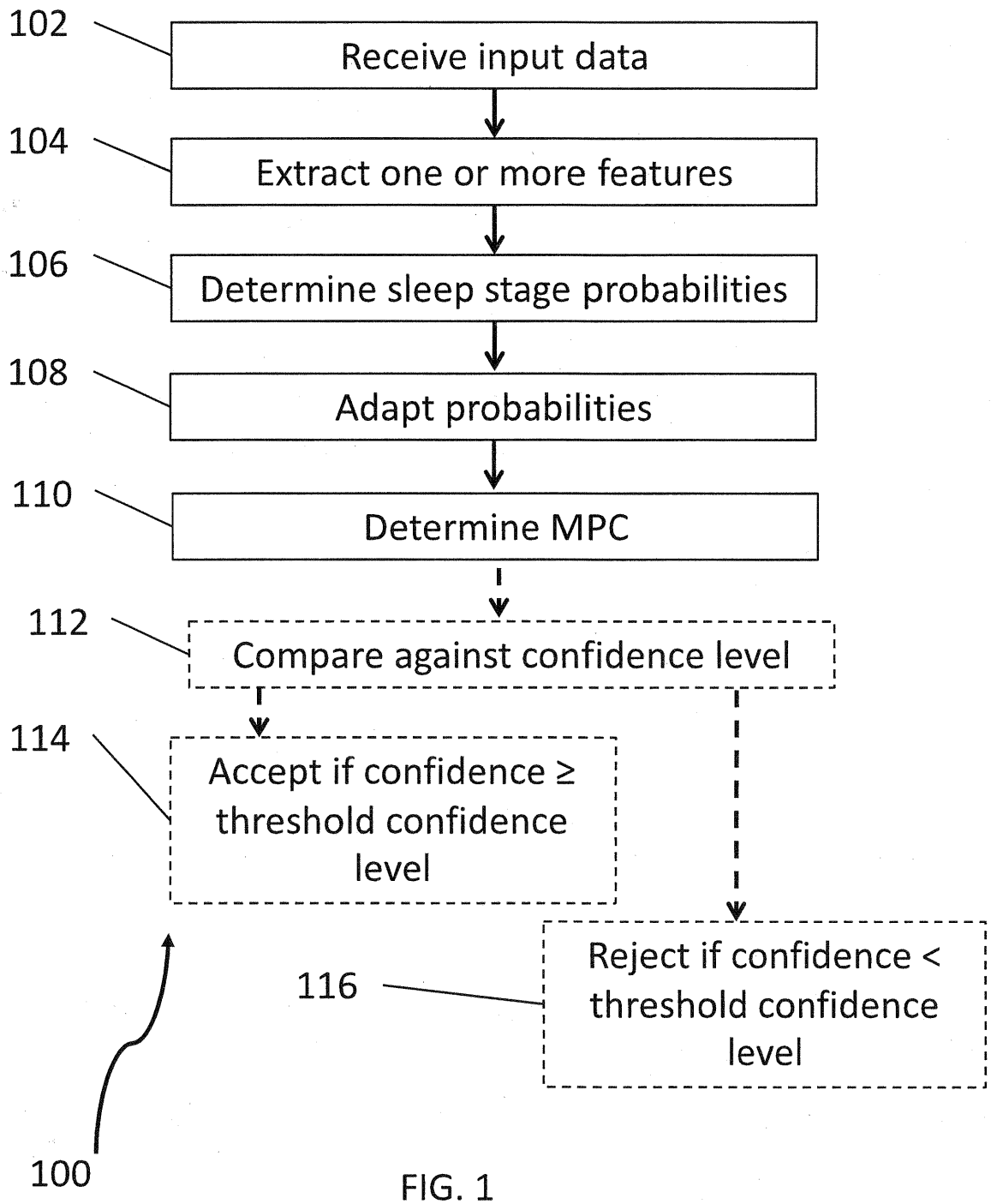

102
Receive input data
104
Extract one or more features
106
Determine sleep stage probabilities
108
Adapt probabilities
110
Determine MPC
112
Compare against confidence level
114
Accept if confidence ≥ threshold confidence level
116
Reject if confidence < threshold confidence level
100

FIG. 1

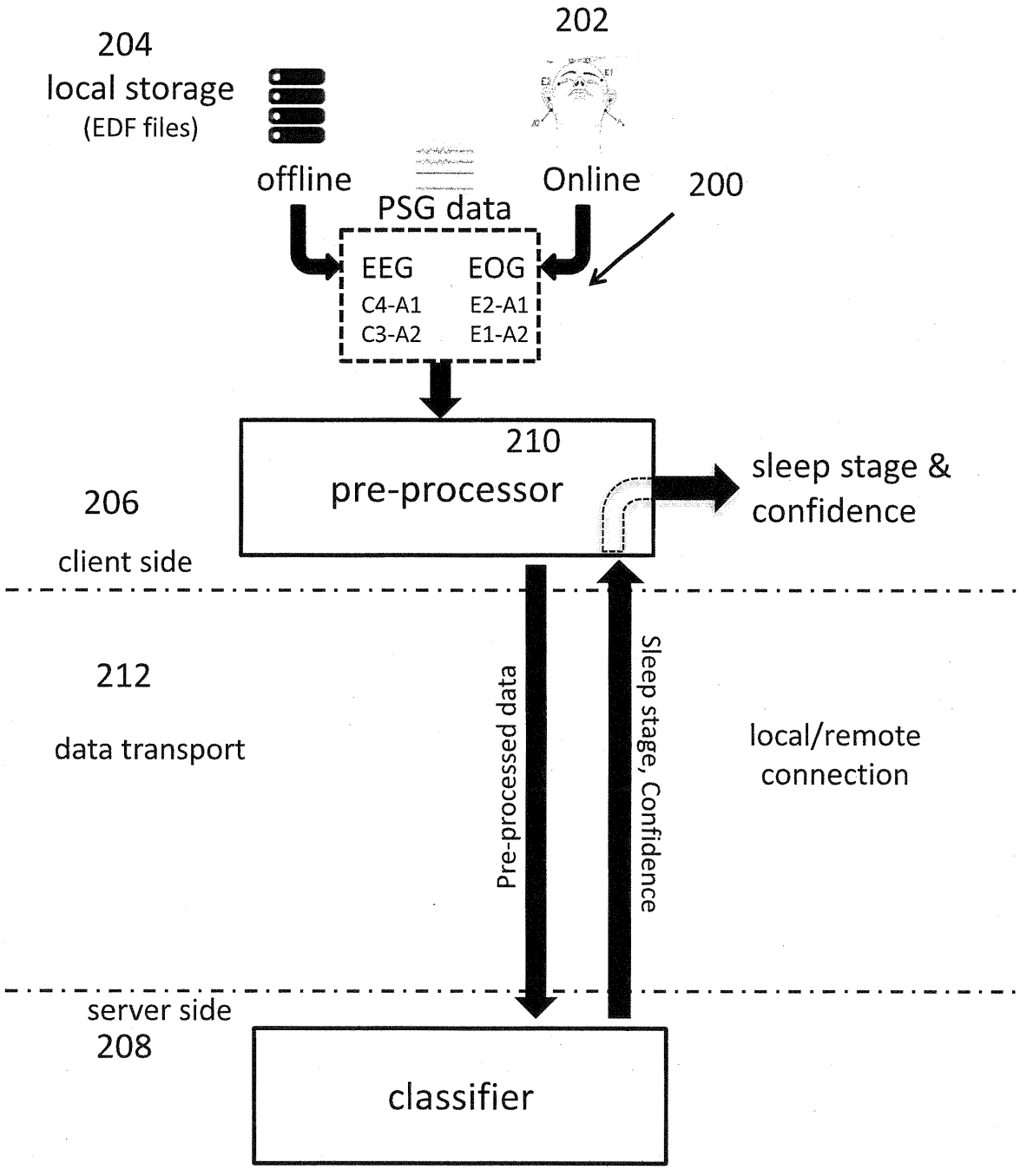

202
204
local storage
(EDF files)
offline
PSG data
Online
200
EEG
EOG
C4-A1
E2-A1
C3-A2
E1-A2
210
pre-processor
sleep stage &
confidence
206
client side
212
data transport
Pre-processed data
Sleep stage, Confidence
local/remote
connection
server side
208
classifier

FIG. 2

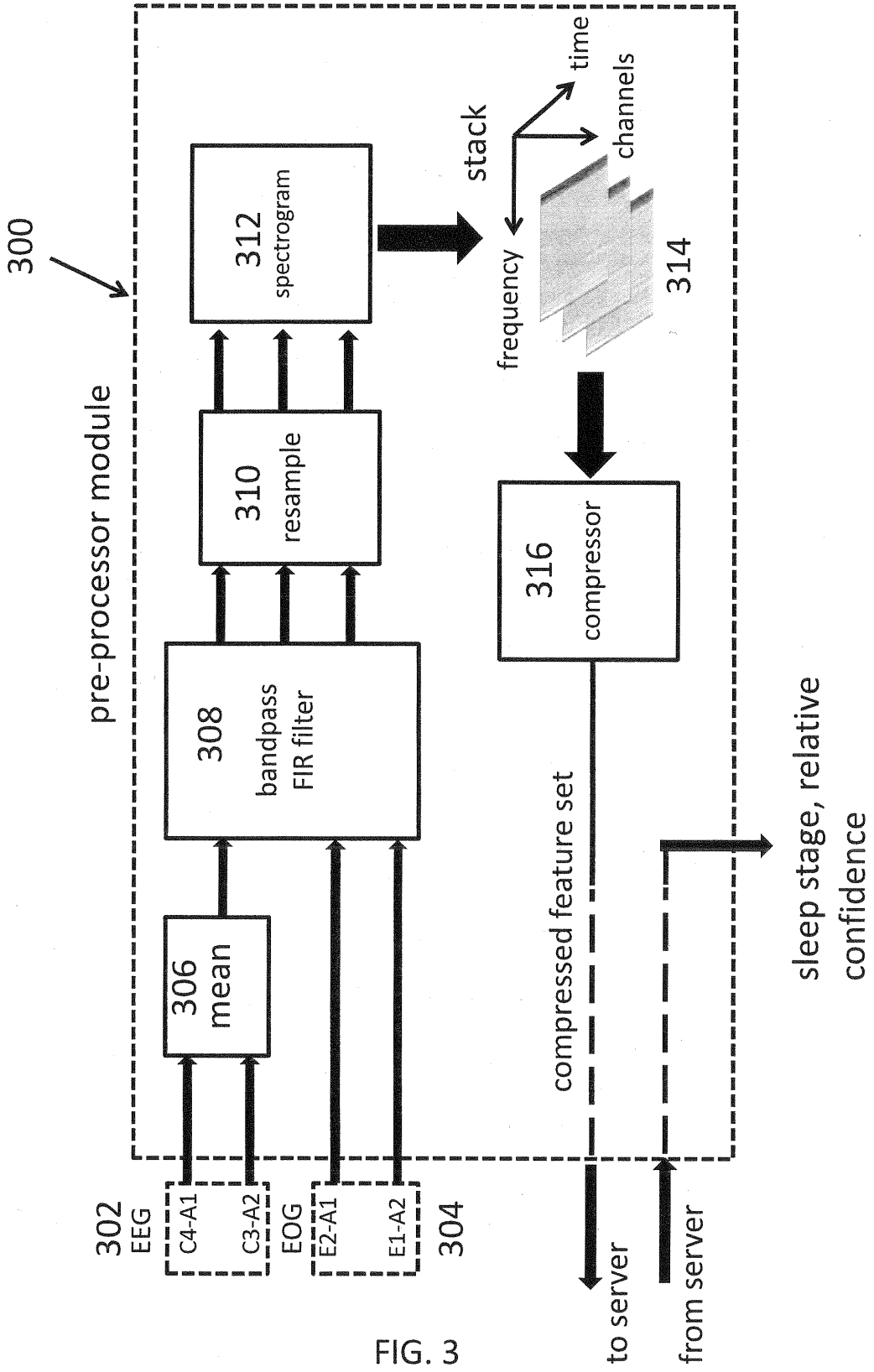

300
pre-processor module
302
EEG
C4-A1
C3-A2
EOG
E2-A1
E1-A2
304
306
mean
308
bandpass
FIR filter
310
resample
312
spectrogram
stack
time
channels
frequency
314
316
compressor
compressed feature set
to server
from server
sleep stage, relative
confidence

FIG. 3

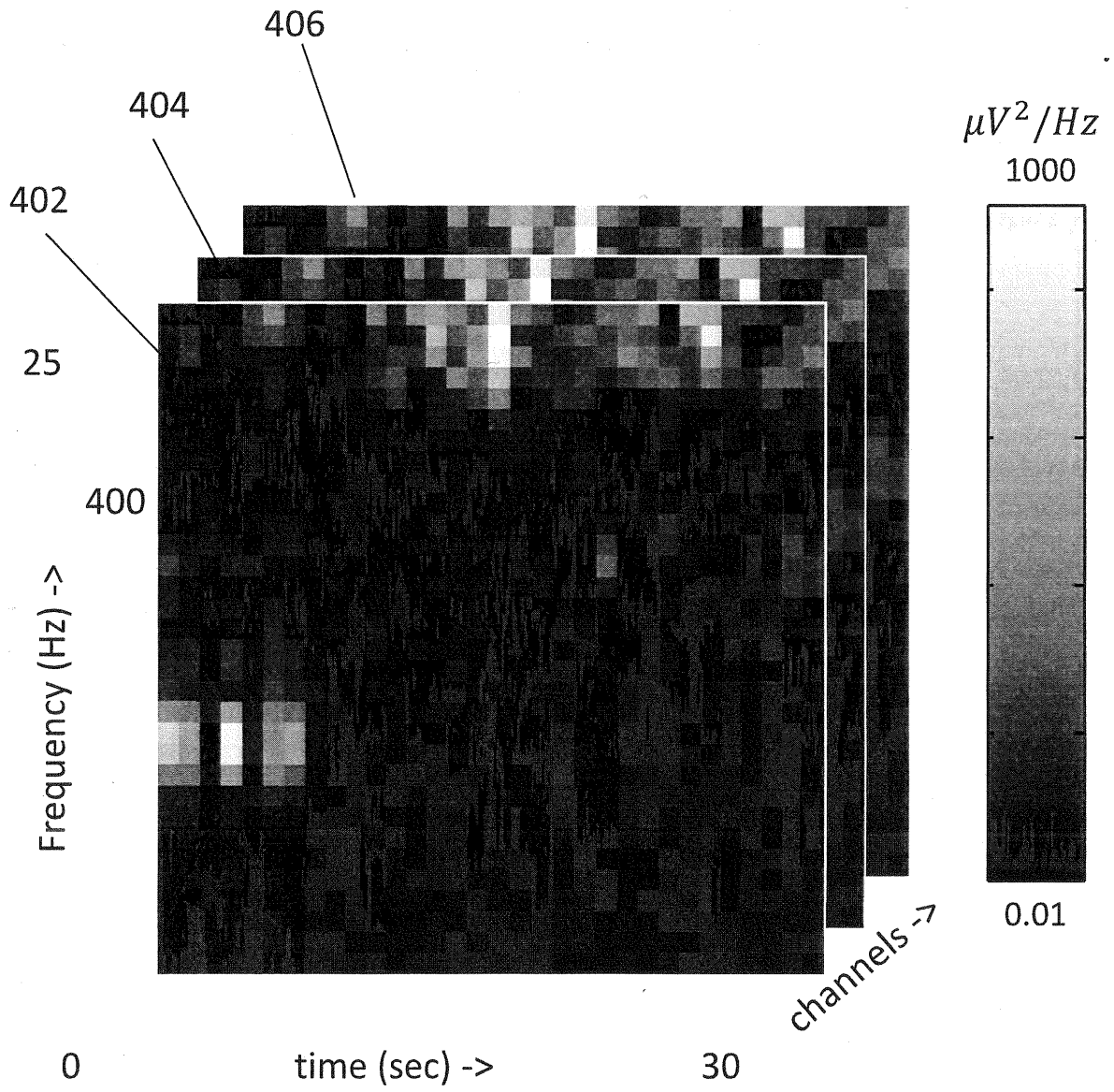

406
404
402
25
400
Frequency (Hz) ->
$\mu V^2/Hz$
1000
0.01
channels ->
0
time (sec) ->
30

FIG. 4

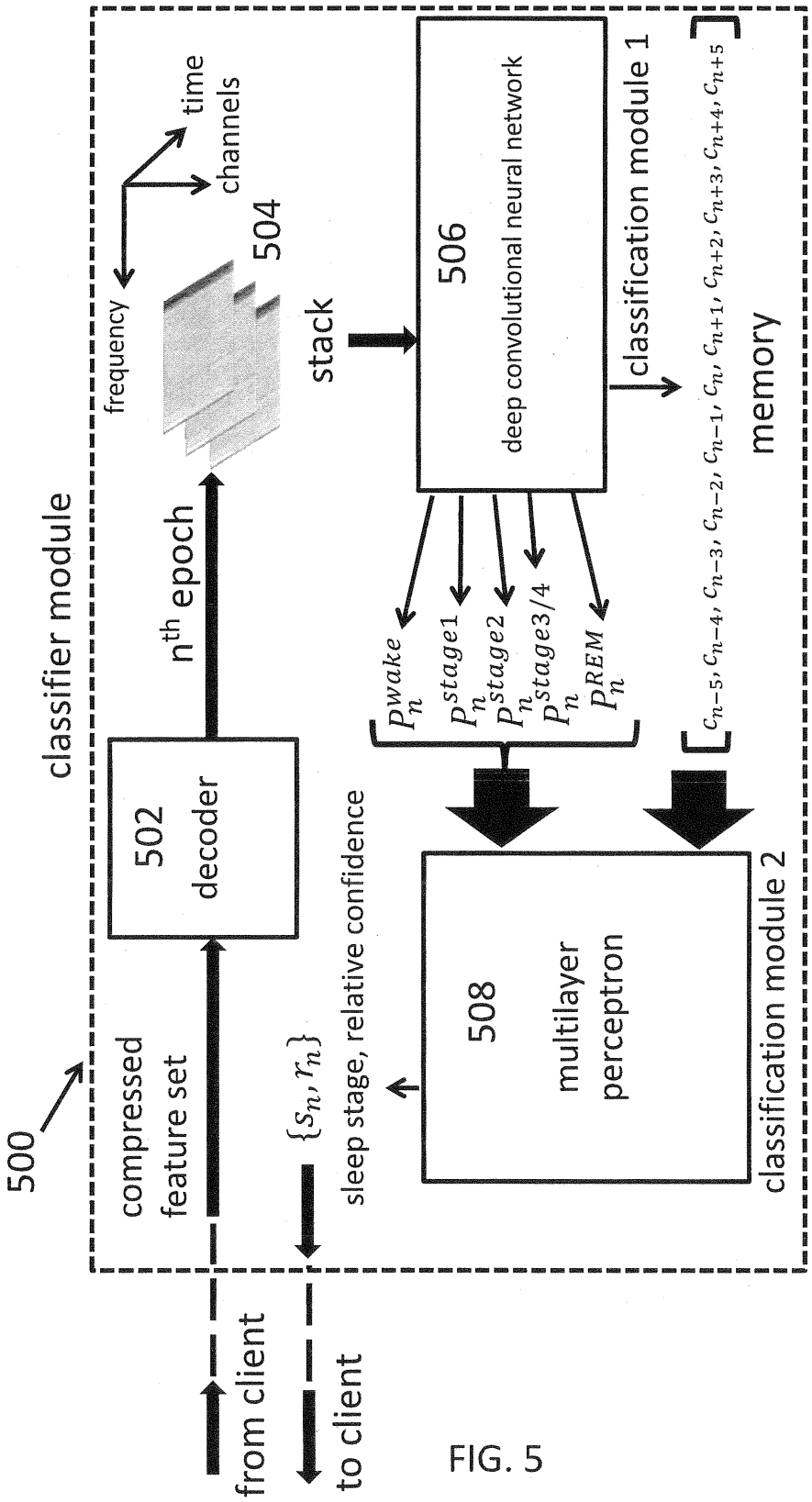

500
classifier module
compressed feature set
502 decoder
n^{th} epoch
frequency
time
channels
504
stack
506 deep convolutional neural network
classification module 1
memory
P_n^{wake} P_n^{stage1} P_n^{stage2} $P_n^{stage3/4}$ P_n^{REM}
$c_{n-5}, c_{n-4}, c_{n-3}, c_{n-2}, c_{n-1}, c_n, c_{n+1}, c_{n+2}, c_{n+3}, c_{n+4}, c_{n+5}$
508 multilayer perceptron
classification module 2
$\{s_n, r_n\}$
sleep stage, relative confidence
from client
to client

FIG. 5

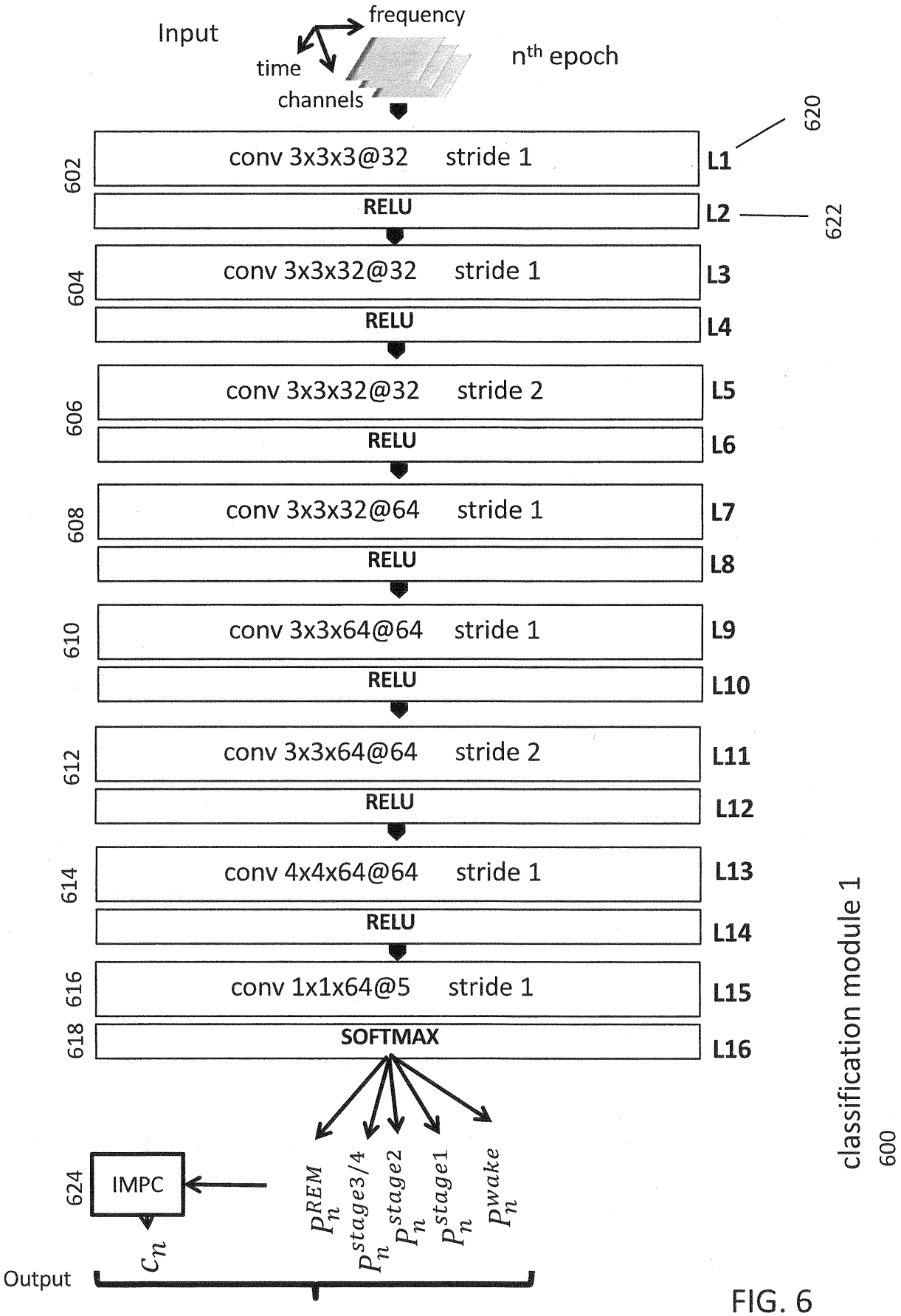

Input
frequency
time
channels
n^th epoch
620
602
conv 3x3x3@32 stride 1
L1
RELU
L2
622
604
conv 3x3x32@32 stride 1
L3
RELU
L4
606
conv 3x3x32@32 stride 2
L5
RELU
L6
608
conv 3x3x32@64 stride 1
L7
RELU
L8
610
conv 3x3x64@64 stride 1
L9
RELU
L10
612
conv 3x3x64@64 stride 2
L11
RELU
L12
614
conv 4x4x64@64 stride 1
L13
RELU
L14
616
conv 1x1x64@5 stride 1
L15
618
SOFTMAX
L16
624
IMPC
P_n^{REM}
$P_n^{stage3/4}$
P_n^{stage2}
P_n^{stage1}
P_n^{wake}
c_n
Output
classification module 1
600

FIG. 6

layer number	Type	filter support	filter dimension	no. of filters	stride	data size	weights
input	n/a	n/a	n/a	n/a	n/a	32x32x3	n/a
L1	conv	3X3	3	32	1	30X30X32	896
L2	RELU	1X1	n/a	n/a	1	30X30X32	n/a
L3	conv	3X3	32	32	1	28X28X32	9248
L4	RELU	1X1	n/a	n/a	1	28X28X32	n/a
L5	conv	3X3	32	32	2	13X13X32	9248
L6	RELU	1X1	n/a	n/a	1	13X13X32	n/a
L7	conv	3X3	32	64	1	11X11X64	18496
L8	RELU	1X1	n/a	n/a	1	11X11X64	n/a
L9	conv	3X3	64	64	1	9X9X64	36928
L10	RELU	1X1	n/a	n/a	1	9X9X64	n/a
L11	conv	3X3	64	64	2	4X4X64	36928
L12	RELU	1X1	n/a	n/a	1	4X4X64	n/a
L13	conv	4X4	64	64	1	64	65600
L14	RELU	1	n/a	n/a	1	64	n/a
L15	conv	1	64	5	1	5	325
L16	softmax	1	n/a	n/a	1	5	n/a
output	n/a	n/a	n/a	n/a	n/a	6	n/a



700

FIG. 7

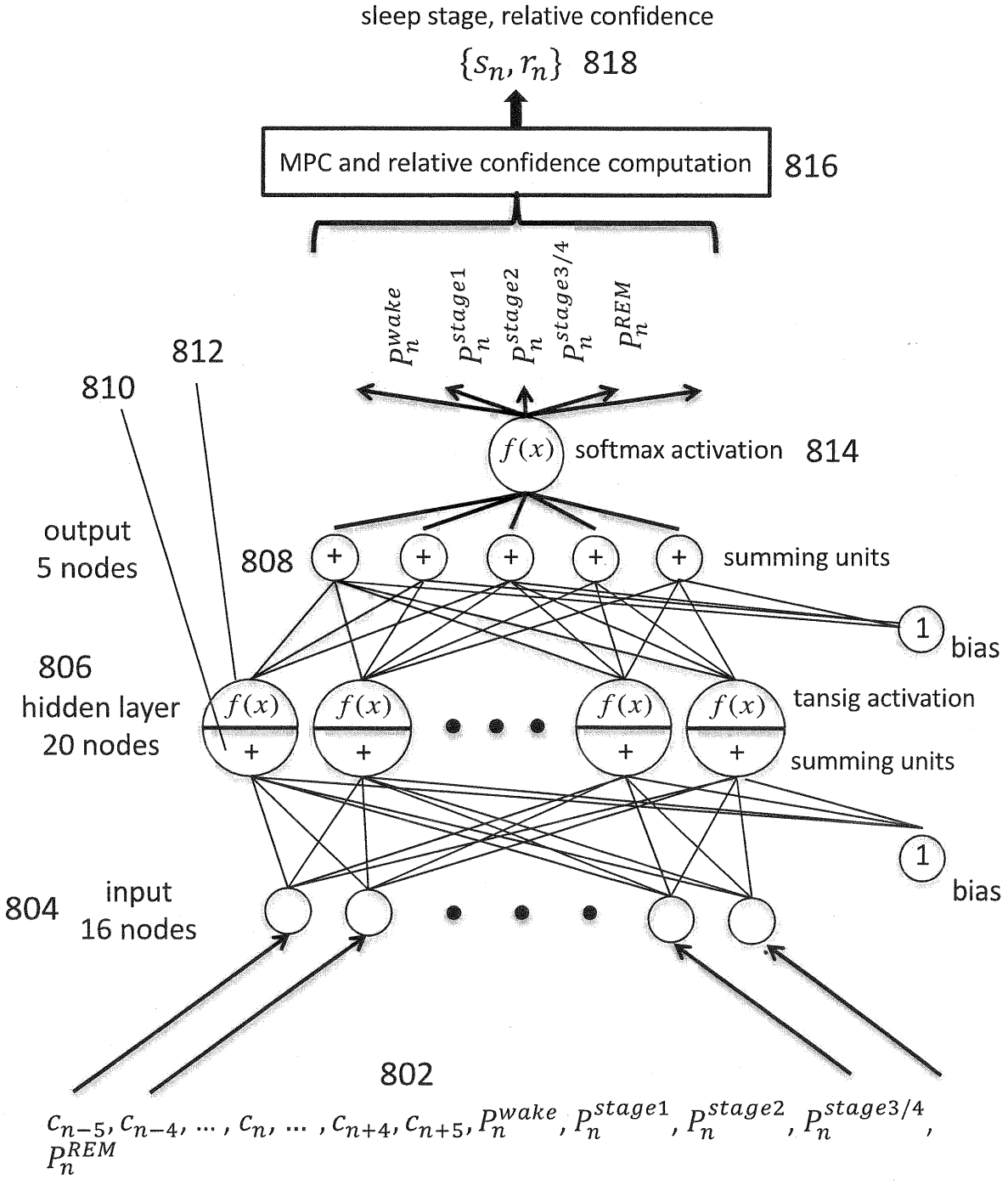

sleep stage, relative confidence
$\{s_n, r_n\}$ 818
MPC and relative confidence computation
816
P_n^{wake}
P_n^{stage1}
P_n^{stage2}
$P_n^{stage3/4}$
P_n^{REM}
812
810
$f(x)$ softmax activation 814
output
5 nodes
808
summing units
1 bias
806
hidden layer
20 nodes
tansig activation
summing units
1 bias
804
input
16 nodes
802
$c_{n-5}, c_{n-4}, \ldots, c_n, \ldots, c_{n+4}, c_{n+5}, P_n^{wake}, P_n^{stage1}, P_n^{stage2}, P_n^{stage3/4}, P_n^{REM}$
classification module 2

FIG. 8

800

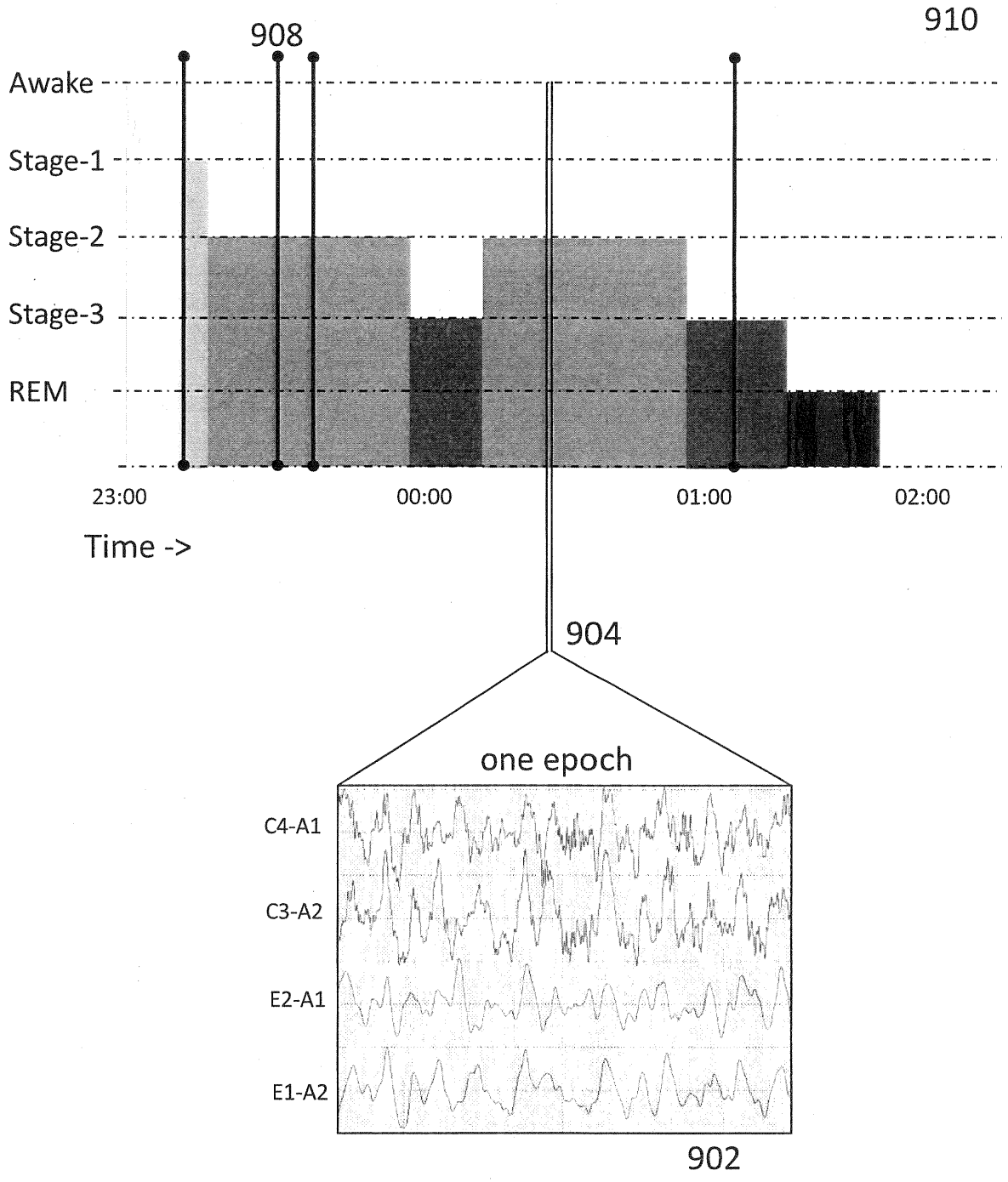

908
910
Awake
Stage-1
Stage-2
Stage-3
REM
23:00
00:00
01:00
02:00
Time ->
904
one epoch
C4-A1
C3-A2
E2-A1
E1-A2
902

FIG. 9

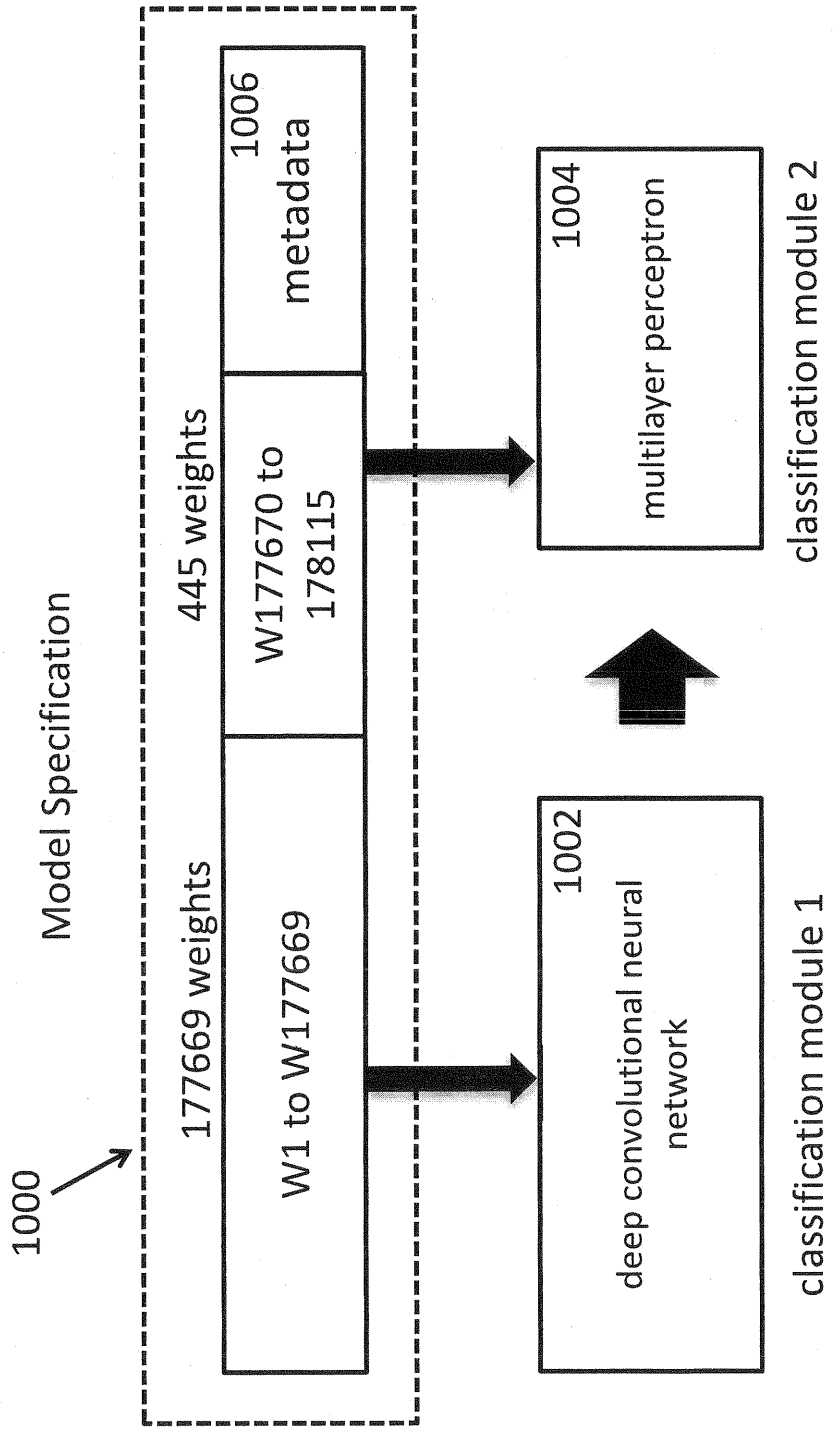

1000
Model Specification
177669 weights
W1 to W177669
445 weights
W177670 to 178115
1006
metadata
1002
deep convolutional neural network
classification module 1
1004
multilayer perceptron
classification module 2

FIG. 10

1100

Model Name: NFS1-CSL1-CSL2
Date: 22-Feb-2016
Dataset Size: 648,451 epochs from three independent datasets 1102
Training Format: Randomly shuffled; 70% training, 15% testing and 15% validation
Demographics: Healthy young subjects 1104
Recommended threshold: 1.5 1106

Training Confusion Matrix 1112

Output Class \ Target Class	W	S1	S2	S3	R	
W	8105 1.8%	2262 0.5%	115 0.0%	1738 0.4%	1113 0.2%	60.8% 39.2%
S1	5133 1.1%	156311 34.7%	6285 1.4%	1484 0.3%	4502 1.0%	90.0% 10.0%
S2	222 0.0%	5170 1.1%	87634 19.4%	369 0.1%	14 0.0%	93.8% 6.2%
S3	2491 0.6%	1543 0.3%	312 0.1%	77098 17.1%	803 0.2%	93.7% 6.3%
R	3663 0.8%	5899 1.3%	25 0.0%	1295 0.3%	77229 17.1%	87.6% 12.4%
	41.3% 58.7%	91.3% 8.7%	92.9% 7.1%	94.0% 6.0%	92.3% 7.7%	**90.1%** **9.9%**

Validation Confusion Matrix 1110

Output Class \ Target Class	W	S1	S2	S3	R	
W	1726 1.8%	540 0.6%	24 0.0%	406 0.4%	239 0.2%	58.8% 41.2%
S1	1134 1.2%	33728 34.9%	1362 1.4%	323 0.3%	969 1.0%	89.9% 10.1%
S2	45 0.0%	1078 1.1%	18540 19.2%	69 0.1%	3 0.0%	93.9% 6.1%
S3	583 0.6%	337 0.3%	83 0.1%	16575 17.2%	182 0.2%	93.3% 6.7%
R	751 0.8%	1276 1.3%	2 0.0%	265 0.3%	16363 16.9%	87.7% 12.3%
	40.7% 59.3%	91.3% 8.7%	92.6% 7.4%	94.0% 6.0%	92.2% 7.8%	**90.0%** **10.0%**

Test Confusion Matrix 1108

Output Class \ Target Class	W	S1	S2	S3	R	
W	1765 1.8%	436 0.5%	18 0.0%	400 0.4%	223 0.2%	62.1% 37.9%
S1	1111 1.2%	33520 34.7%	1384 1.4%	288 0.3%	989 1.0%	89.9% 10.1%
S2	50 0.1%	1123 1.2%	18887 19.6%	80 0.1%	6 0.0%	93.8% 6.2%
S3	530 0.5%	313 0.3%	53 0.1%	16529 17.1%	187 0.2%	93.9% 6.1%
R	778 0.8%	1236 1.3%	7 0.0%	281 0.3%	16409 17.0%	87.7% 12.3%
	41.7% 58.3%	91.5% 8.5%	92.8% 7.2%	94.0% 6.0%	92.1% 7.9%	**90.2%** **9.8%**

All Confusion Matrix

Output Class \ Target Class	W	S1	S2	S3	R	
W	11596 1.8%	3238 0.5%	157 0.0%	2544 0.4%	1575 0.2%	60.7% 39.3%
S1	7378 1.1%	223559 34.7%	9031 1.4%	2095 0.3%	6460 1.0%	90.0% 10.0%
S2	317 0.0%	7371 1.1%	125061 19.4%	518 0.1%	23 0.0%	93.8% 6.2%
S3	3604 0.6%	2193 0.3%	448 0.1%	110202 17.1%	1172 0.2%	93.7% 6.3%
R	5192 0.8%	8411 1.3%	34 0.0%	1841 0.3%	110001 17.1%	87.7% 12.3%
	41.3% 58.7%	91.3% 8.7%	92.8% 7.2%	94.0% 6.0%	92.3% 7.7%	**90.1%** **9.9%**

W: wake, S1: stage-1, S2: stage-2, S3: stage-3/4, R: REM

FIG. 11

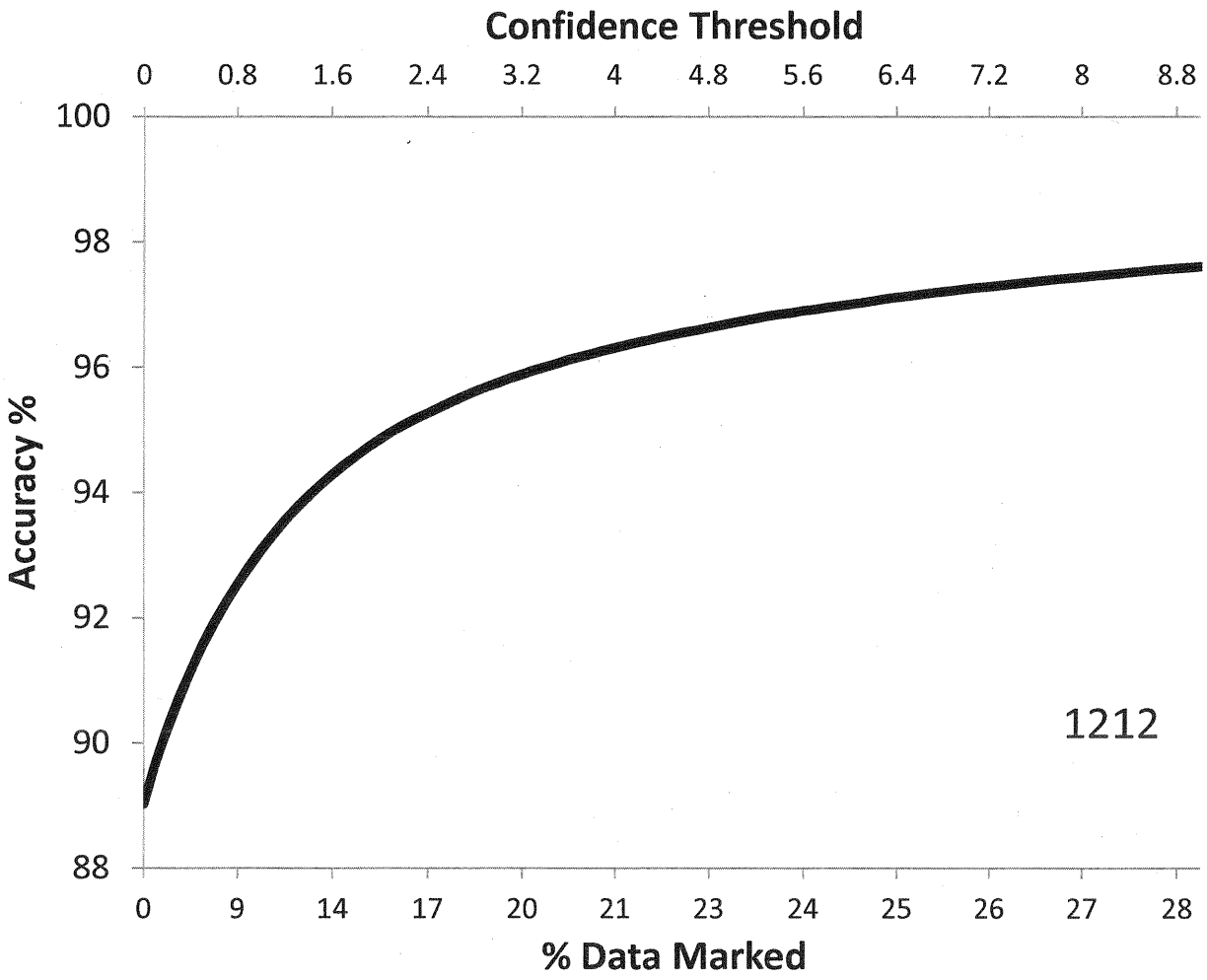

Confidence Threshold
0
0.8
1.6
2.4
3.2
4
4.8
5.6
6.4
7.2
8
8.8
100
98
96
94
92
90
88
Accuracy %
1212
0
9
14
17
20
21
23
24
25
26
27
28
% Data Marked

FIG. 12

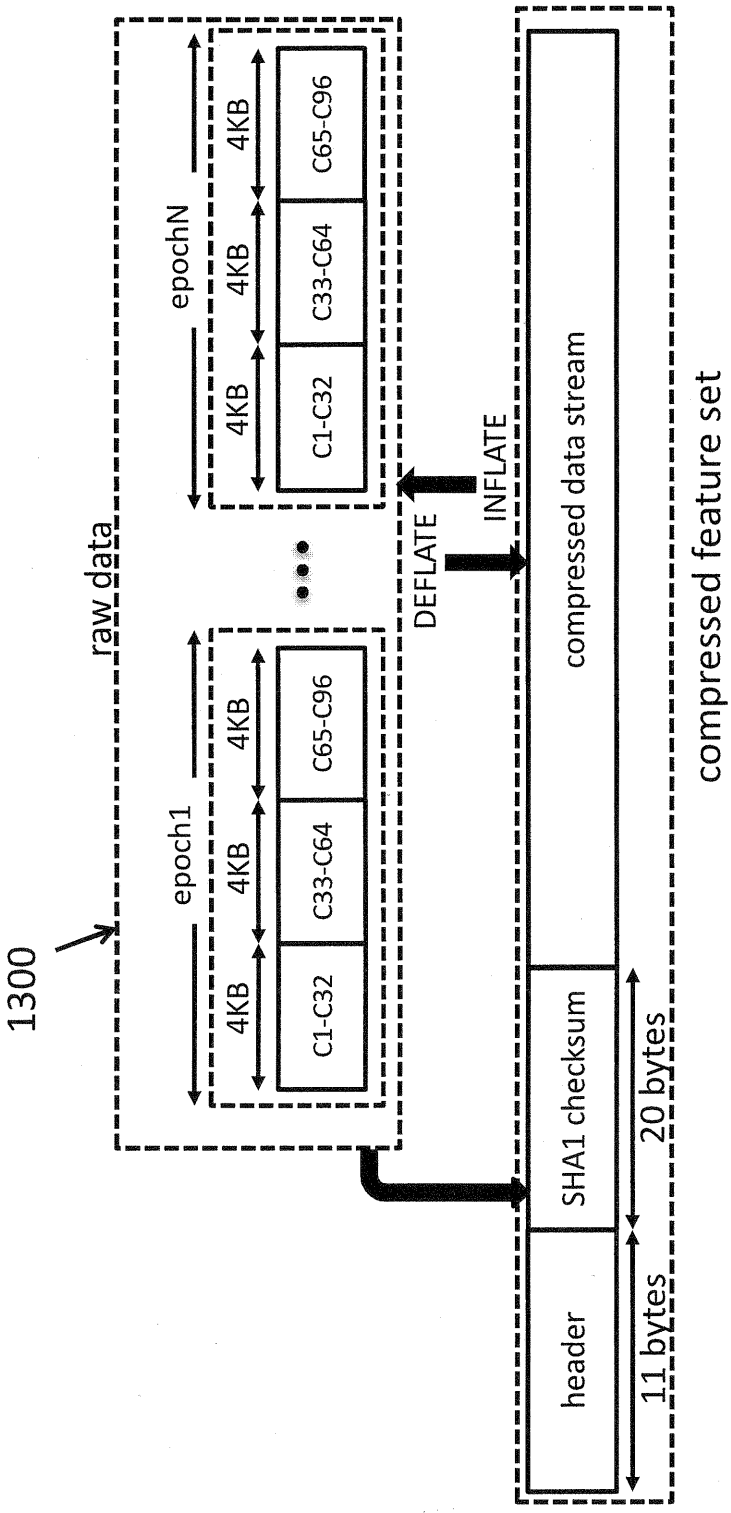

1300
raw data
epochN
epoch1
4KB
C1-C32
C33-C64
C65-C96
DEFLATE
INFLATE
compressed data stream
SHA1 checksum
header
20 bytes
11 bytes
compressed feature set

FIG. 13

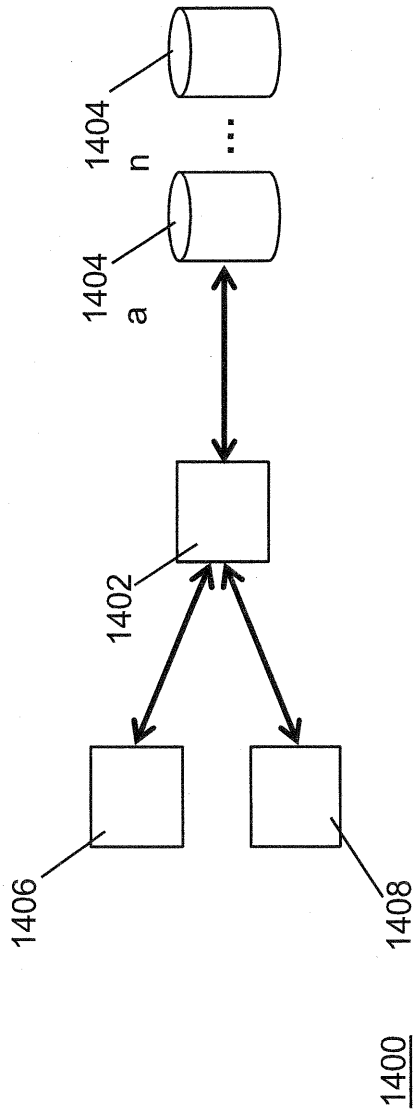


FIG. 14

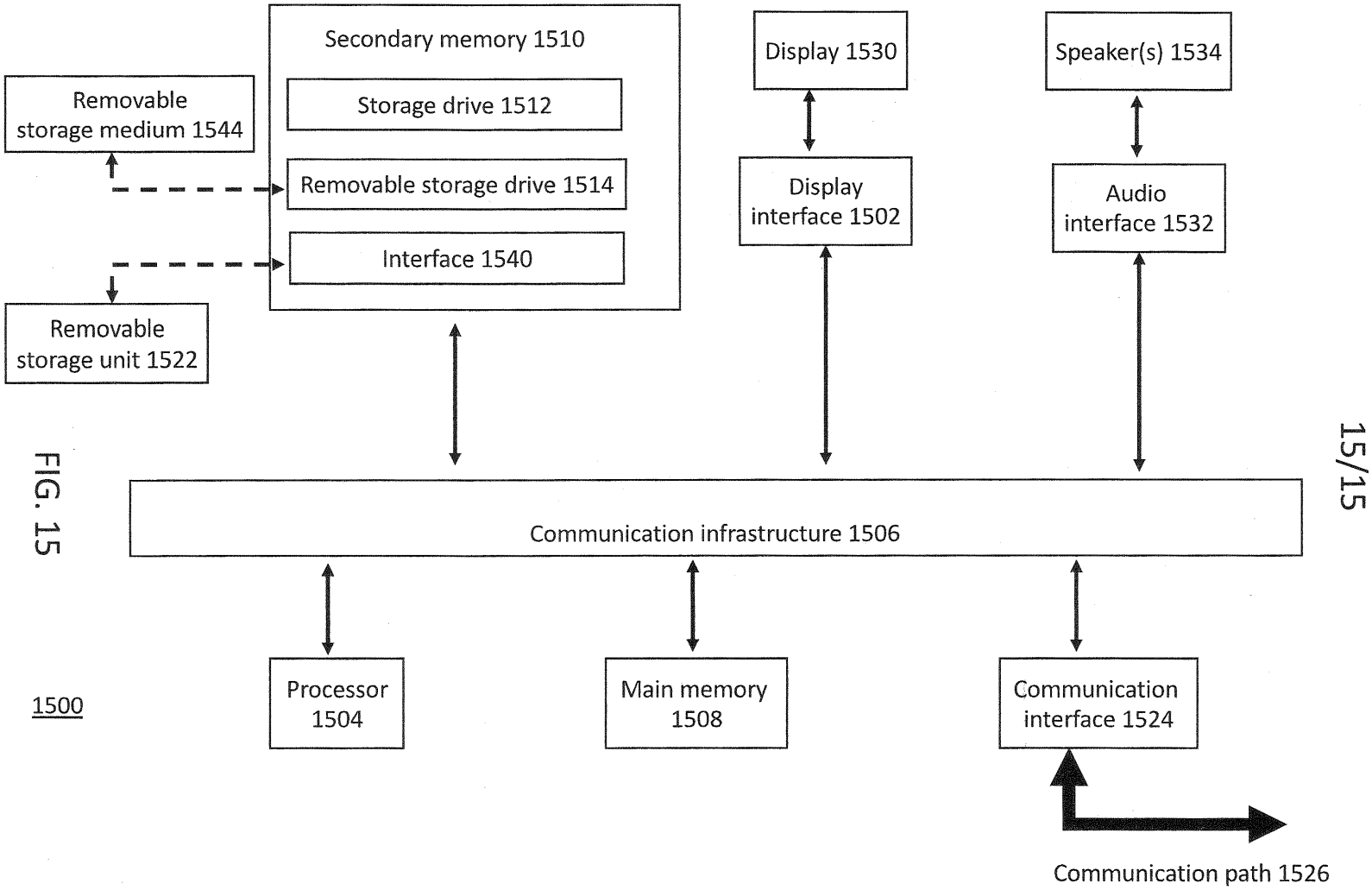

Secondary memory 1510
Storage drive 1512
Removable storage drive 1514
Interface 1540
Removable storage medium 1544
Removable storage unit 1522
Display 1530
Display interface 1502
Speaker(s) 1534
Audio interface 1532
Communication infrastructure 1506
Processor 1504
Main memory 1508
Communication interface 1524
Communication path 1526
1500

FIG. 15