^+_2 are ephemeral blinding factors generated by Backend 2 **1620**. This completes round-one processing by Backend 1 **1615** and Backend 2 **1620**. e_1 and e^+_1 may be identical or distinct and are preferably generated as discussed previously for generation of e_1. e_2 and e^+_2 may be identical or distinct and are preferably generated as discussed previously for generation of e_2. Using e_2 eP, e^+_2 eP, $b_{2,5}{}^t$ $b_{2,6}$ G and $d_{2,5}{}^t$ $d_{2,6}$ G received via **1645**, Backend 1 **1615** transmits e_1 [e_2 eP], e^+_1 [e^+_2 eP], ($e_1{}^{-1}$ $b_{1,1}{}^t$ $b_{1,2}$ hash($b_{1,5}{}^t$ $b_{1,6}$ [$b_{2,5}{}^t$ $b_{2,6}$ G])) mod n and ($e^+_1{}^{-1}$ $d_{1,1}{}^t$ $d_{1,2}$ hash($d_{1,5}{}^t$ $d_{1,6}$ [$d_{2,5}{}^t$ $d_{2,6}$ G])) mod n to the Requestor **1610** at **1655**, thus completing its role in round-two processing. Similarly, using e_1 eP, e^+_1 eP, $b_{1,3}{}^t$ $b_{1,4}$ G and $d_{1,3}{}^t$ $d_{1,4}$ G received via **1650**, Backend 2 **1620** transmits e_2 [e_1 eP], e^+_2 [e^+_1 eP], ($e_2{}^{-1}$ $b_{2,1}{}^t$ $b_{2,2}$ hash($b_{2,3}{}^t$ $b_{2,4}$ [$b_{1,3}{}^t$ $b_{1,4}$ G])) mod n and ($e^+_2{}^{-1}$ $d_{2,1}{}^t$ $d_{2,2}$ hash($d_{2,3}{}^t$ $d_{2,4}$ [$d_{1,3}{}^t$ $d_{1,4}$ G])) mod n to the Requestor **1610** at **1660**, thus completing its role in round-two processing. At **1665**, the Requestor **1610** verifies equality of the first output of **1655** and the first output of **1660**, and equality of the second output of **1655** and the second output of **1660**, respectively. Also at **1665**, the Requestor **1610** computes the product of: the third output of **1655**, the third output of **1660** and the first output of **1655**. The Requestor **1610** unblinds the resultant product to derive TOKEN=e^{-1} [($e_1{}^{-1}$ $b_{1,1}{}^t$ $b_{1,2}$ hash($b_{1,5}{}^t$ $b_{1,6}$ $b_{2,5}{}^t$ $b_{2,6}$ G))mod n] [($e_2{}^{-1}$ $b_{2,1}{}^t$ $b_{2,2}$ hash($b_{2,3}{}^t$ $b_{2,4}$ $b_{1,3}{}^t$ $b_{1,4}$ G)) mod n] [e_1 e_2 eP]=($b_{1,1}$ $b_{2,1}$)^t $b_{1,2}$ $b_{2,2}$ hash(($b_{1,3}$ $b_{2,3}$)^t $b_{1,4}$ $b_{2,4}$ G) hash(($b_{1,5}$ $b_{2,5}$)^t $b_{1,6}$ $b_{2,6}$ G) P. Further at **1665**, the Requestor **1610** computes the product of: the fourth output of **1655**, the fourth output of **1660** and the second output of **1655**. Finally at **1665**, the Requestor **1610** unblinds the resultant product to derive KEY_TOKEN=[e^{-1} [($e^+_1{}^{-1}$ $d_{1,1}{}^t$ $d_{1,2}$ hash($d_{1,5}{}^t$ $d_{1,6}$ $d_{2,5}{}^t$ $d_{2,6}$ G)) mod n] [($e^+_2{}^{-1}$ $d_{2,1}{}^t$ $d_{2,2}$ hash($d_{2,3}{}^t$ $d_{2,4}$ $d_{1,3}{}^t$ $d_{1,4}$ G)) mod n] [e^+_1 e^+_2 eP]=($d_{1,1}$ $d_{2,1}$)^t $d_{1,2}$ $d_{2,2}$ hash(($d_{1,3}$ $d_{2,3}$)^t $d_{1,4}$ $d_{2,4}$ G) hash(($d_{1,5}$ $d_{2,5}$)^t $d_{1,6}$ $d_{2,6}$ G) P.

[0184] Referring now to FIG. **17**, stepping through a TOKEN-to-KEY_TOKEN version of detokenization processing as an alternative to Embodiment 6, first the Requestor **1710** transmits e'TOKEN to Backend 1 **1715** at **1725**, and transmits e'TOKEN to Backend 2 **1720** at **1730**. Backend 1 **1715** responds at **1735** with e'_1 [e'TOKEN], $b_{1,3}{}^t$ $b_{1,4}$ G and $d_{1,3}{}^t$ $d_{1,4}$ G, and Backend 2 **1720** responds with e'_2 [e'TOKEN], $b_{2,5}{}^t$ $b_{2,6}$ G and $d_{2,5}{}^t$ $d_{2,6}$ G at **1740**, where e_1 is an ephemeral blinding factor generated by Backend 1 **1715** and e_2 is an ephemeral blinding factor generated by Backend

2 **1720**. This completes round-one processing by Backend 1 **1715** and Backend 2 **1720**. e'_1 and e'_2 are preferably generated as discussed previously for such parameters. Using e'_2 e'TOKEN, $b_{2,5}{}^{t}\ b_{2,6}$ G and $d_{2,5}{}^{t}\ d_{2,6}$ G received via **1745**, Backend 1 **1715** transmits e'_1 [e'_2 e'TOKEN] and $(e'_1{}^{-1}(b_{1,1}{}^{-1}\ d_{1,1})^{t}\ b_{1,2}{}^{-1}\ d_{1,2}\ (\text{hash}(b_{1,5}{}^{t}\ b_{1,6}\ [b_{2,5}{}^{t}\ b_{2,6}\ G]))^{-1}$ hash $(d_{1,5}{}^{t}\ d_{1,6}\ [d_{2,5}{}^{t}\ d_{2,6}\ G]))$ mod n to the Requestor **1710** at **1755**, thus completing its role in round-two processing. Similarly, using e'_1 e'TOKEN, $b_{1,3}{}^{t}\ b_{1,4}$ G and $d_{1,3}{}^{t}\ d_{1,4}$ G received via **1750**, Backend 2 **1720** transmits e'_2 [e'_1 e'TOKEN] and $(e'_2{}^{-1}(b_{2,1}{}^{-1}\ d_{2,1})^{t}\ b_{2,2}{}^{-1}\ d_{2,2}\ (\text{hash}(b_{2,3}{}^{t}\ b_{2,4}\ [b_{1,3}{}^{t}\ b_{1,4}\ G]))^{-1}$ hash$(d_{2,3}{}^{t}\ d_{2,4}\ [d_{1,3}{}^{t}\ d_{1,4}\ G]))$ mod n to the Requestor **1710** at **1760**, thus completing its role in round-two processing. At **1765**, the Requestor **1710** verifies equality of the first output of **1755** and the first output of **1760**. Also at **1765**, the Requestor **1710** computes the product of: the second output of **1755**, the second output of **1760** and the first output of **1755**. The Requestor unblinds the resultant product to recover $\text{KEY\_TOKEN}=e'^{-1}\ [(e'_1{}^{-1}\ [(b_{1,1}{}^{-1}\ d_{1,1})^{t}\ b_{1,2}{}^{-1}\ d_{1,2}\ (\text{hash}(b_{1,5}{}^{t}\ b_{1,6}\ [b_{2,5}{}^{t}\ b_{2,6}\ G]))^{-1}\ \text{hash}(d_{1,5}{}^{t}\ d_{1,6}\ [d_{2,5}{}^{t}\ d_{2,6}\ G]))^{-1}\ \text{mod n}]\ [(e'_2{}^{-1}(b_{2,1}{}^{-1}\ d_{2,1})^{t}\ b_{2,2}{}^{-1}\ d_{2,2}\ (\text{hash}\ (b_{2,3}{}^{t}\ b_{2,4}\ [b_{1,3}{}^{t}\ b_{1,4}\ G]))^{-1}\ \text{hash}(d_{2,3}{}^{t}\ d_{2,4}\ [d_{1,3}{}^{t}\ d_{1,4}\ G]))\ \text{mod n}]\ [e'_1\ e'_2\ e'\text{TOKEN}]=(d_{1,1}\ d_{2,1})^{t}\ d_{1,2}\ d_{2,2}\ \text{hash}((d_{1,3}\ d_{2,3})^{t}\ d_{1,4}\ d_{2,4}\ G)\ \text{hash}((d_{1,5}\ d_{2,5})^{t}\ d_{1,6}\ d_{2,6}\ G)P$.

[0185] Referring now to FIG. **18**, stepping through a token translation version of tokenization processing as a supplement to Embodiment 3 that results in a TOKEN under scope label t_{new} using a TOKEN under scope label t as input, first the Requestor **1810** transmits eTOKEN to Backend 1 **1815** at **1825**, and transmits eTOKEN to Backend 2 **1820** at **1830**. Backend 1 **1815** responds at **1835** with $b_{1,1}{}^{t_{new}-t}$ [eTOKEN] and $(b_{1,1}{}^{t}\ b_{1,2})^{-1}\ d_{1,1}{}^{t_{new}}\ d_{1,2}$ [eTOKEN], and Backend 2 **1820** responds with $b_{2,1}{}^{t_{new}-t}$ [eTOKEN] and $(b_{2,1}{}^{t}\ b_{2,2})^{-1}\ d_{2,1}{}^{t_{new}}\ d_{2,2}$ [eTOKEN] at **1840**. This completes round-one processing by Backend 1 **1815** and Backend 2 **1820**. Using $b_{2,1}{}^{t_{new}-t}$ eTOKEN and $(b_{2,1}{}^{t}\ b_{2,2})^{-1}\ d_{2,1}{}^{t_{new}}\ d_{2,2}$ eTOKEN received via **1845**, Backend 1 **1815** transmits $b_{1,1}{}^{t_{new}-t}$ [$b_{2,1}{}^{t_{new}-t}$ eTOKEN] and $(b_{1,1}{}^{t}\ b_{1,2})^{-1}\ d_{1,1}{}^{t_{new}}\ d_{1,2}\ [(b_{2,1}{}^{t}\ b_{2,2})^{-1}\ d_{2,1}{}^{t_{new}}\ d_{2,2}$ eTOKEN] to the Requestor **1810** at **1855**, thus completing its role in round-two processing. Similarly, using $b_{1,1}{}^{t_{new}-t}$ eTOKEN and $(b_{1,1}{}^{t}\ b_{1,2})^{-1}\ d_{1,1}{}^{t_{new}}\ d_{1,2}$ eTOKEN received via **1850**, Backend 2 **1820** transmits $b_{2,1}{}^{t_{new}-t}$ [$b_{1,1}{}^{t_{new}-t}$ eTOKEN] and $(b_{2,1}{}^{t}\ b_{2,2})^{-1}\ d_{2,1}{}^{t_{new}}\ d_{2,2}\ [(b_{1,1}{}^{t}\ b_{1,2})^{-1}\ d_{1,1}{}^{t_{new}}\ d_{1,2}$ eTOKEN] to the Requestor **1810** at **1860**, thus completing its role in round-two processing. At **1865**, the Requestor **1810** verifies equality of the first output of **1855** and the first output of **1860**, and verifies equality of the second output of **1855** and the second output of **1860**, respectively. Also at **1865**, the Requestor **1810** unblinds the first output of **1855** to derive $\text{TOKEN}_{new}=e^{-1}\ [b_{1,1}{}^{t_{new}-t}\ b_{2,1}{}^{t_{new}-t}\ \text{eTOKEN}]=(b_{1,1}\ b_{2,1})^{t_{new}-t}\ (b_{1,1}\ b_{2,1})^{t}\ b_{1,2}\ b_{2,2}\ P=(b_{1,1}\ b_{2,1})^{t_{new}}\ b_{1,2}\ b_{2,2}\ P$. Finally at **1865**, the Requestor **1810** unblinds the second output of **1855** and then applies a truncated hash function to the result of unblinding to derive $\text{checkBits}_{new}=\text{truncHash}(e^{-1}\ [(b_{1,1}{}^{t}\ b_{1,2})^{-1}\ d_{1,1}{}^{t_{new}}\ d_{1,2}\ (b_{2,1}{}^{t}\ b_{2,2})^{-1}\ d_{2,1}{}^{t_{new}}\ d_{2,2}\ \text{eTOKEN}])=\text{truncHash}((b_{1,1}{}^{t}\ b_{1,2})^{-1}\ d_{1,1}{}^{t_{new}}\ d_{1,2}\ (b_{2,1}{}^{t}\ b_{2,2})^{-1}\ d_{2,1}{}^{t_{new}}\ d_{2,2}\ (b_{1,1}\ b_{2,1})^{t}\ b_{1,2}\ b_{2,2}=\text{truncHash}((b_{1,1}\ b_{2,1})^{-1}\ (b_{1,1}\ b_{2,1})^{t}\ (b_{1,2}\ b_{2,2})^{-1}b_{1,2}\ b_{2,2}\ (d_{1,1}\ d_{2,1})^{t_{new}}\ d_{1,2}\ d_{2,2}\ P)=\text{truncHash}((d_{1,1}\ d_{2,1})^{t_{new}}\ d_{1,2}\ d_{2,2}\ P)$.

[0186] As an alternative to the processing depicted by FIG. **18**, an enhanced flow can be used to have Backend 1 and Backend 2 regenerate the original checkBits value associated with scope t as a check against a checkBits value submitted by the Requestor, where matching of the submitted and the recomputed checkBits values is used as a precondition of release by Backend 1 and Backend 2 of their round-two outputs.

[0187] Referring now to FIG. **19**, stepping through a token translation version of tokenization processing as a supplement to Embodiment 6 that results in a TOKEN under scope label t_{new} using a TOKEN under scope label t as input, first the Requestor **1910** transmits eTOKEN to Backend 1 **1915** at **1925**, and transmits eTOKEN to Backend 2 **1920** at **1930**. Backend 1 **1915** responds at **1935** with e_1 [eTOKEN], $b_{1,3}{}^{t}\ b_{1,4}$ G and $b_{1,3}{}^{t_{new}}\ b_{1,4}$ G, and Backend 2 **1920** responds with e_2 e[TOKEN], $b_{2,5}{}^{t}\ b_{2,6}$ G and $b_{2,5}{}^{t_{new}}\ b_{2,6}$ G at **1940**. This completes round-one processing by Backend **1915** and Backend 2 **1920**. Using e_2 eTOKEN, $b_{2,5}{}^{t}\ b_{2,6}$ G and $b_{2,5}{}^{t_{new}}\ b_{2,6}$ G received via **1945**, Backend 1 **1915** transmits e_1 [e_2 eTOKEN] and $e_1{}^{-1}\ b_{1,1}{}^{t_{new}-t}\ (\text{hash}(b_{1,5}{}^{t}\ b_{1,6}\ [b_{2,5}{}^{t}\ b_{2,6}\ G]))^{-1}$ hash$(b_{1,5}{}^{t_{new}}\ b_{1,6}\ [b_{2,5}{}^{t_{new}}\ b_{2,6}\ G])$ to the Requestor **1910** at **1955**, thus completing its role in round-two processing. Similarly, using e_1 eTOKEN, $b_{1,3}{}^{t}\ b_{1,4}$ G and $b_{1,3}{}^{t_{new}}\ b_{1,4}$ G received via **1950**, Backend 2 **1920** transmits e_2 [e_1 eTOKEN] and $e_2{}^{-1}\ b_{2,1}{}^{t_{new}-t}\ (\text{hash}(b_{2,3}{}^{t}\ b_{2,4}\ [b_{1,3}{}^{t}\ b_{1,4}\ G]))^{-1}$ hash$(b_{2,3}{}^{t_{new}}\ b_{2,4}\ [b_{1,3}{}^{t_{new}}\ b_{1,4}\ G])$ to the Requestor **1910** at **1960**, thus completing its role in round-two processing. At **1965**, the Requestor **1910** verifies equality of the first output of **1955** and the first output of **1960**. Also at **1965**, the Requestor **1910** computes the product of the second output of **1955**, the second output of **1960** and the first output of **1955**. Finally at **1965**, the Requestor **1910** unblinds the resultant product to derive $\text{TOKEN}_{new}=e^{-1}\ [(e_1{}^{-1}\ b_{1,1}{}^{t_{new}-t}\ (\text{hash}(b_{1,5}{}^{t}\ b_{1,6}\ b_{2,5}{}^{t}\ b_{2,6}\ G))^{-1}\ \text{hash}(b_{1,5}{}^{t_{new}}\ b_{1,6}\ b_{2,5}{}^{t_{new}}\ b_{2,6}\ G))\ \text{mod n}]\ [(e_2{}^{-1}\ b_{2,1}{}^{t_{new}-t}\ (\text{hash}(b_{2,3}{}^{t}\ b_{2,4}\ b_{1,3}{}^{t}\ b_{1,4}\ G))_{-1}\ \text{hash}\ (b_{2,3}{}^{t_{new}}\ b_{2,4}\ [b_{1,3}{}^{t_{new}}\ b_{1,4}\ G]))\ \text{mod n}]\ [e_1\ e_2\ \text{eTOKEN}]=b_{2,1})^{t_{new}-t}\ (\text{hash}((b_{1,5}\ b_{2,5})^{t}\ b_{1,6}\ b_{2,6}\ G))^{-1}\ \text{hash}((b_{1,5}\ b_{2,5})^{t_{new}}\ b_{1,6}\ b_{2,6}\ G)\ (\text{hash}((b_{1,3}\ b_{2,3})^{t}\ b_{1,4}\ b_{2,4}\ G))^{-1}\ \text{hash}((b_{1,3}\ b_{2,3})^{t_{new}}\ b_{1,4}\ b_{2,4}\ G)\ (b_{1,1}\ b_{2,1})^{t}\ b_{1,2}\ b_{2,2}\ \text{hash}((b_{1,3}\ b_{2,3})^{t}\ b_{1,4}\ b_{2,4}\ G)\ \text{hash}((b_{1,5}\ b_{2,5})^{t}\ b_{1,6}\ b_{2,6}\ G)\ P=(b_{1,1}\ b_{2,1})^{t_{new}}\ b_{1,2}\ b_{2,2}\ \text{hash}\ ((b_{1,3}\ b_{2,3})^{t_{new}}\ b_{1,4}\ b_{2,4}\ G)\ \text{hash}((b_{1,5}\ b_{2,5})^{t_{new}}\ b_{1,6}\ b_{2,6}\ G)\ P$.

[0188] Relevant to FIG. **20** with the resultant tokenization processor secrets usable for tokenization as depicted in FIG. **2** and FIG. **4**, and detokenization as depicted in FIG. **3** and FIG. **5**, by one approach, a third party sets up a plurality of tokenization processors, wherein the third party computes an inverse of a first sum of first tokenization processor secrets and splits, preferably randomly, the inverse as a second sum, that is distinct from the first sum, of second tokenization processor secrets. Moreover, the third party transmits at least one of the first tokenization processor secrets and at least one of the second tokenization processor secrets to a first tokenization processor, and does not transmit these tokenization processor secrets to a second tokenization processor. The third party also transmits to the second tokenization processor at least one of the first tokenization processor secrets that differs from tokenization processor secrets that are sent to the first tokenization processor, and at least one of the second tokenization processor secrets that differs from tokenization processor secrets that are sent to the first tokenization processor. Further, at least one of the tokenization processor secrets used by the first tokenization processor for tokenization processing, as derived from the tokenization processor secrets received by the first tokenization processor from the third party is different than at least one of the tokenization processor secrets used by the second tokenization processor for tokenization processing, as

derived from the tokenization processor secrets received by the second tokenization processor from the third party.

[0189] Referring now to FIG. **20**, 3rd party **2030** (aka third party), communicates with Backend 1 **2010** and Backend 2 **2020** in order to execute its role in third-party setup usable, in particular, for Embodiment 1 tokenization and detokenization as depicted in FIG. **2** and FIG. **3**, respectively (where $(b'_1+b'_2)$ (b_1+b_2)=1 mod n), and for Embodiment 2 tokenization and detokenization as depicted in FIG. **4** and FIG. **5**, respectively (where $(b'_{1,2}+b'_{2,2})$ $(b_{1,2}+b_{2,2})$=1 mod n). At **2035**, 3rd party **2030** generates initial tokenization processor secrets b_1 and b_2, and computes their modulo n sum at **2040**. At **2045**, 3rd party **2030** inverts the sum and splits it into initial tokenization processor secrets b'_1 and b'_2. The distribution of b_1 and b'_1 to Backend 1 **2010**, and of b_2 and b'_2 to Backend 2 **2020** is depicted at **2050** and **2055**, respectively. At **2060**, Backend 1 **2010** and Backend 2 **2020** agree on parameters m, j and k that preferably are not exposed to 3rd party **2030**. At **2065**, Backend 1 **2010** uses j to resplit the initial collective secret (b_1+b_2) mod n into b_1+j and b_2−j, and uses m as a multiplier so that the new value of (b_1+b_2) mod n is preferably independent of the initial value of (b_1+b_2) mod n that was and may still be available to 3rd party **2030**. The value of m cannot be reconstructed by potential collusion between 3rd party **2030** and either Backend 1 **2010** (using the initial value of b_1 and the new value of b_1) or Backend 2 **2020** (using the initial value of b_2 and the new value of b_2) once the value of j is no longer accessible because it has been deleted. Similarly at **2065**, Backend 1 **2010** uses k to resplit $(b'_1+b'_2)$ mod n and m^{-1} to preferably render the new value of $(b'_1+b'_2)$ independent of its initial value. m^{-1} is used in order to preserve the equality: $(b'_1+b'_2)$ (b_1+b_2)=1 mod n. At **2070**, the operations analogous to those of **2065** are carried out by Backend 2 **2020**. At **2075**, Backend 1 **2010** stores the new values of b_1 and b'_1. At **2080**, Backend 2 **2020** stores the new values of b_2 and b'_2.

[0190] Relevant to FIG. **21**, by one approach, a third party sets up a plurality of tokenization processors, wherein the third party computes an inverse of a first sum of first tokenization processor secrets, and derives a value from the inverse and from second tokenization processor secrets. The third party then splits that value, preferably randomly, as a second sum of second tokenization processor secrets that is distinct from the first sum. Further, the first tokenization processor secrets and the second tokenization processor secrets differ in at least one tokenization processor secret.

[0191] Referring now to FIG. **21**, 3rd party **2130** (aka third party), communicates with Backend 1 **2110** and Backend 2 **2120** in order to execute its role in third-party setup usable, in particular, for TOKEN-plus-KEY_TOKEN alternative version of Embodiment 1 tokenization processing as depicted in FIG. **14**, and TOKEN-to-KEY_TOKEN alternative version of detokenization processing depicted in FIG. **15**, respectively (where (b_1+b_2) $(b'_1+b'_2)$=(d_1+d_2) mod n). At **2135**, 3rd party **2130** generates initial tokenization processor secrets b_1, b_2, d_1 and d_2 and determines the modulo n product of the inverse of the sum of b_1 and b_2 and the sum of di and d_2 at **2140**. At **2145**, 3rd party **2130** splits the resultant product of **2140** into initial tokenization processor secrets b'_1 and b'_2. The distribution of b_1, d_1 and b'_1 to Backend 1 **2110**, and of b_2, d_2 and b'_2 to Backend 2 **2120** is depicted at **2150** and **2155**, respectively. At **2160**, Backend 1 **2110** and Backend 2 **2120** agree on parameters m, m', j, j' and k that preferably are not exposed to 3rd party **2130**. At **2165**, Backend 1 **2110** uses j to resplit the initial collective secret (b_1+b_2) mod n into b_1+j and b_2−j, and uses m as a multiplier so that the new value of (b_1+b_2) mod n is preferably independent of the initial value of (b_1+b_2) mod n that was and may still be available to 3rd party **2130**. The value of m cannot be reconstructed by potential collusion between 3rd party **2130** and either Backend 1 **2110** (using the initial value of b_1 and the new value of b_1) or Backend 2 **2120** (using the initial value of b_2 and the new value of b_2) once the value of j is no longer accessible because it has been deleted. Similarly at **2165**, Backend 1 **2110** uses j' to resplit (d_1+d_2) mod n and m' to preferably render the new value of (d_1+d_2) independent of its initial value. Further at **2165**, Backend 1 **2110** uses k to resplit $(b'_1+b'_2)$ mod n and $m^{-1}m'$ to preferably render the new value of $(b'_1+b'_2)$ independent of its initial value. $m^{-1}m'$ is used in order to preserve the equality: $(b_1+b_2)+b'_2)=(d_1+d_2)$ mod n). At **2170**, the operations analogous to those of **2165** are carried out by Backend 2 **2120**. At **2175**, Backend 1 **2010** stores the new values of b_1, d_1 and b'_1. At **2180**, Backend 2 **2120** stores the new values of b_2, d_2 and b'_2.

[0192] The following algorithm expresses an example embodiment of deriving an elliptic curve point P from Data as source for use with direct tokenization of Data:

[0193] Below, Data_len_var is the field (of byte-length denoted by Data_len_var length) that indicates the value of Data_len (which denotes the byte-length of the input Data).

[0194] 1. Convert the Data_len to a fixed-length byte string (with a length of 1 byte).

[0195] 2. Determine rand_len in bytes by computing (for example elliptic curves P-256, P-384 and P-521, respectively):

[0196] a. For P-256: rand_len=32−Data_len−(Data_len_var length).

[0197] b. For P-384: rand_len=48−Data_len−(Data_len_var length).

[0198] c. For P-521: rand_len=66−Data_len−(Data_len_var length).

[0199] Preferably, rand_len is at least 8 bytes.

[0200] 3. Use HKDF-Extract to generate rand and truncate it to rand_len bytes:

[0201] a. rand=HKDF-Extract(salt=counter, input keying material (IKM)=Data), where counter=0 on the first run and is incremented with each successive run.

[0202] b. rand_trun=truncate(rand, rand_len).

[0203] 4. Use HKDF-Expand to generate vector where rand_trun is the input keying material and the vector length is the Data_len:

[0204] a. vector=HKDF-Expand(rand_trun, key length=Data_len).

[0205] 5. Compute Data xor=Data.XOR. vector.

[0206] 6. Concatenate rand_trun, Data_xor and Data_len_var, and convert the resultant bytes to an integer to derive x_0:

[0207] a. x_0=(rand_trun||Data_xor||Data_len_var).

[0208] 7. Determine if $((x\_0)^3-3x\_0+b)$ (mod p) is a quadratic residue, say y^2 (mod p). If not, increment counter and do steps 4 through 7 over. Once a valid x_0 is found, define x_found=x_0. Note that there are (p+1)/2 quadratic residues (including 0). Therefore, since every time an x_0 is tried there is ½+½p~½ chance that x_0 yields a quadratic residue, this loop should not be extensive.

[0209] a. The following check should preferably be added in order to avoid bias: Reject any candidate x-coordinate values that involve modulo p wrap-around, i.e., for which $2^{256}>x\_0>p-1$. This bias-avoidance technique has a negligible impact on computation time. The proof here shows the probability of getting a value that does not pass this check on the first try is extremely low in the case of P-256. This proof is also described in U.S. Pat. No. 11,374,910. Although not further described herein, the method for determining this probability is the same for curves P-224, P-384, and P-521, with analogous results.

[0210] i. $2^{-33}=2^{223}/2^{256}<(2^{256}-p)/2^{256}=(2^{256}-(2^{256}-2^{224}+2^{192}+2^{96}-1)/2^{256}<2^{224}/2^{256}=2^{-32}$.

[0211] 8. Denote by y_found the smaller of y and −y reduced mod p, such that

[0212] a. $(y^2=(x\_found)^3-3x\_found+b) \pmod p$.

[0213] 9. The point P is defined as (x_found, y_found).

[0214] Referring now to FIG. **22** that encapsulates the steps above for generating P from Data as flow **2200**: at **2205**, rand is generated from Data and the current counter value that can be initialized at, say, 0. At **2210**, rand is truncated to rand_len bytes. At **2215**, vector is generated by expanding the resultant value of **2210** to the length of Data. At **2220**, vector is exclusive-or added to Data. At **2225**, an x-coordinate is formed to generate a candidate value of P. At **2230**, the candidate value of P is checked for its validity as a point on the intended elliptic curve. Then, either the flow advances to **2235** or the counter value is incremented and fed back into **2205**.

[0215] Referring now to FIG. **23** that depicts flow **2300**, an alternative decision tree for elliptic curve point generation is depicted, where counter is removed from HKDF-Extract as an input to the optional "salt" field and placed instead in HKDF-Expand as an input to the optional "info" field. At **2305**, rand is generated from Data. At **2310**, rand is truncated to rand_len bytes. At **2315**, vector is generated by expanding the resultant value of **2310** to the length of Data, using the current counter value that can be initialized at, say, 0. At **2320**, vector is exclusive-or added to Data. At **2325**, an x-coordinate is formed to generate a candidate value of P. At **2330**, the candidate value of P is checked for its validity as a point on the intended elliptic curve. Then, either the flow advances to **2335** or the counter value is incremented at **2340** and fed back into **2315**.

[0216] An example recovery procedure to extract Data from elliptic curve point P is presented below as corresponding to the algorithm depicted in FIG. **22** for the generation of P:

[0217] The x-coordinate of P, as an integer, is converted to bytes, where this byte string is denoted as x.

[0218] 1. Determine rand_trun and Data_xor based on x=(rand trun||Data_xor||Data_len_var), where Data_len_var is the field (of byte-length denoted by Data_len_var length) that indicates the value of Data_len.

[0219] 2. Use HKDF-Expand to generate vector=HKDF-Expand(rand_trun, Data_len).

[0220] 3. Data=Data_xor.XOR. vector.

[0221] 4. Integrity check (optional): An integrity check may be executed here by computing rand'=HKDF-Extract(counter, Data) using the recovered value of Data and checking for a match of the proper truncation of the resultant rand' value against the value in the rand_trun field. The value of counter is incremented until there is a successful match and/or a preset limit on tries has been reached. NOTE: Dependent on the use-case specifics such as pertaining to the adversarial model, an internal redundancy check on the recovered Data may potentially be used instead of or in addition to the rand'-based integrity check.

[0222] Note that the choice of whether to insert the counter value into the HKDF-Extract operation vs. the HKDF-Expand operation has bearing on the integrity verification process, which comprises recomputing the truncated rand value from recovered Data and checking for a match against the truncated rand field. Note also that if the counter value is incorporated into HKDF-Expand, then successful recovery of Data relies on choosing the correct value of counter, since such recovery is dependent on the Data.XOR. vector field where recovery of vector is as an output of HKDF-Expand. Verifying such choices of counter may involve checking for internal redundancy of the instances of recovered Data. Further, the counter value affects integrity verification processing even if the counter value is not incorporated into HKDF-Extract, in that recovered Data is an input to HKDF-Extract. In alternative embodiments, the counter value may instead be incorporated as an explicit field. An integrity verification process may be considered optional in some configurations. In the non-deterministic sub-case, rand may be randomly or pseudorandomly generated if a self-contained integrity check feature is not required. Alternatively, if an integrity check feature is required, the truncated rand field entry can, for example, be populated by a randomly or pseudorandomly generated prefix of appropriate bit-length concatenated with a preset-length truncated hash of a value that comprises a concatenation of the prefix and Data.

[0223] The following algorithm expresses an example embodiment of deriving an elliptic curve point P from Data as source for use with TOKEN-and-KEY_TOKEN-based tokenization:

[0224] Generate point P on the elliptic curve from Data:

[0225] 1. Concatenate the following and turn the bytes into an integer to get x_0:

[0226] a. x_0=hash(Data||Pad) where Pad is a string of pre-set length using, say, all zeroes on the first run and is incremented with each successive run.

[0227] 2. Determine if $((x\_0)^3-3x\_0+b) \pmod p$ is a quadratic residue, say $y^2 \pmod p$. If not, increment Pad and repeat steps 1 and 2. Once a valid x_0 is found, define x_found=x_0.

[0228] a. There are (p+1)/2 quadratic residues (including 0). Therefore, every time an x_0 is tried there is ½+½p~½ chance that x_0 yields a quadratic residue, which implies that this loop should not be extensive.

[0229] b. Preferably, the following additional check is added in order to avoid bias: Reject any candidate x-coordinate values that involve modulo p wrap-around, i.e., for which $2^{256}>x\_0>p-1$. This bias-avoidance technique has a negligible impact on computation time as discussed in U.S. Pat. No. 11,374,910.

[0230] 3. Denote by y_found the smaller of y and −y reduced mod p, such that

[0231] a. $y^2=((x\_found)^3-3x\_found+b) \pmod p$.

[0232] The point P is now defined as (x_found, y_found).

[0233] Referring now to FIG. **24** that encapsulates the steps above for generating P from Data as flow **2400**: At **2405**, a candidate x-coordinate is generated from Data using a Pad value, that may be initialized as, say, a string of all zeroes. At **2410**, the x-coordinate generated at **2405** is tested for its validity as corresponding to a point on the intended elliptic curve. If yes, then advance to **2415**. If no, then increase the value of Pad and return to **2405**.

[0234] Following tokenization: The Requestor uses KEY_TOKEN as an input to HKDF to derive rand, key (as encryption key) and nonce (as initialization vector (IV)) used to encrypt the Data. Encrypt plaintext that incorporates, at least, Data with AES-CTR mode using the key and nonce to derive ciphertext. (Optional) integrity check: an integrity check may be enabled here for the recovery by using, for example, AES-GCM authenticated encryption as opposed to AES-CTR mode.

[0235] Following detokenization: Decrypt the ciphertext with the key and nonce to recover (rand||Data||Data_len_var), and thus recover Data. If AES-GCM is used to encrypt, then the generated Authentication Tag is usable to verify the integrity of Data.

[0236] The encryption in the symmetric-key case can be handled via various methods, such as, for example, using AES-GCM mode if authenticated encryption is desired, or using AES-CTR mode otherwise. The AES (or other encryption engine-) symmetric key and Initialization Vector (also denoted as a nonce) can be derived from a KEY_TOKEN using a key derivation method such as HKDF. Alternatively, HKDF or (potentially truncated) hash can be applied to a KEY_TOKEN with the result exclusive-or added to a value that can comprise, for example, [TruncatedHash(Data)||Data||Data bit-length], where || denotes concatenation and TruncatedHash(Data) as a truncation of hash(Data) can be eliminated if an integrity check is not required and/or Data bit-length can be eliminated if the bit-length of Data is not considered sensitive and thus there is no need to pad out to constant length. Note that the function of KEY_TOKEN (whether computed using HKDF, a hash function, or other method) can be configured so that its bit-length matches that of the function of Data that it is exclusive-or added to. In the deterministic sub-case, the generation of KEY_TOKEN (and of TOKEN from which KEY_TOKEN is derived upon a recovery operation) can be based, for example, on hash (Data pad) as (or similarly as) described in U.S. Pat. No. 11,374,910. In the non-deterministic sub-case, the generation of KEY_TOKEN (and of Token from which KEY_TOKEN is derived upon a recovery operation) can instead be based, for example, on hash(random/pseudorandom

[0237] Those skilled in the art will recognize that a wide variety of modifications, alterations, and combinations can be made with respect to the above-described embodiments without departing from the scope of the invention, and that such modifications, alterations, and combinations are to be viewed as being within the ambit of the inventive concept.

What is claimed is:

1. A method for tokenization, as a process resulting in at least one reversible token, using a plurality of control circuits wherein each of the control circuits is configured as a tokenization processor that communicates with a requesting network element acting as a requestor, the method comprising:

setting up by a third party of a plurality of tokenization processors, wherein the setting up comprises, at least in part, computation by the third party of an inverse of a first sum of first tokenization processor secrets and randomized splitting of the inverse as a second sum of second tokenization processor secrets, and wherein the first sum and second sum are distinct from one another;

transmitting third tokenization processors secrets comprising at least one of the first tokenization processor secrets and at least one of the second tokenization processor secrets to a first tokenization processor of the plurality of tokenization processors, and transmitting fourth tokenization processor secrets comprising at least one of the first tokenization processor secrets and at least one of the second tokenization processor secrets to a second tokenization processor of the plurality of tokenization processors, wherein the first tokenization processor and the second tokenization processor differ from one another, the third tokenization processor secrets include at least one of the at least one of the first tokenization processor secrets and at least one of the at least one of the second tokenization processor secrets not included within the fourth tokenization processor secrets, and the fourth tokenization processor secrets include at least one of the at least one of the first tokenization processor secrets and at least one of the at least one of the second tokenization processor secrets not included within the third tokenization processor secrets; and

generating by at least the first tokenization processor and the second tokenization processor at least one reversible token, wherein the generating entails use by the first tokenization processor of at least one tokenization processor secret derived from the third tokenization processor secrets and use by the second tokenization processor of at least one tokenization processor secret derived from the fourth tokenization processor secrets, wherein the at least one tokenization processor secret derived from the third tokenization processor secrets and the at least one tokenization processor secret derived from the fourth tokenization processor secret secrets differ from one another.

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

enabling role-based access control via cryptographic isolation of scopes from one another as based on assignment of distinct scope-specific tokenization processor secrets, wherein each such scope-specific tokenization processor secret is updateable without affecting values of the reversible tokens that are generated jointly by at least two distinct tokenization processors of the plurality of tokenization processors using one or more of the scope-specific tokenization processor secrets of each tokenization processor of the at least two distinct tokenization processors.

3. A method for tokenization, as a process resulting in at least one reversible token, using at least one control circuit configured as a tokenization processor that communicates with a requesting network element acting as a requestor, the method comprising: generating, by at least a first tokenization processor, at least one pair comprising a reversible token and a cryptographic integrity token; and

attempted matching of a first cryptographic integrity token, of a first pair comprising a purported first reversible token and a purported first cryptographic integrity token that is submitted by the requesting network element, by at least a second tokenization processor against a second cryptographic integrity token that is derived from the purported first reversible token by at least a third tokenization processor, wherein the purported first reversible token may be submitted in blinded form or unblinded form, wherein the at least a first tokenization processor, the at least a second tokenization processor and the at least a third tokenization processor may differ in their inclusion of tokenization processors.

4. A method for tokenization, as a process resulting in at least one pair comprising a token and a key token, using at least one control circuit configured as a tokenization processor that communicates with requesting network elements each acting as a requestor, the method comprising:

generating, by at least one tokenization processor, at least the one pair; and

deriving cryptographic keying material from at least the key token by a first requesting network element of the requesting network elements each acting as a requestor, and recovering the cryptographic keying material from at least the key token by a second requesting network element of the requesting network elements each acting as a requestor, wherein the key token is regenerated during detokenization, with the generating and the detokenization each using one or more tokenization processors of the at least one control circuit configured as a tokenization processor, and wherein the first requesting network element may differ from the second requesting network element.

5. The method of claim **4** further comprising:

setting up, by a third party, a plurality of tokenization processors, wherein the setting up comprises, at least in part, computation of an inverse of a first sum of first tokenization processor secrets and randomized splitting of a value derived from the inverse and from second tokenization processor secrets as a second sum of second tokenization processor secrets, and wherein the first sum and the second sum are distinct from one another and the first tokenization processor secrets and the second tokenization processor secrets differ in at least one tokenization processor secret.

6. A method for tokenization, as a process resulting in at least one reversible token, using at least a first control circuit configured as a first tokenization processor and a second control circuit configured as a second tokenization processor that is different than the first tokenization processor, wherein the first tokenization processor and the second tokenization processor communicate with a first requesting network element acting as a first requestor, the method comprising:

embedding by the first tokenization processor and the second tokenization processor of a first set of one or more role-based access control scope parameters and a second set of tokenization processor secrets into a first reversible token of the at least one reversible token, wherein the first reversible token remains invariant under updating of the tokenization processor secrets across the first tokenization processor and the second tokenization processor.

7. The method of claim **6** further comprising:

detokenization wherein successful detokenization relies on matching a third set of one or more role-based access control scope parameters embedded during the detokenization against the first set of one or more role-based access control scope parameters.

8. The method of claim **6** further comprising:

extracting ciphertext from at least one of the at least one reversible token that is consistent with format of source data input to the tokenization, wherein when a first source data input is distinct from a second data input, resultant first ciphertext and second ciphertext are distinct from one another.

9. The method of claim **6** further comprising:

generating at least one of the at least one reversible token, at least in part, via combining by the first requestor of at least:

source data input that is supplied by the first requestor in ephemerally blinded form, blinded using a first blinding factor that is independently generated by the first requestor, and that is further ephemerally blinded by the first tokenization processor via a second blinding factor that is independently generated by the first tokenization processor, and that is further ephemerally blinded by the second tokenization processor via a third blinding factor that is independently generated by the second tokenization processor;

a scope-dependent first output of the first tokenization processor that is invariant of the source data input and of the first blinding factor; and

a scope-dependent second output of the second tokenization processor that is invariant of the source data input and of the first blinding factor;

wherein the first output is computed as: a first function of the second blinding factor; and

a second function of tokenization processor secrets that include at least one tokenization processor secret of the first tokenization processor and at least one tokenization processor secret of the second tokenization processor;

and wherein the second output is computed as: a third function of the third blinding factor; and a fourth function of the tokenization processor secrets that include at least one tokenization processor secret of the first tokenization processor and at least one tokenization processor secret of the second tokenization processor; and

wherein the first output and the second output are distinct from one another.

10. The method of claim **9** further comprising:

detokenization effected via analogous combining based on input that includes at least one of the at least one reversible token rather than on input that includes source data.

11. An apparatus for tokenization, configured to carry out a process resulting in at least one reversible token, wherein the apparatus comprises:

a plurality of network interfaces;

a plurality of control circuits each operably coupled to one of the network interfaces wherein each of the control circuits is configured as a tokenization processor that communicates with a requesting network element acting as a requestor, wherein the plurality of control circuits is further configured:

to respond to setting up by a third party of a plurality of tokenization processors, wherein the setting up comprises, at least in part, computation by the third party of an inverse of a first sum of first tokenization processor secrets and randomized splitting of the inverse as a second sum of second tokenization processor secrets, and wherein the first sum and second sum are distinct from one another;

to receive third tokenization processor secrets comprising at least one of the first tokenization processor secrets and at least one of the second tokenization processor secrets by a first tokenization processor of the plurality of tokenization processors, and to receive fourth tokenization processor secrets comprising at least one of the first tokenization processor secrets and at least one of the second tokenization processor secrets by a second tokenization processor of the plurality of tokenization processors, wherein the first tokenization processor and the second tokenization processor differ from one another, the third tokenization processor secrets include at least one of the at least one of the first tokenization processor secrets and at least one of the at least one of the second tokenization processor secrets not included within the fourth tokenization processor secrets, and the fourth tokenization processor secrets include at least one of the at least one of the first tokenization processor secrets and at least one of the at least one of the second tokenization processor secrets not included within the third tokenization processor secrets; and

to generate, as a generating operation, by at least the first tokenization processor and the second tokenization processor at least one reversible token, wherein the generating operation entails use by the first tokenization processor of at least one tokenization processor secret derived from the third tokenization processor secrets and use by the second tokenization processor of at least one tokenization processor secret derived from the fourth tokenization processor secrets, wherein the at least one tokenization processor secret derived from the third tokenization processor secrets and the at least one tokenization processor secret derived from the fourth tokenization processor secret secrets differ from one another.

12. The apparatus of claim **11** further comprising:

cryptographic isolation of scopes from one another as based on assignment of distinct scope-specific tokenization processor secrets enables role-based access control, wherein each such scope-specific tokenization processor secret updates without affecting values of the reversible tokens that are generated jointly by at least two distinct tokenization processors of the plurality of tokenization processors using one or more of the scope-specific tokenization processor secrets of each tokenization processor of the at least two distinct tokenization processors.

13. An apparatus for tokenization, configured to carry out a process resulting in at least one reversible token, wherein the apparatus comprises:

at least one network interface;

at least one control circuit each operably coupled to one of the at least one network interface wherein each of the at least one control circuit is configured as a tokenization processor that communicates with a requesting network element acting as a requestor, wherein the at least one control circuit is further configured:

to generate, by at least a first tokenization processor, at least one pair comprising a reversible token and a cryptographic integrity token; and

to attempt matching of a first cryptographic integrity token, of a first pair comprising a purported first reversible token and a purported first cryptographic integrity token that is submitted by the requesting network element, by at least a second tokenization processor against a second cryptographic integrity token that is derived from the purported first reversible token by at least a third tokenization processor, wherein the purported first reversible token may be submitted in blinded form or unblinded form, wherein the at least a first tokenization processor, the at least a second tokenization processor and the at least a third tokenization processor may differ in their inclusion of tokenization processors.

14. An apparatus for tokenization, configured to carry out a process resulting in at least one pair comprising a token and a key token, wherein the apparatus comprises:

at least one network interface;

at least one control circuit each operably coupled to one of the at least one network interface wherein each of the at least one control circuit is configured as a tokenization processor that communicates with requesting network elements each acting as a requestor, wherein the apparatus is further configured:

to generate during the tokenization, by at least one tokenization processor, at least the one pair; and

to derive cryptographic keying material from at least the key token by a first requesting network element of the requesting network elements each acting as a requestor, and to recover the cryptographic keying material from at least the key token by a second requesting network element of the requesting network elements each acting as a requestor, wherein the key token is regenerated during detokenization, with the tokenization and the detokenization each using one or more tokenization processors of the at least one control circuit configured as a tokenization processor, and wherein the first requesting network element may differ from the second requesting network element.

15. The apparatus of claim **14** further comprising:

a third party sets up, as a setting up operation, a plurality of tokenization processors, wherein the setting up operation comprises, at least in part, computation of an inverse of a first sum of first tokenization processor secrets and randomized splitting of a value derived from the inverse and from second tokenization processor secrets as a second sum of second tokenization processor secrets, and wherein the first sum and the second sum are distinct from one another and the first tokenization processor secrets and the second tokenization processor secrets differ in at least one tokenization processor secret.

16. An apparatus for tokenization, configured to carry out a process resulting in at least one reversible token, wherein the apparatus comprises:

at least one network interface;

at least a first control circuit configured as a first tokenization processor operably coupled to one of the at least one network interface, and at least a second control

circuit configured as a second tokenization processor that is different than the first tokenization processor wherein the first tokenization processor and the second tokenization processor communicate with a first requesting network element acting as a first requestor, and wherein the at least a first control circuit and the at least a second control circuit are further configured:

to embed, by the first tokenization processor and the second tokenization processor, a first set of one or more role-based access control scope parameters and a second set of tokenization processor secrets into a first reversible token of the at least one reversible token, wherein the first reversible token remains invariant under updating of the tokenization processor secrets across the first tokenization processor and the second tokenization processor.

17. The apparatus of claim **16** further comprising:

The first tokenization processor and the second tokenization processor detokenizes, as a detokenization operation, wherein success of the detokenization operation relies on matching a third set of one or more role-based access control scope parameters embedded during the detokenization against the first set of one or more role-based access control scope parameters.

18. The apparatus of claim **16** further comprising:

the first requestor extracts ciphertext from at least one of the at least one reversible token that is consistent with format of source data input to the tokenization, wherein when a first source data input is distinct from a second data input, resultant first ciphertext and second ciphertext are distinct from one another.

19. The apparatus of claim **16** further comprising:

the first requestor generates at least one of the at least one reversible token, at least in part, via combining of at least:

source data input that is supplied by the first requestor in ephemerally blinded form, blinded using a first blinding factor that is independently generated by the first requestor, and that is further ephemerally blinded by the first tokenization processor via a second blinding factor that is independently generated by the first tokenization processor, and that is further ephemerally blinded by the second tokenization processor via a third blinding factor that is independently generated by the second tokenization processor;

a scope-dependent first output of the first tokenization processor that is invariant of the source data input and of the first blinding factor; and

a scope-dependent second output of the second tokenization processor that is invariant of the source data input and of the first blinding factor;

wherein the apparatus computes the first output as: a first function of the second blinding factor; and a second function of tokenization processor secrets that include at least one tokenization processor secret of the first tokenization processor and at least one tokenization processor secret of the second tokenization processor;

and wherein the apparatus computes the second output as: a third function of the third blinding factor; and a fourth function of the tokenization processor secrets that include at least one tokenization processor secret of the first tokenization processor and at least one tokenization processor secret of the second tokenization processor; and

wherein the first output and the second output are distinct from one another.

20. The apparatus of claim **19** further comprising:

the first requestor effects detokenization by analogously combining based on input that includes at least one of the at least one reversible token rather than on input that includes source data.

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