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(54) **METHOD AND APPARATUS FOR PROVIDING MOBILE AND OTHER INTERMITTENT CONNECTIVITY IN A COMPUTING ENVIRONMENT**

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See application file for complete search history.

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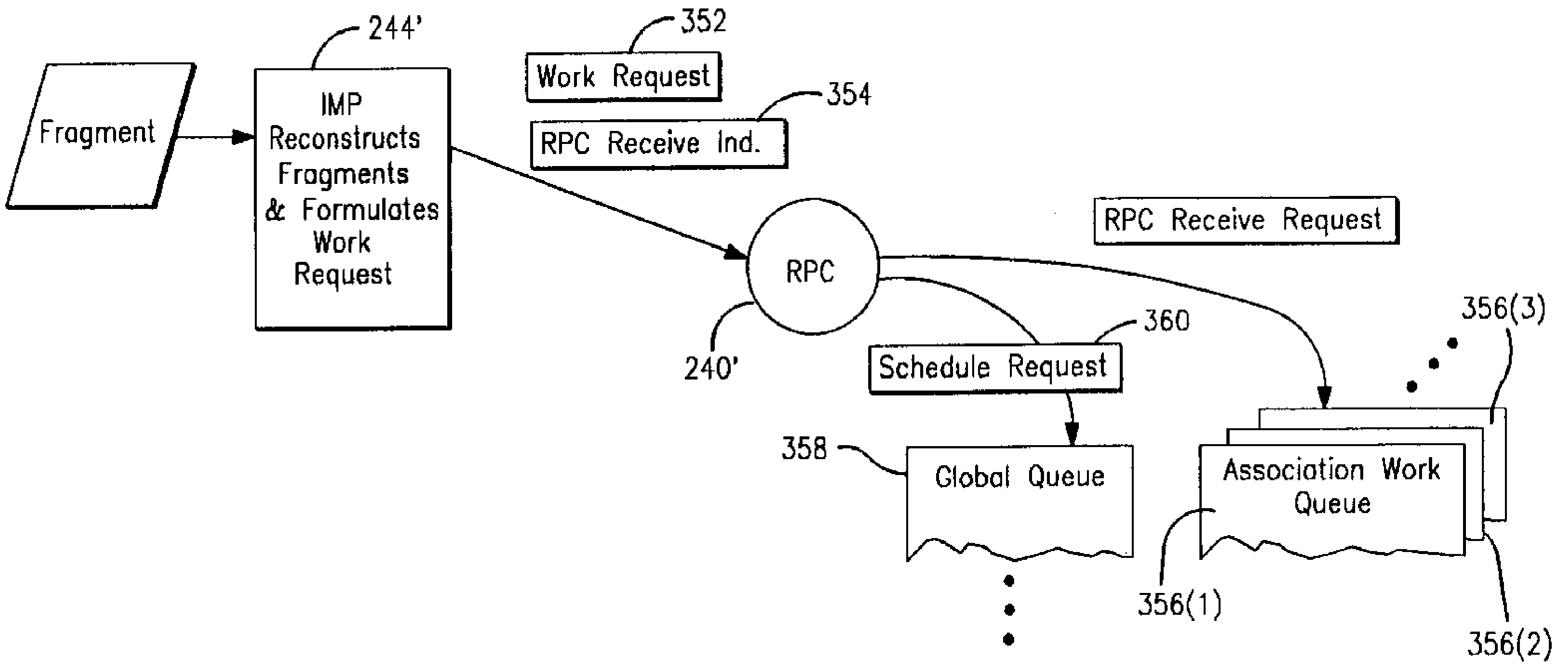
(57) **ABSTRACT**

A seamless solution transparently addresses the characteristics of nomadic systems, and enables existing network applications to run reliably in mobile environments. The solution extends the enterprise network, letting network managers provide mobile users with easy access to the same applications as stationary users without sacrificing reliability or centralized management. The solution combines advantages of existing wire-line network standards with emerging mobile standards to create a solution that works with existing network applications. A Mobility Management Server coupled to the mobile network maintains the state of each of any number of Mobile End Systems and handles the complex session management required to maintain persistent connections to the network and to other peer processes. If a Mobile End System becomes unreachable, suspends, or changes network address (e.g., due to roaming from one network interconnect to another), the Mobility Management Server maintains the connection to the associated peer task—allowing the Mobile End System to maintain a continuous connection even though it may temporarily lose contact with its network medium. In one example, Mobility Management Server communicates with Mobile End Systems using Remote Procedure Call and Internet Mobility Protocols.

1 Claim, 32 Drawing Sheets



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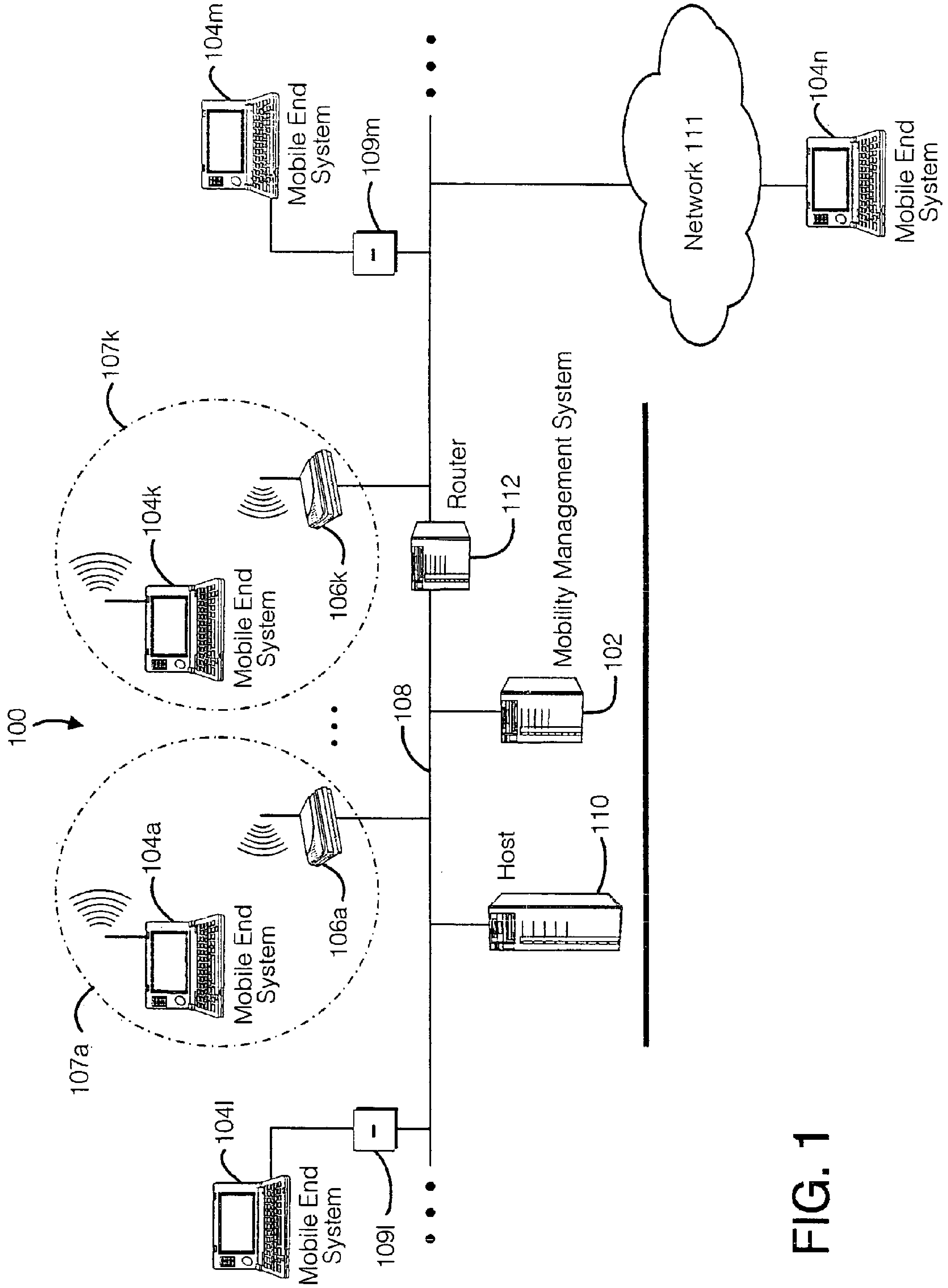
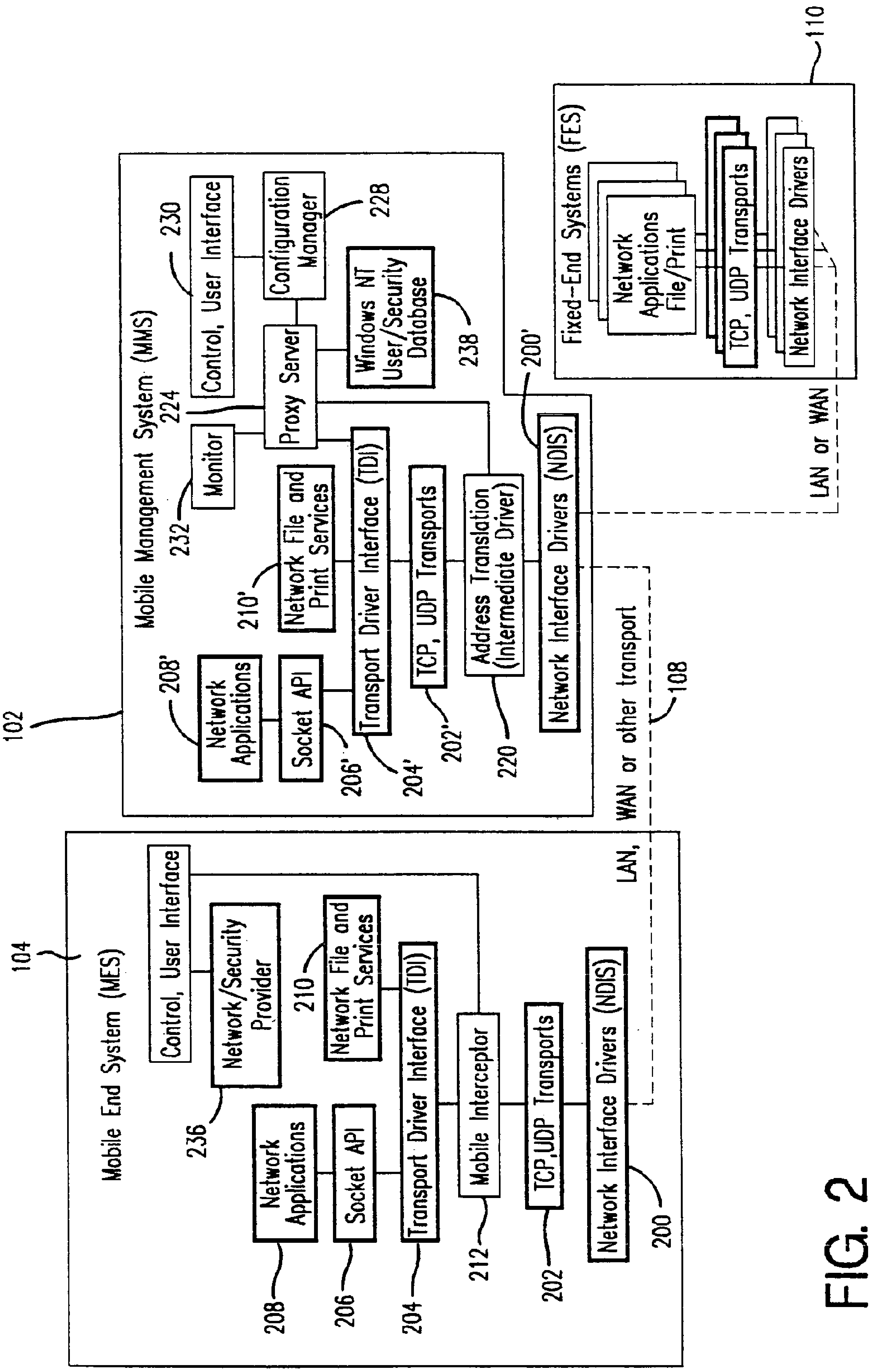

100
104m
Mobile End System
109m
107k
104k
Mobile End System
106k
Router
112
Mobility Management System
102
108
Host
110
104a
Mobile End System
106a
107a
104l
Mobile End System
109l
Network 111
104n
Mobile End System

FIG. 1



Mobile End System (MES)
104
Control, User Interface
Network/Security Provider
236
Network Applications
208
Socket API
206
Network File and Print Services
210
Transport Driver Interface (TDI)
204
Mobile Interceptor
212
TCP,UDP Transports
202
Network Interface Drivers (NDIS)
200
LAN, WAN or other transport
108
Mobile Management System (MMS)
102
Monitor
232
Proxy Server
224
Control, User Interface
230
Configuration Manager
228
Windows NT User/Security Database
238
Network Applications
208'
Socket API
206'
Network File and Print Services
210'
Transport Driver Interface (TDI)
204'
TCP, UDP Transports
202'
Address Translation (Intermediate Driver)
220
Network Interface Drivers (NDIS)
200'
LAN or WAN
Fixed-End Systems (FES)
110
Network Applications File/Print
TCP, UDP Transports
Network Interface Drivers

FIG. 2

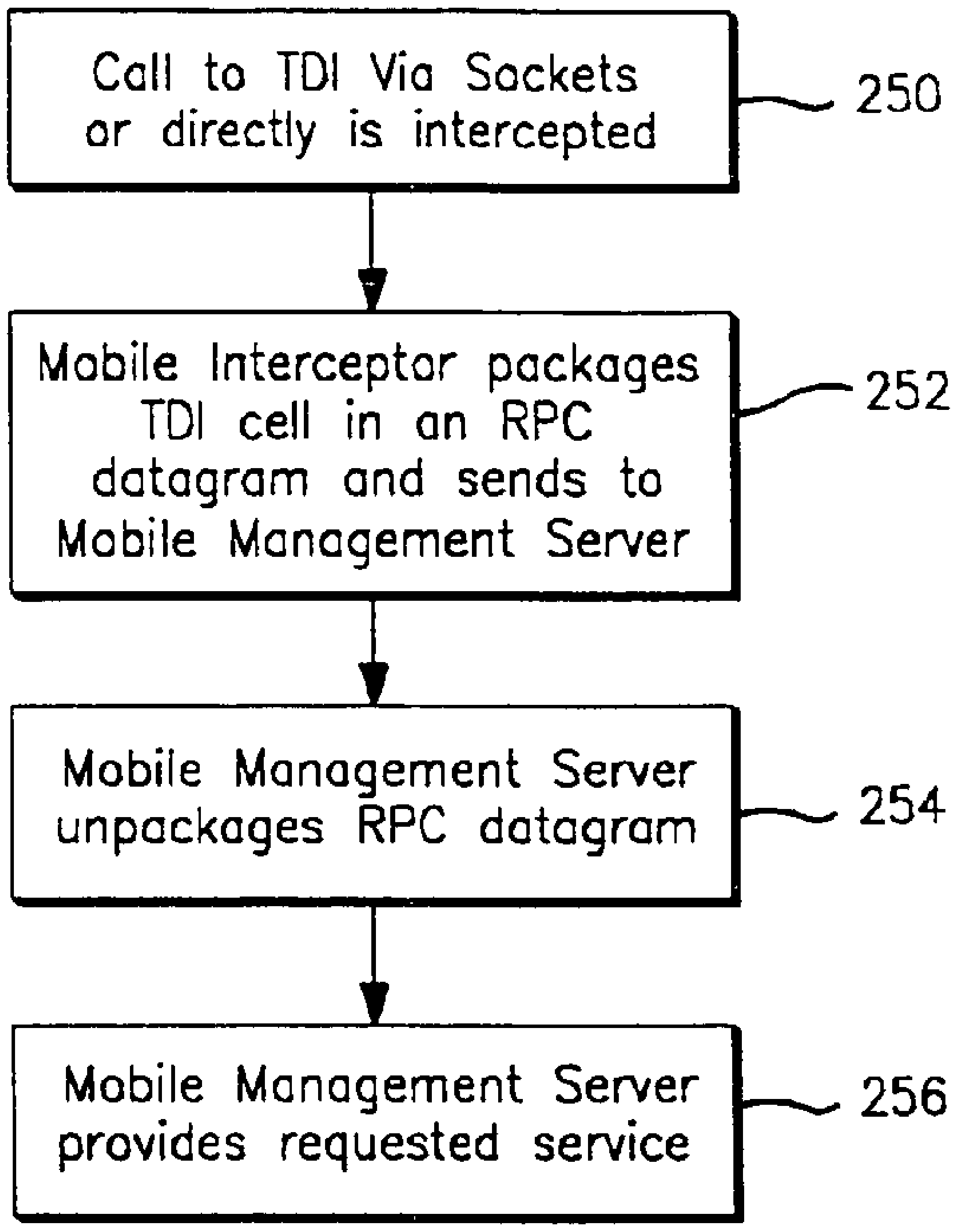

Call to TDI Via Sockets or directly is intercepted
250
Mobile Interceptor packages TDI cell in an RPC datagram and sends to Mobile Management Server
252
Mobile Management Server unpackages RPC datagram
254
Mobile Management Server provides requested service
256

FIG. 2A

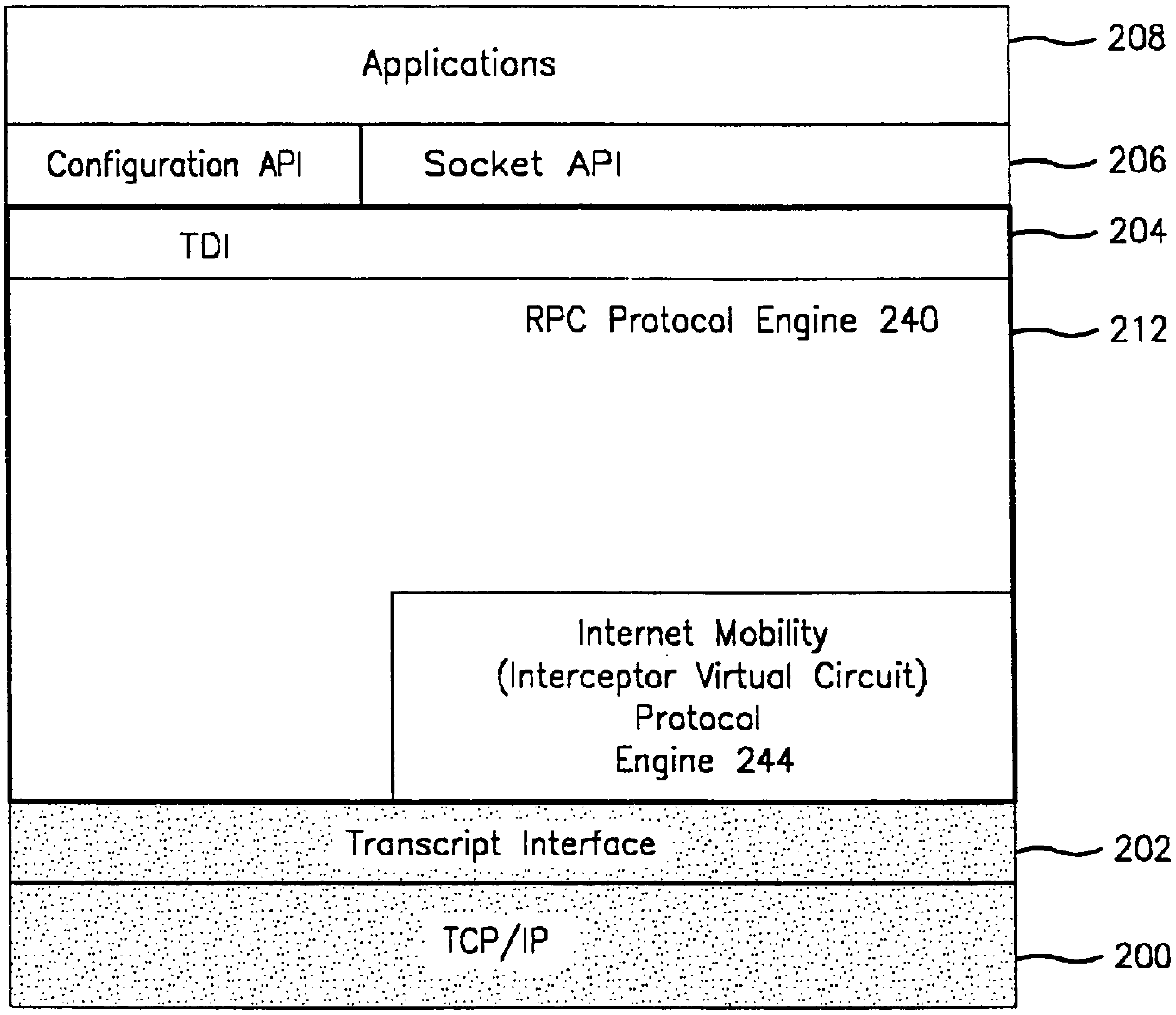

Applications
208
Configuration API
Socket API
206
TDI
204
RPC Protocol Engine 240
212
Internet Mobility (Interceptor Virtual Circuit) Protocol Engine 244
Transcript Interface
202
TCP/IP
200

FIG. 3

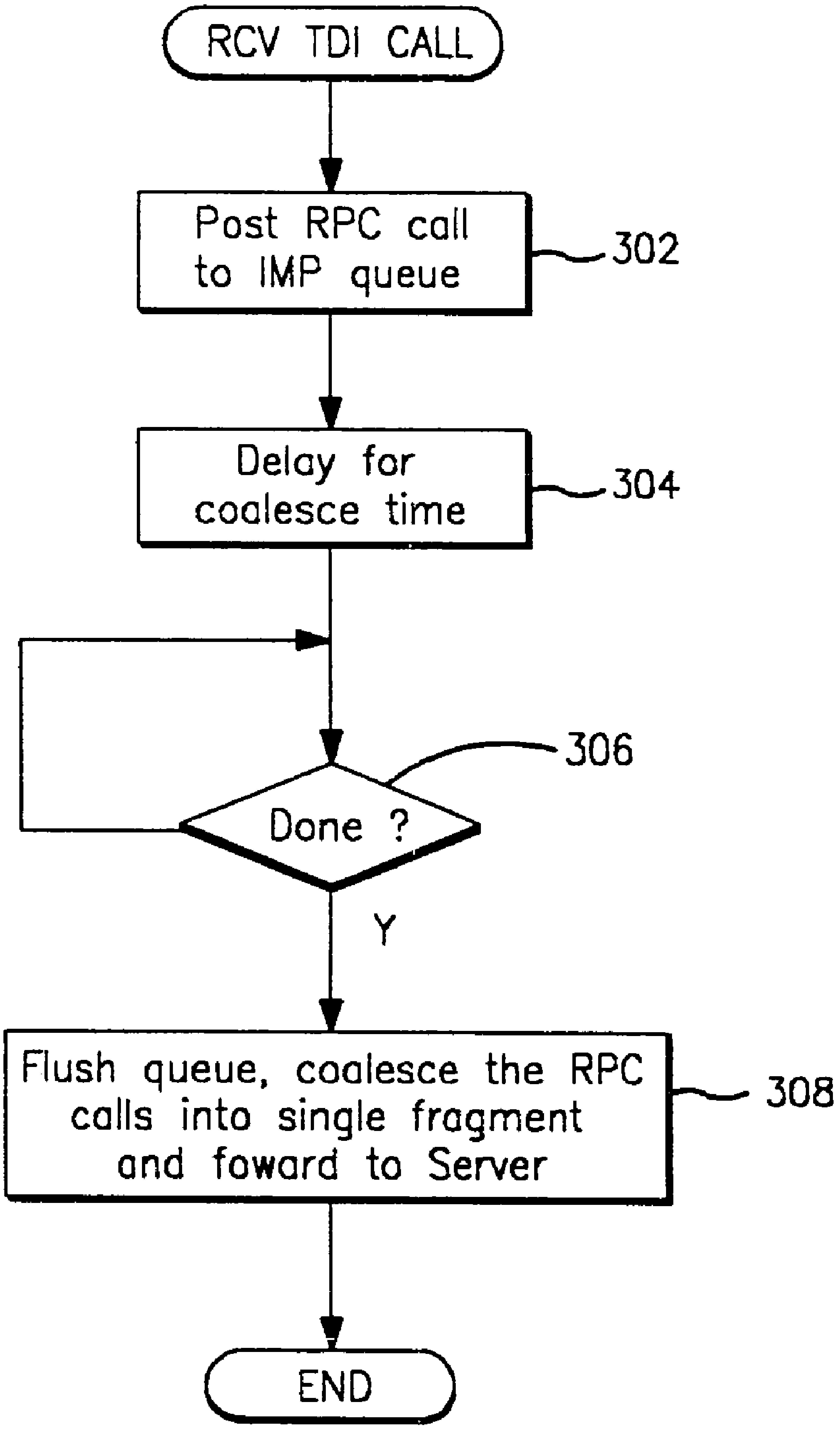

RCV TDI CALL
Post RPC call to IMP queue
302
Delay for coalesce time
304
306
Done ?
Y
Flush queue, coalesce the RPC calls into single fragment and foward to Server
308
END

FIG. 3A

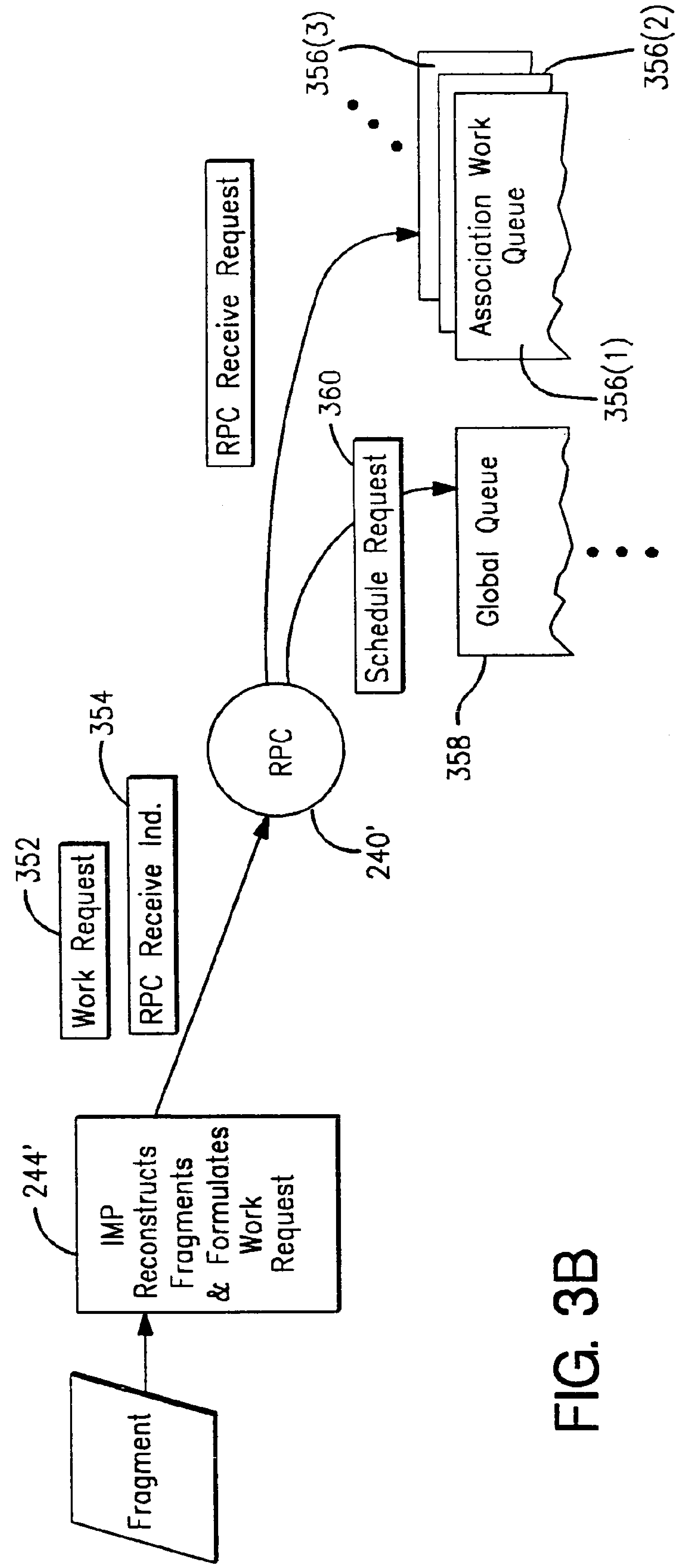

Fragment
244'
IMP Reconstructs Fragments & Formulates Work Request
352
Work Request
354
RPC Receive Ind.
RPC
240'
RPC Receive Request
360
Schedule Request
Global Queue
358
Association Work Queue
356(1)
356(2)
356(3)

FIG. 3B

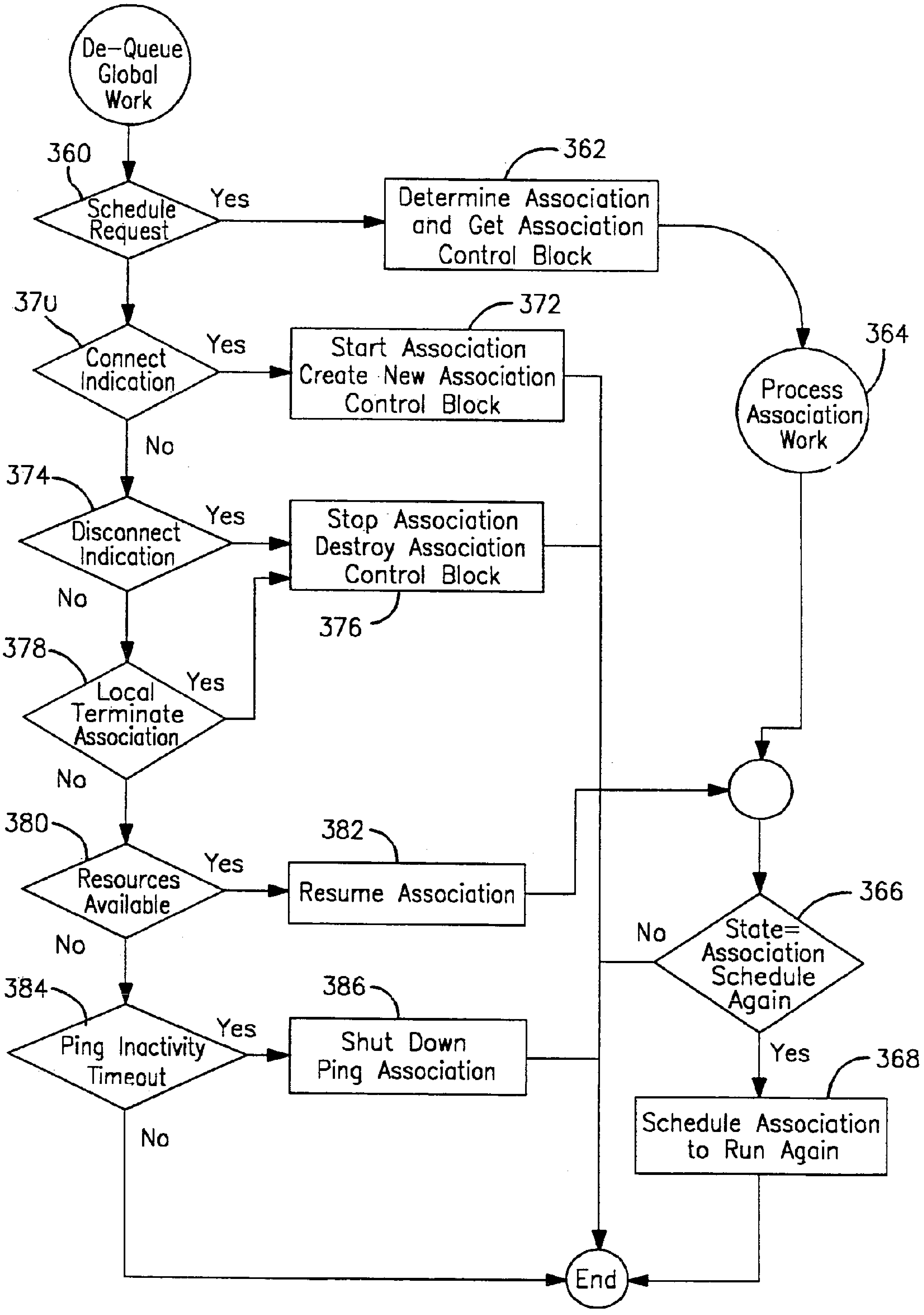

De-Queue Global Work
360
Schedule Request
Yes
362
Determine Association and Get Association Control Block
370
Connect Indication
Yes
372
Start Association Create New Association Control Block
No
364
Process Association Work
374
Disconnect Indication
Yes
Stop Association Destroy Association Control Block
No
376
378
Local Terminate Association
Yes
No
380
Resources Available
Yes
382
Resume Association
No
366
State= Association Schedule Again
No
384
Ping Inactivity Timeout
Yes
386
Shut Down Ping Association
Yes
368
Schedule Association to Run Again
No
End

FIG. 4

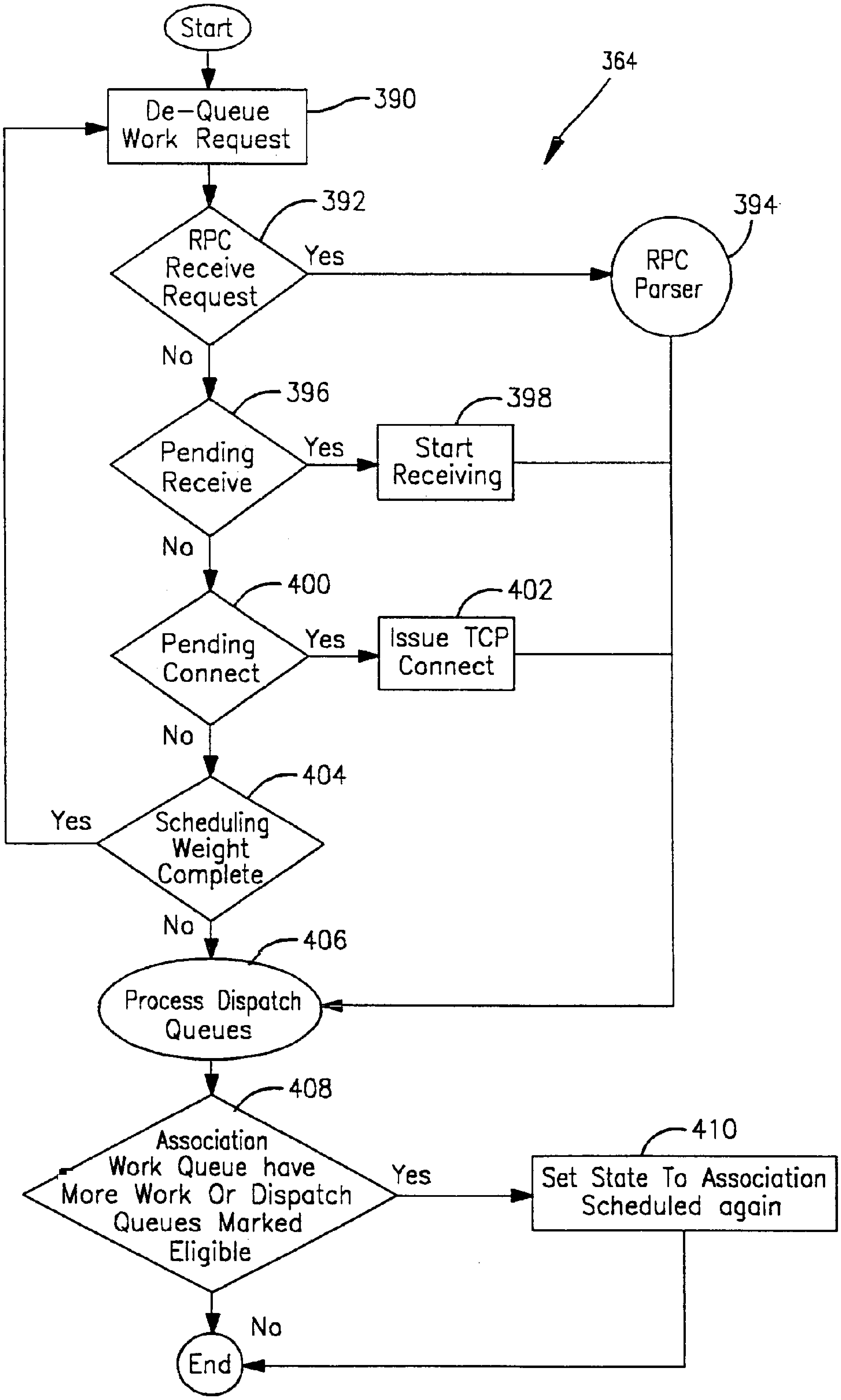


FIG. 5 Process Association Work

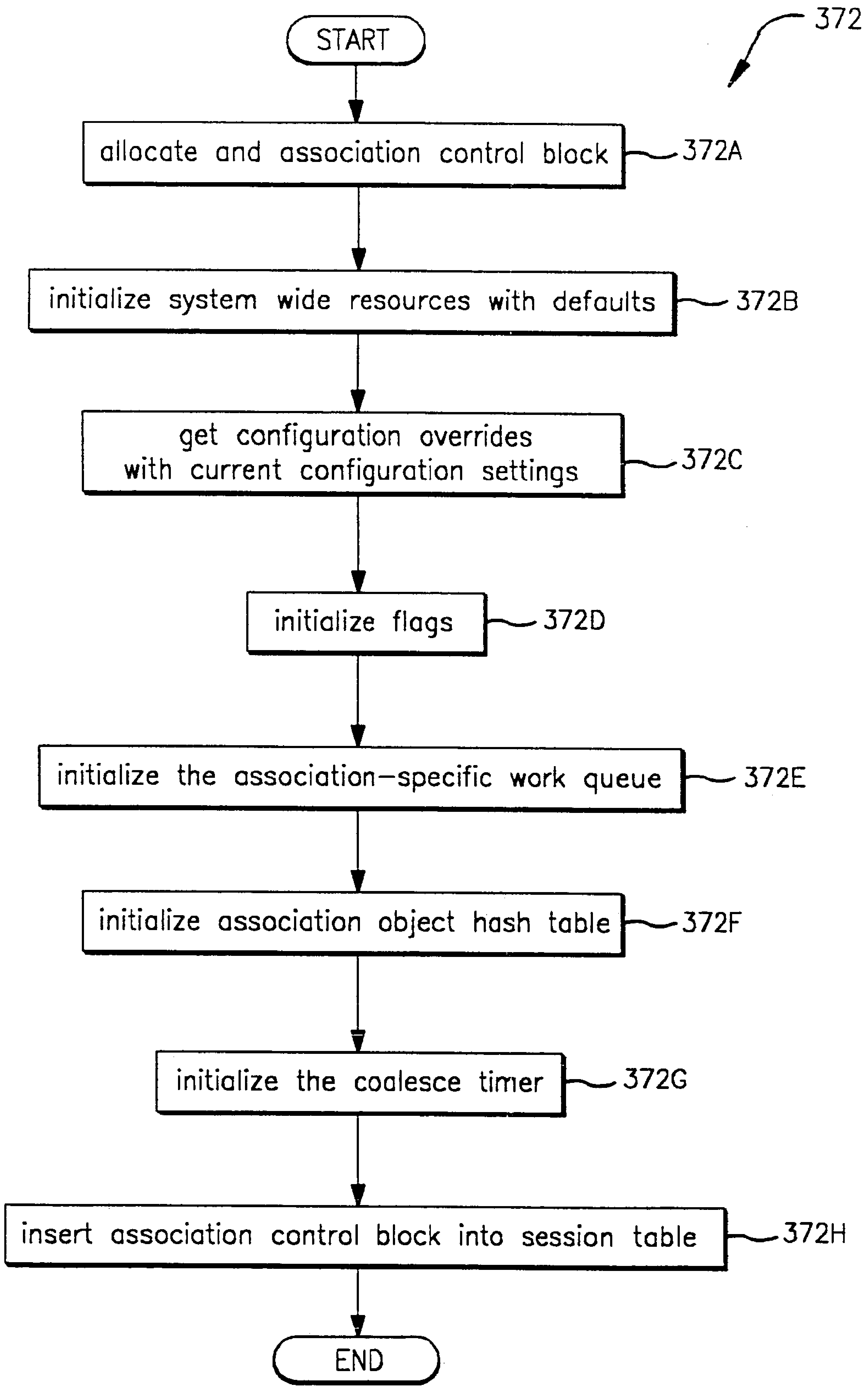

372
START
allocate and association control block
372A
initialize system wide resources with defaults
372B
get configuration overrides with current configuration settings
372C
initialize flags
372D
initialize the association-specific work queue
372E
initialize association object hash table
372F
initialize the coalesce timer
372G
insert association control block into session table
372H
END

FIG. 5A

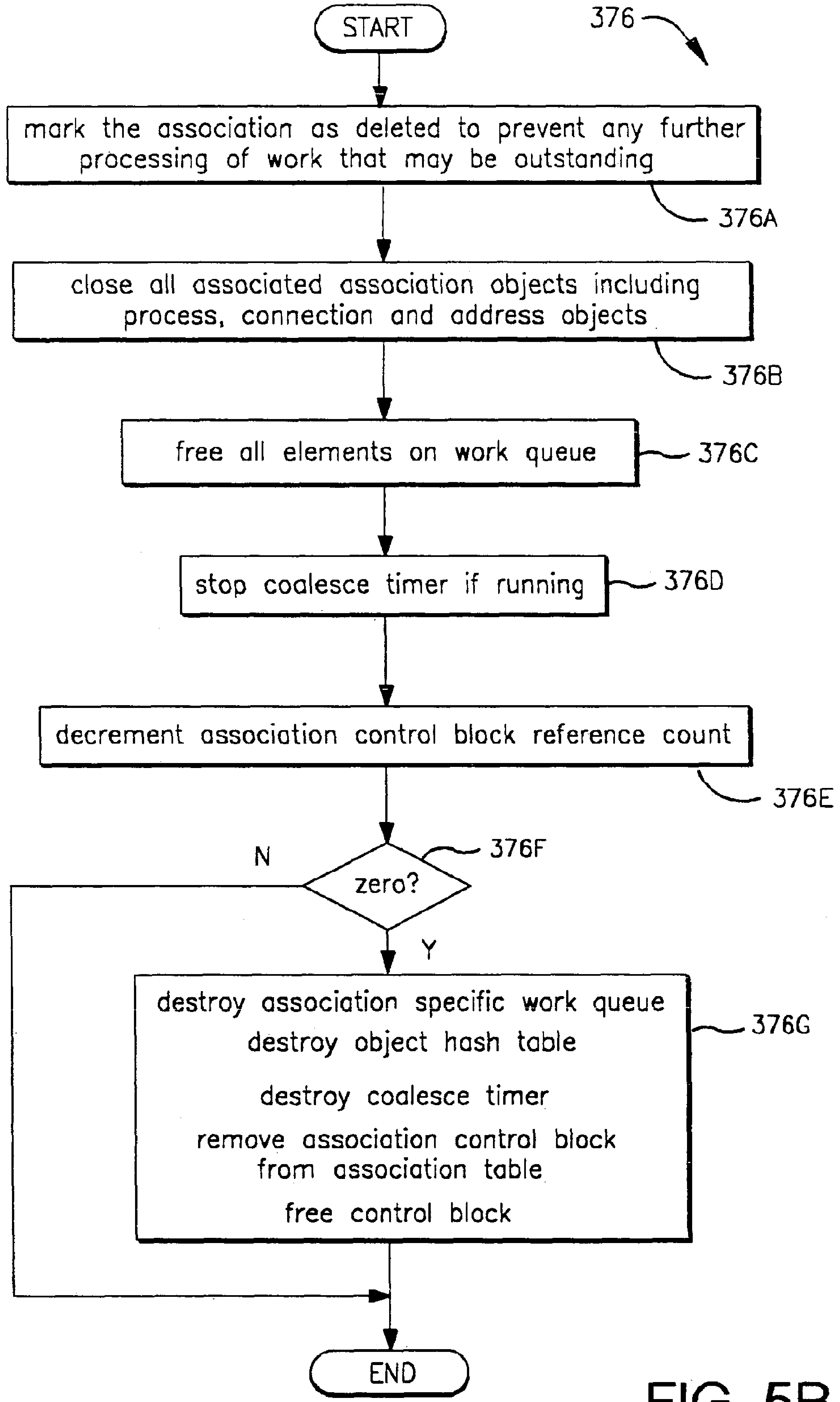

START
376
mark the association as deleted to prevent any further processing of work that may be outstanding
376A
close all associated association objects including process, connection and address objects
376B
free all elements on work queue
376C
stop coalesce timer if running
376D
decrement association control block reference count
376E
N
zero?
376F
Y
destroy association specific work queue
destroy object hash table
destroy coalesce timer
remove association control block from association table
free control block
376G
END

FIG. 5B

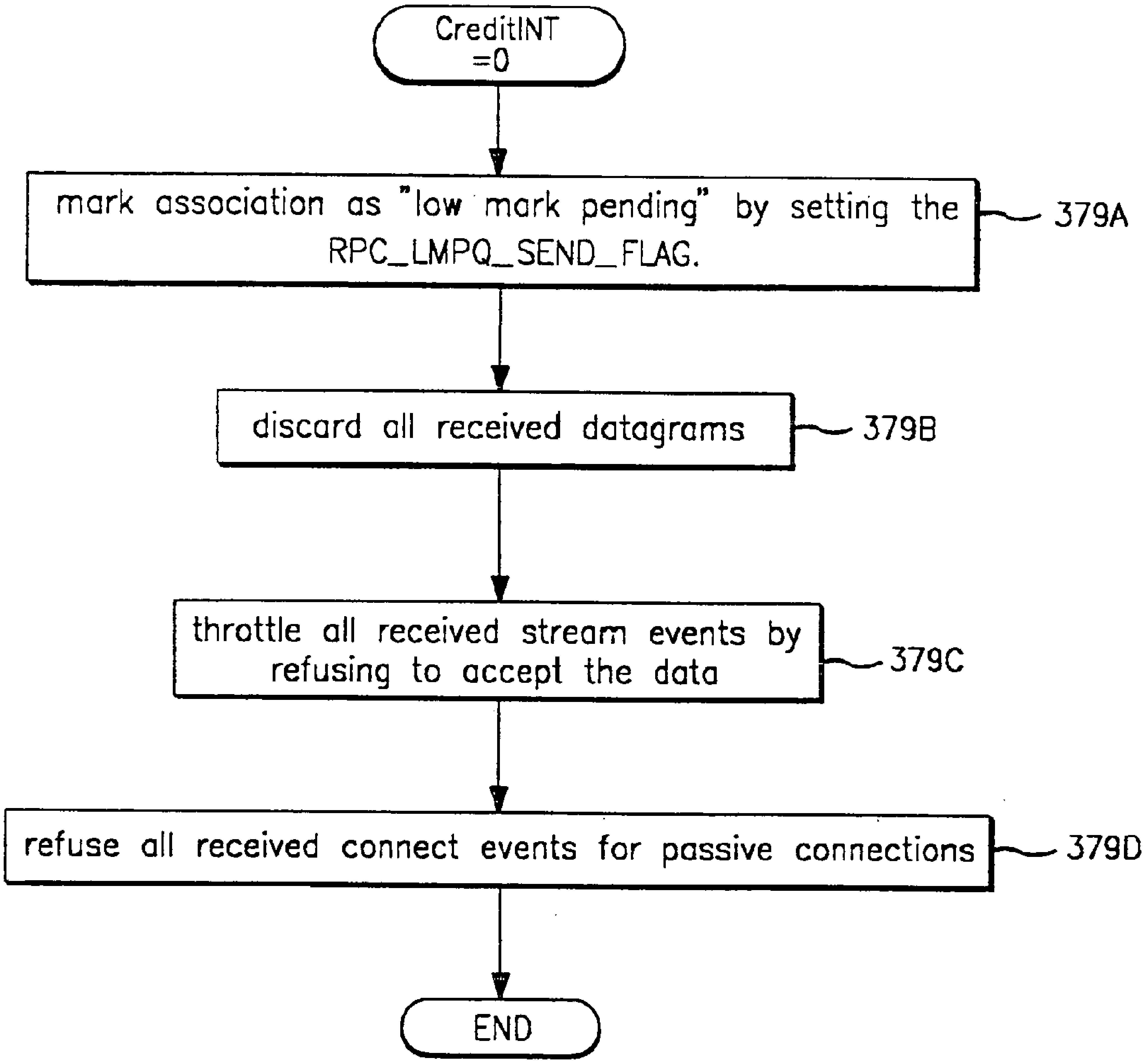

CreditINT =0
mark association as "low mark pending" by setting the RPC_LMPQ_SEND_FLAG.
379A
discard all received datagrams
379B
throttle all received stream events by refusing to accept the data
379C
refuse all received connect events for passive connections
379D
END

FIG. 5C

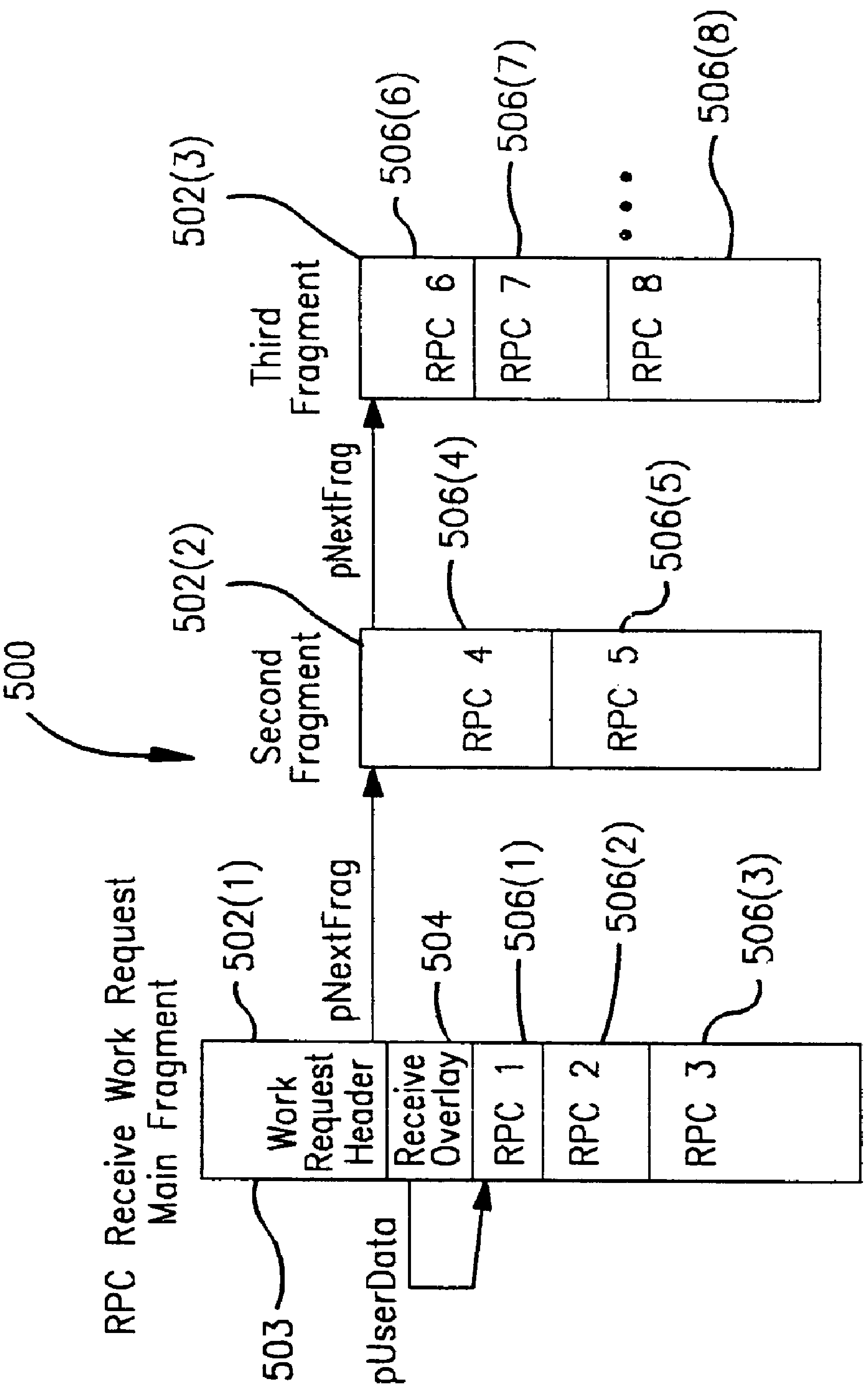

RPC Receive Work Request
Main Fragment
503
502(1)
Work Request Header
Receive Overlay
RPC 1
RPC 2
RPC 3
pUserData
504
506(1)
506(2)
506(3)
pNextFrag
500
Second Fragment
502(2)
RPC 4
RPC 5
506(4)
506(5)
pNextFrag
Third Fragment
502(3)
RPC 6
RPC 7
RPC 8
506(6)
506(7)
506(8)

FIG. 6

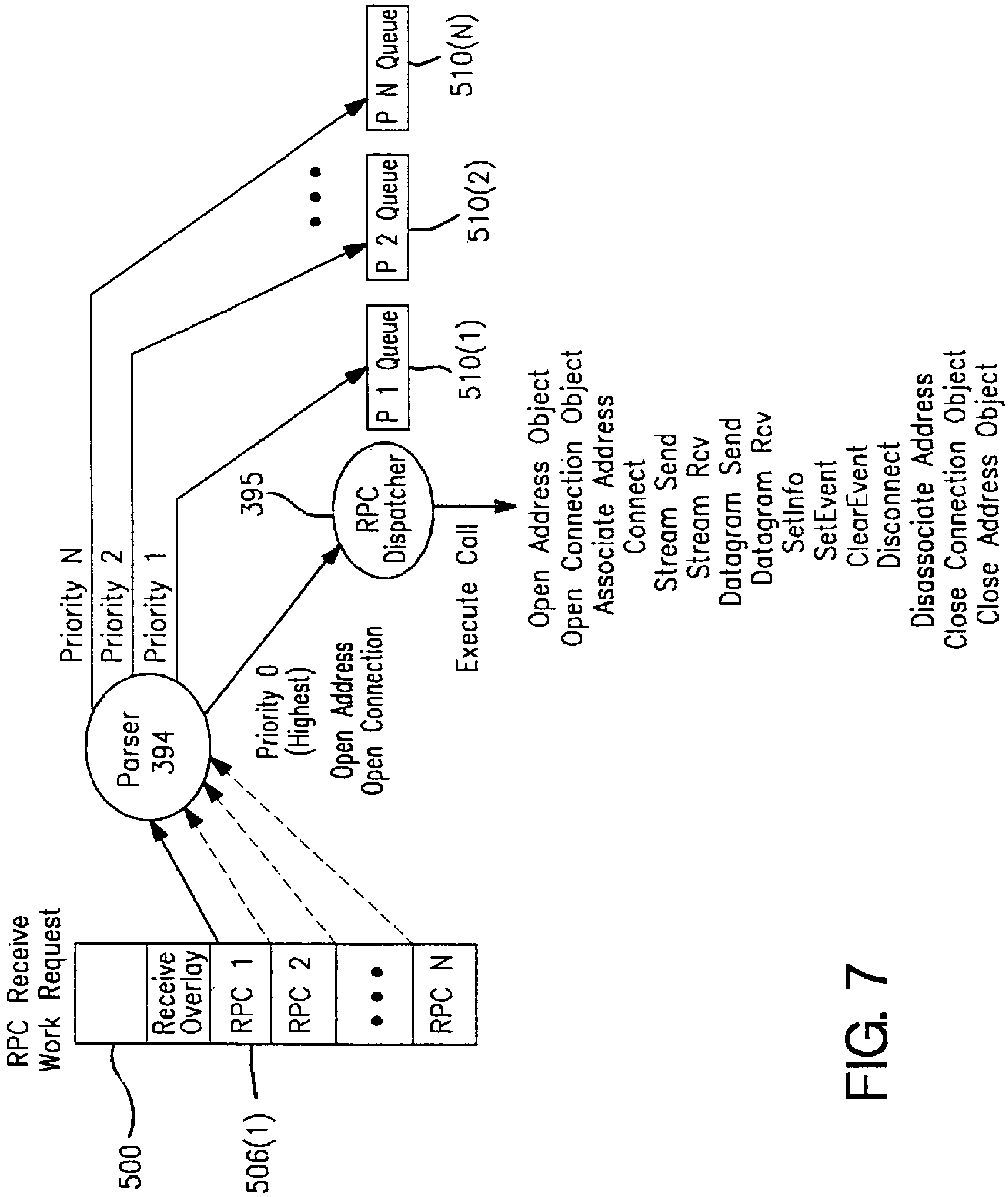

RPC Receive Work Request
500
506(1)
Receive Overlay
RPC 1
RPC 2
•••
RPC N
Parser 394
Priority N
Priority 2
Priority 1
Priority 0 (Highest)
Open Address
Open Connection
395
RPC Dispatcher
P 1 Queue
510(1)
P 2 Queue
510(2)
•••
P N Queue
510(N)
Execute Call
Open Address Object
Open Connection Object
Associate Address
Connect
Stream Send
Stream Rcv
Datagram Send
Datagram Rcv
SetInfo
SetEvent
ClearEvent
Disconnect
Disassociate Address
Close Connection Object
Close Address Object

FIG. 7

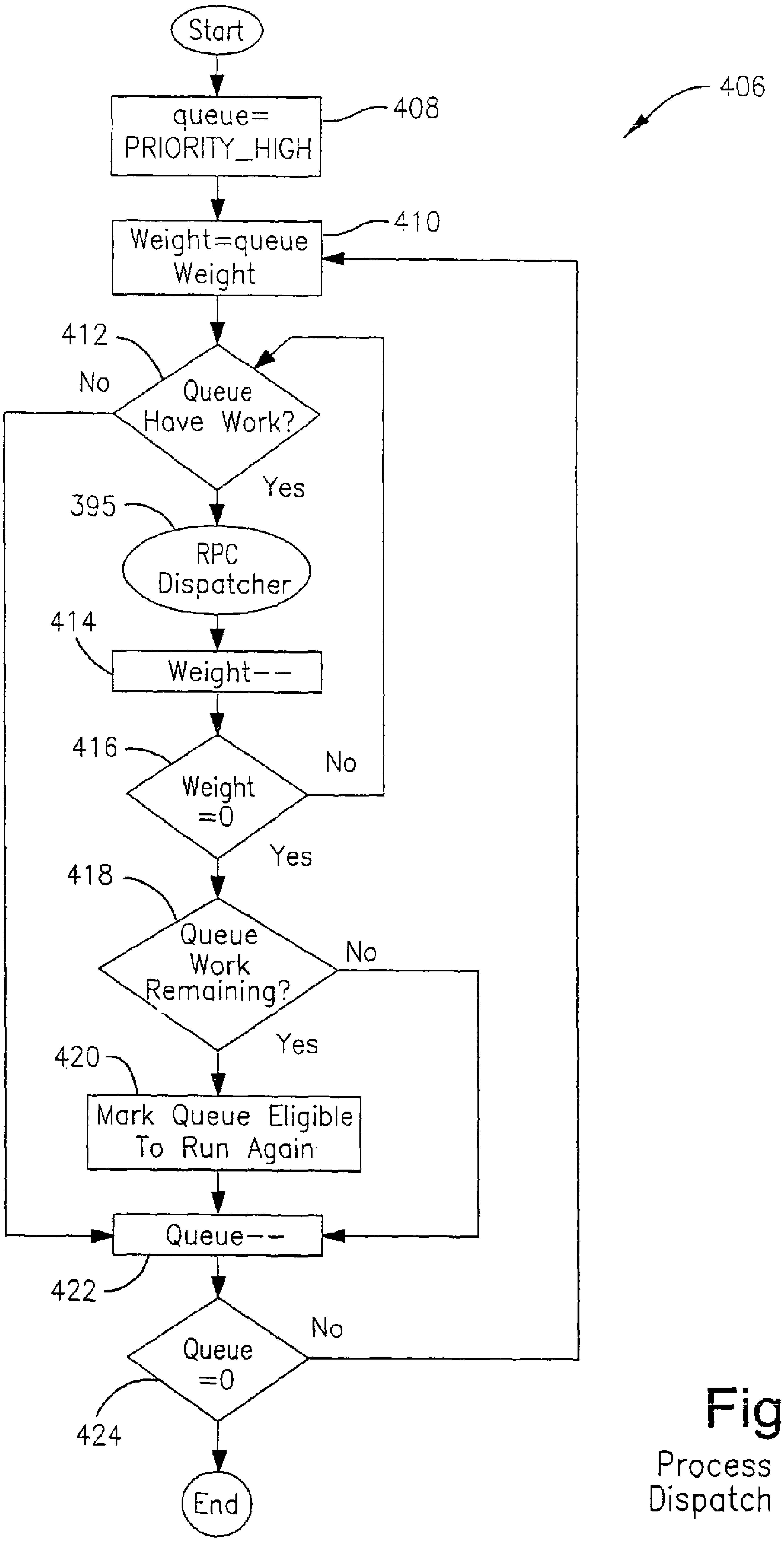


Fig. 8
Process Priority
Dispatch Queues

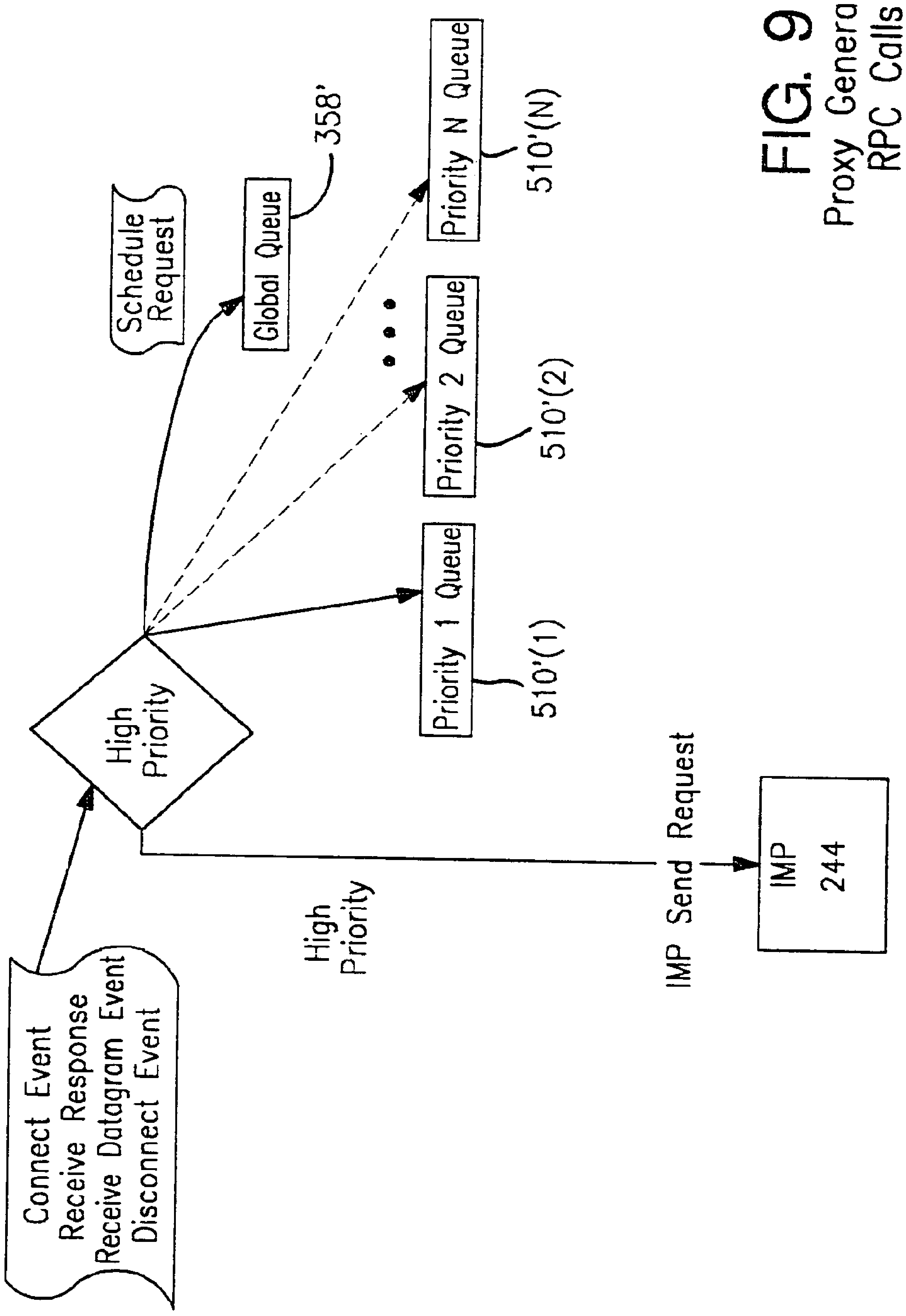


FIG. 9
Proxy Generated RPC Calls

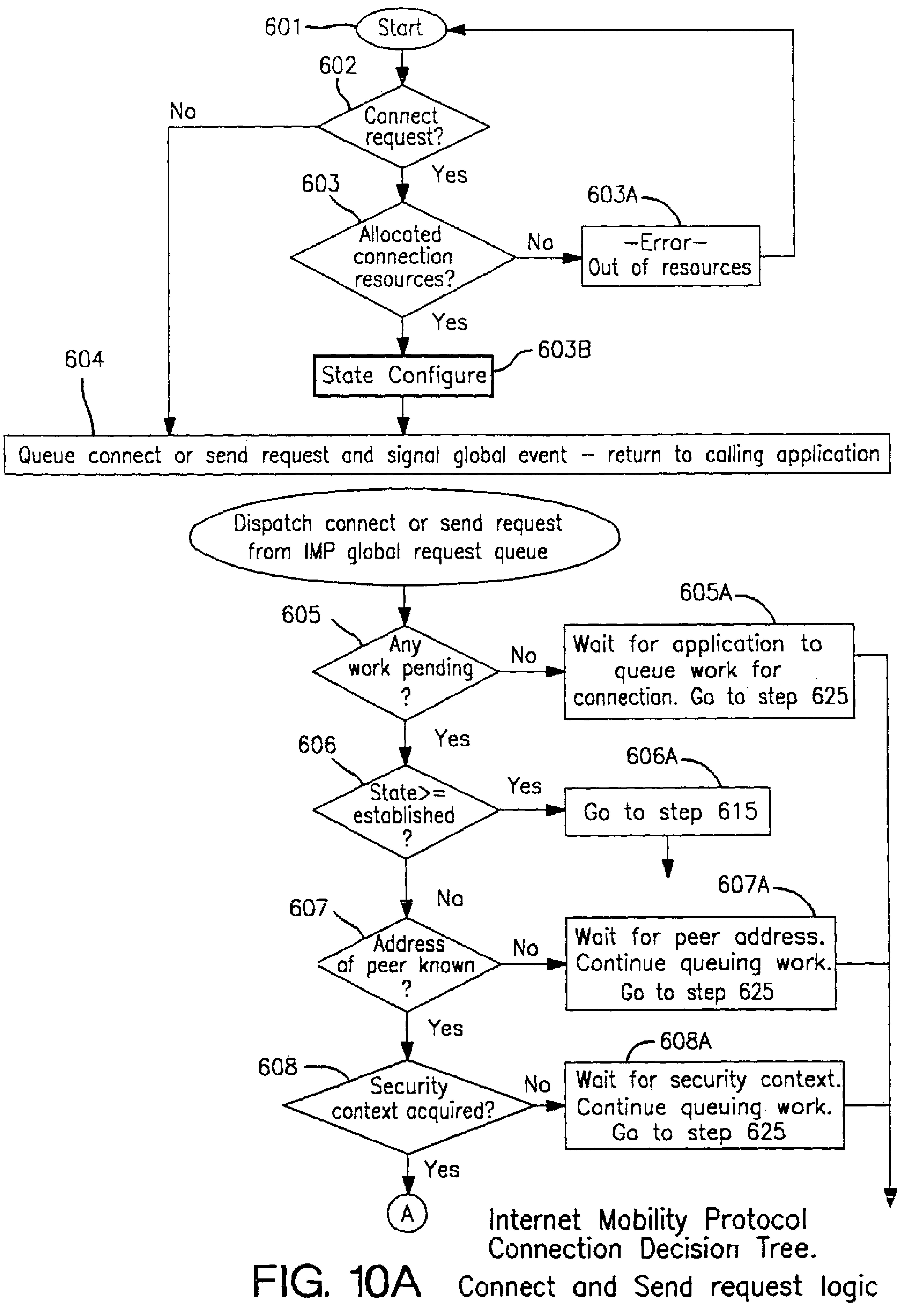


FIG. 10A Internet Mobility Protocol Connection Decision Tree. Connect and Send request logic

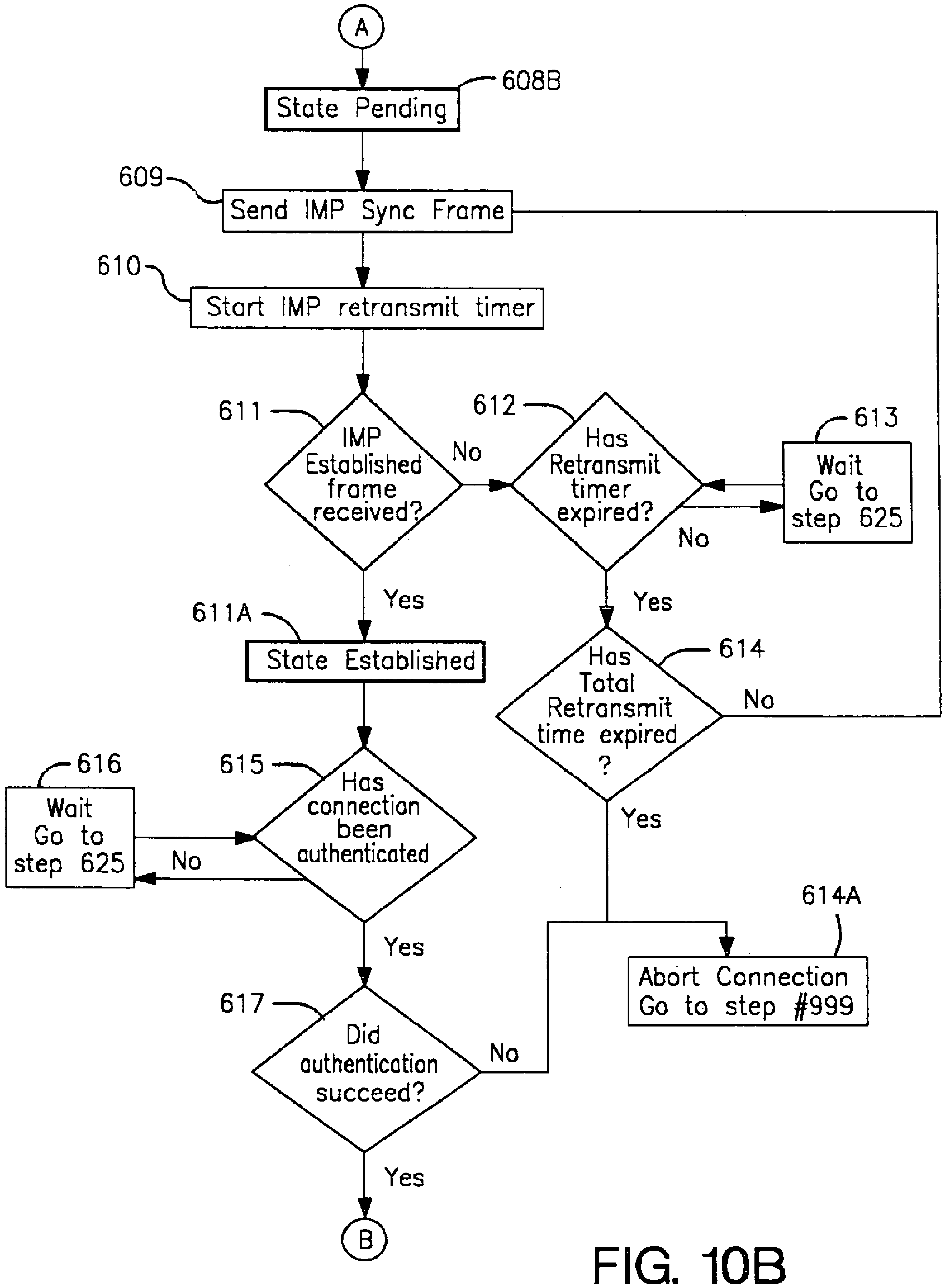

A
608B
State Pending
609
Send IMP Sync Frame
610
Start IMP retransmit timer
611
IMP Established frame received?
No
612
Has Retransmit timer expired?
613
Wait Go to step 625
No
Yes
Yes
611A
State Established
614
Has Total Retransmit time expired ?
No
616
615
Wait Go to step 625
Has connection been authenticated
No
Yes
614A
Abort Connection Go to step #999
Yes
617
Did authentication succeed?
No
Yes
B

FIG. 10B

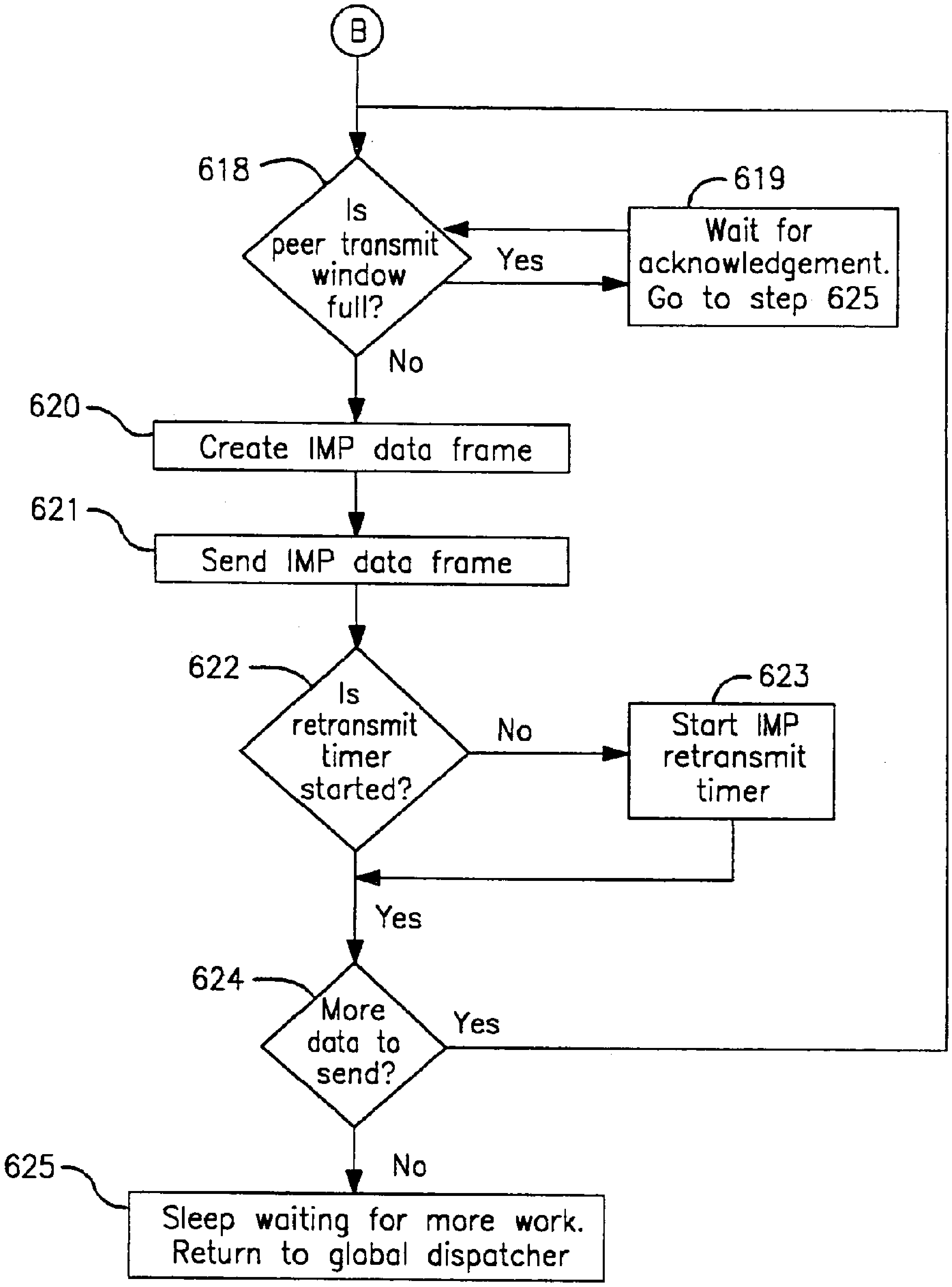

B
618
Is peer transmit window full?
Yes
No
619
Wait for acknowledgement. Go to step 625
620
Create IMP data frame
621
Send IMP data frame
622
Is retransmit timer started?
No
623
Start IMP retransmit timer
Yes
624
More data to send?
Yes
No
625
Sleep waiting for more work. Return to global dispatcher

FIG. 10C

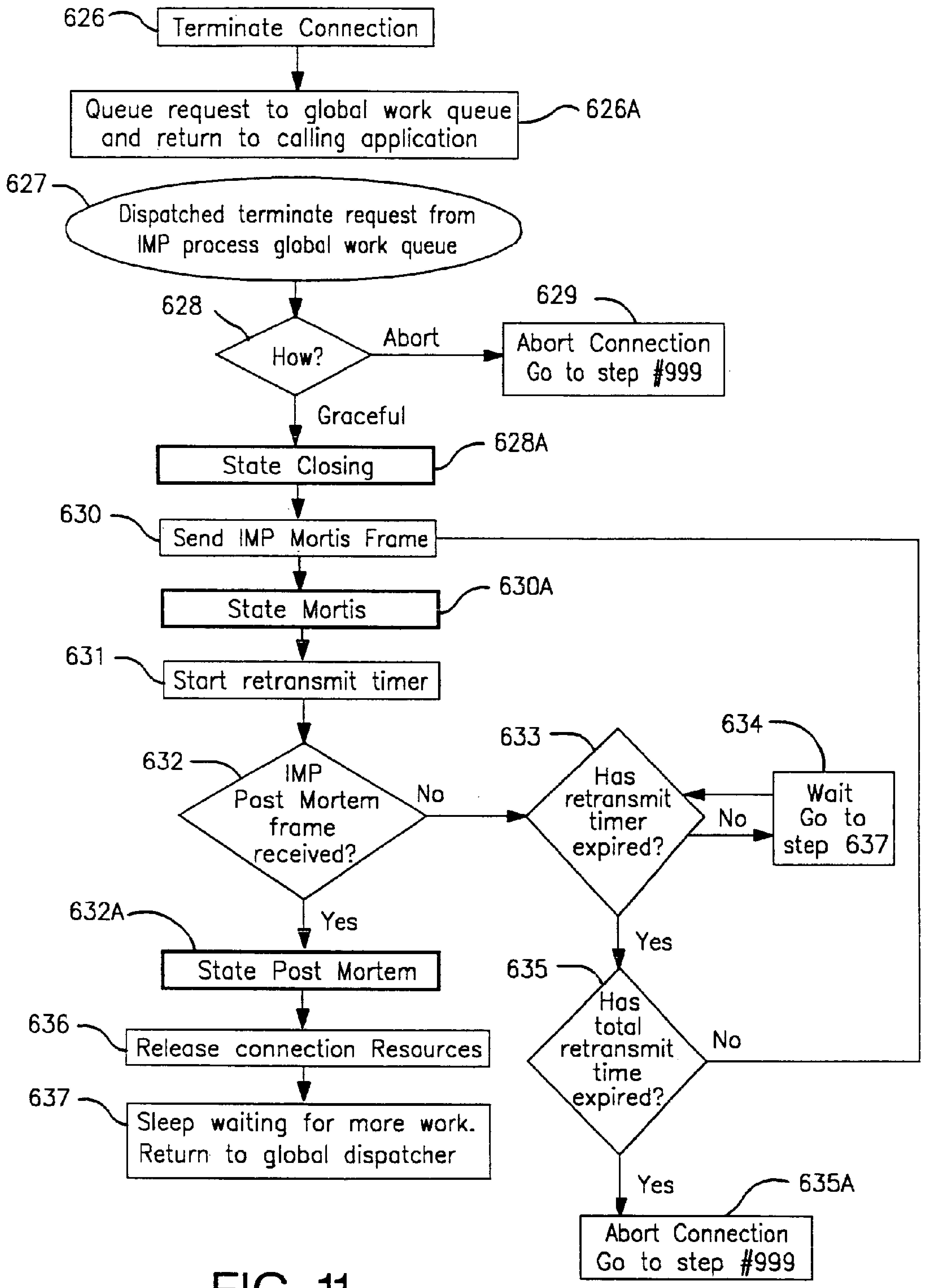


FIG. 11

Terminate Connection request logic

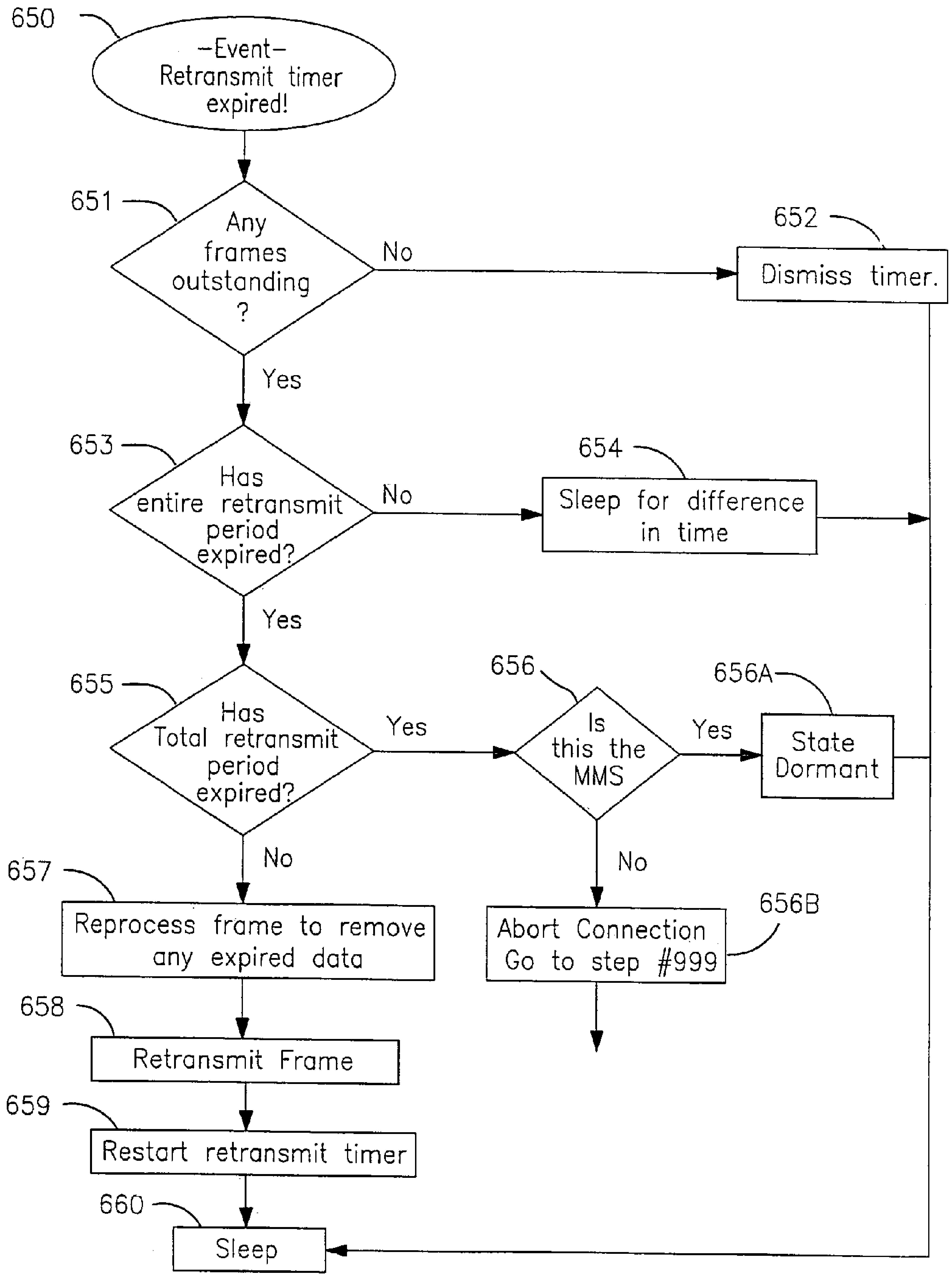


Fig. 12

Retransmit Event Logic

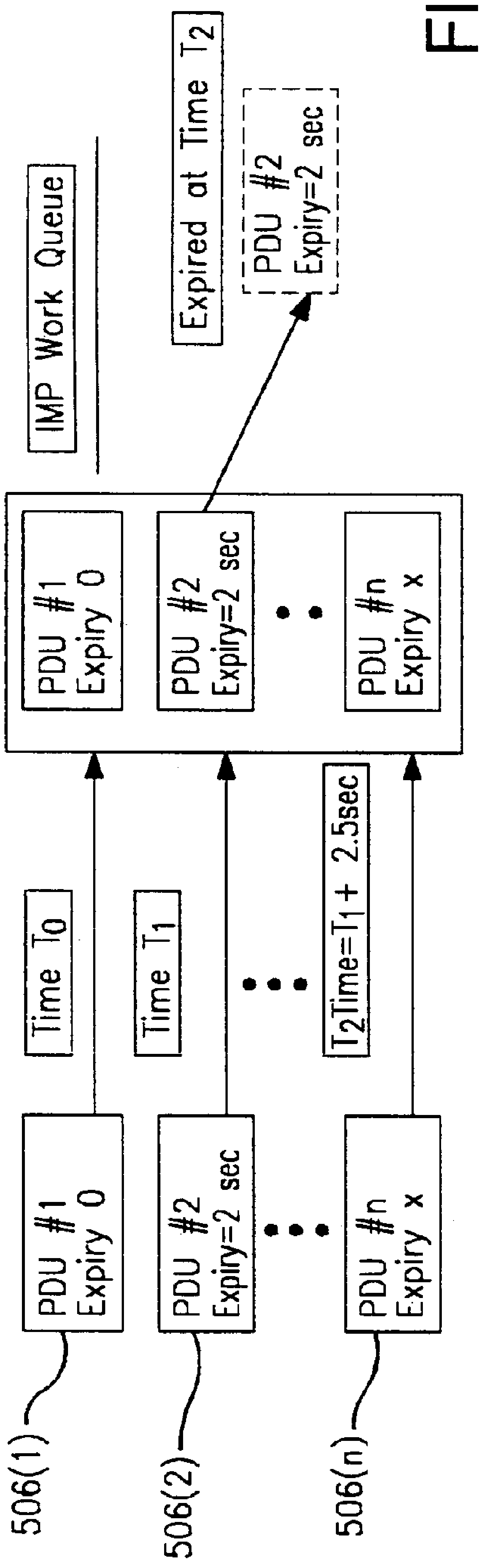


FIG. 12A

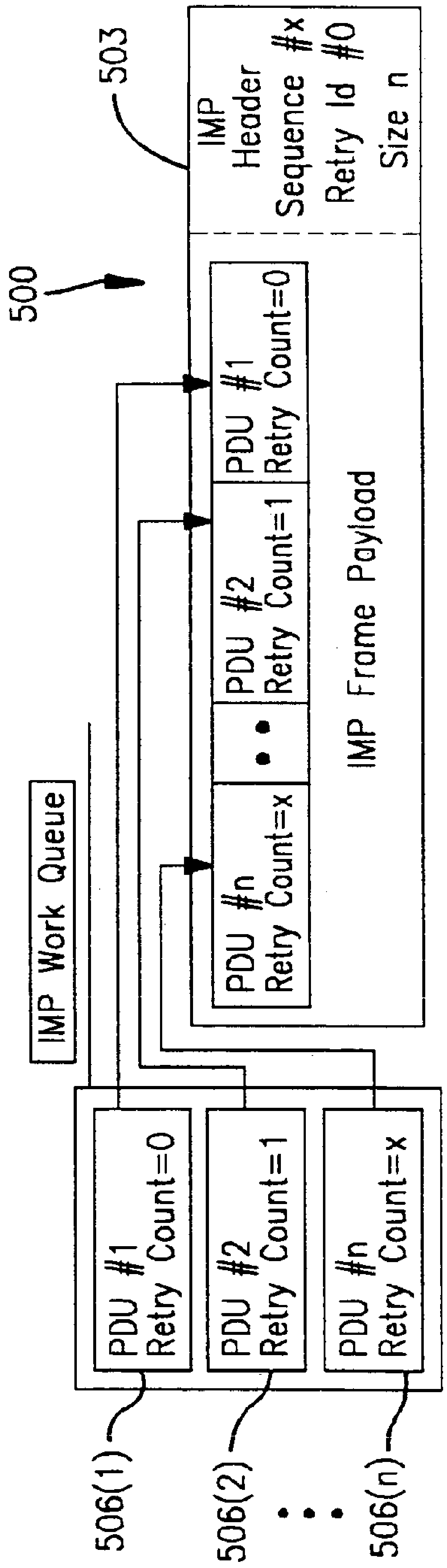


FIG. 12B

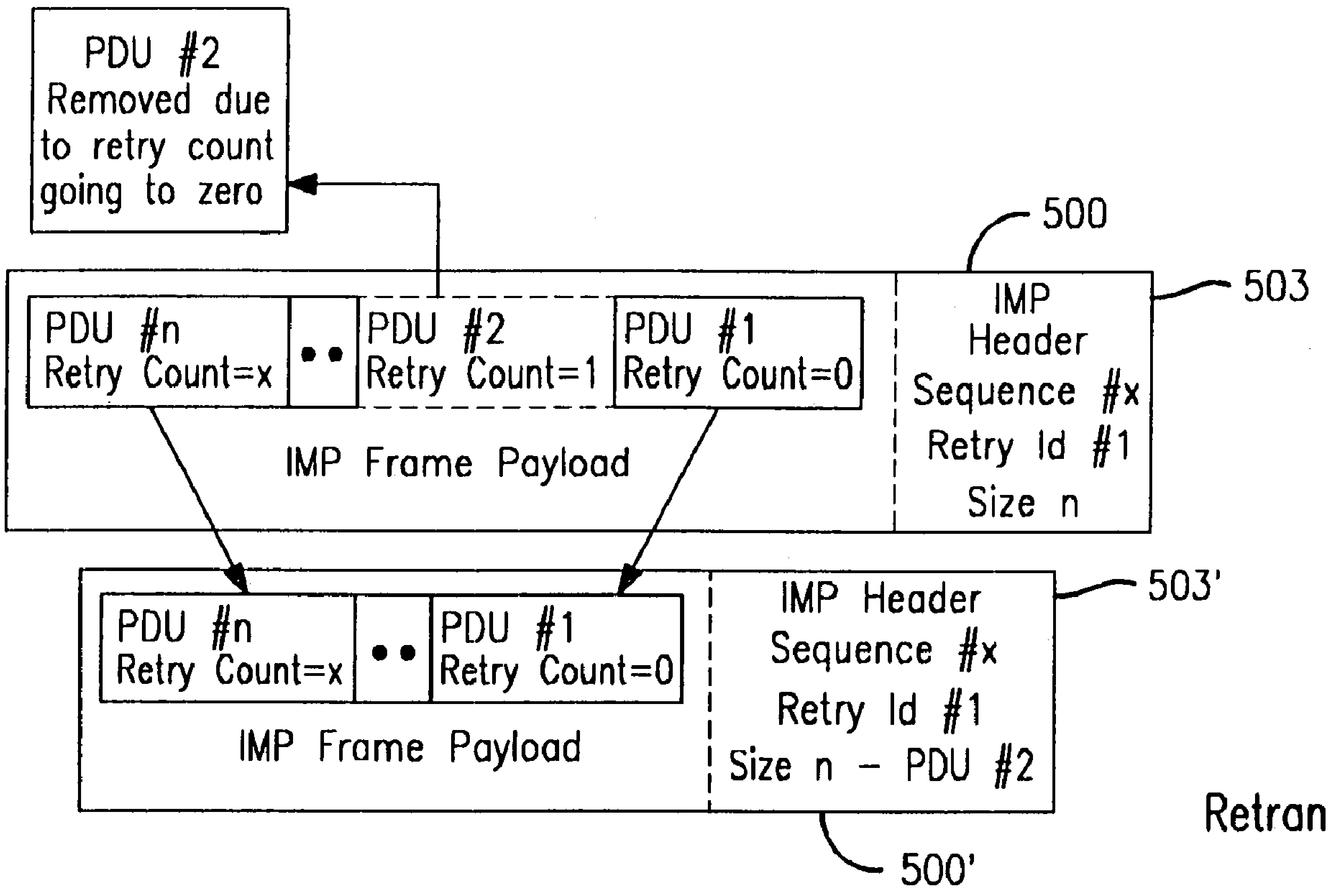


FIG. 12C

Retransmission of IMP Frame

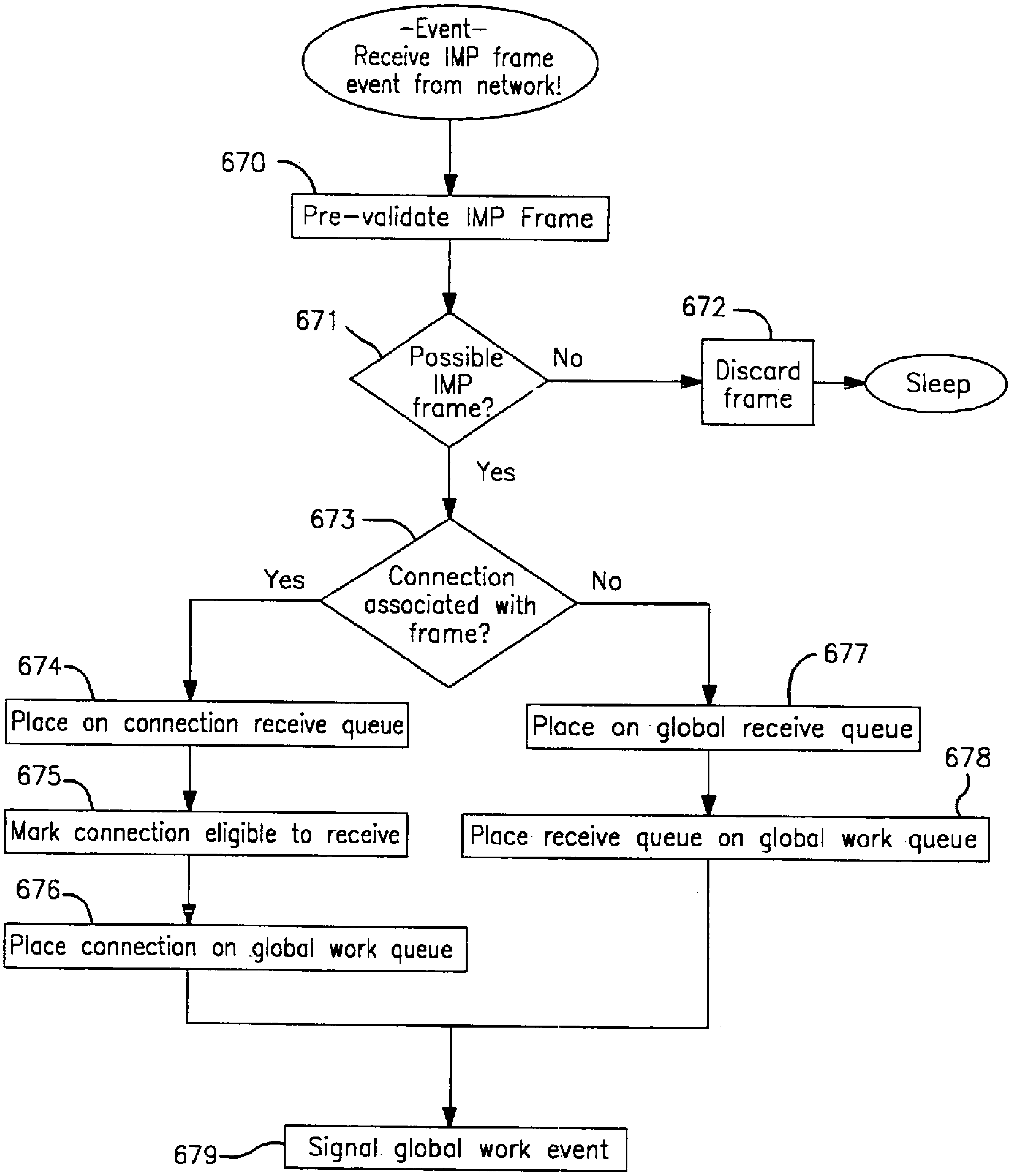


FIG. 13A

Receive Event Logic

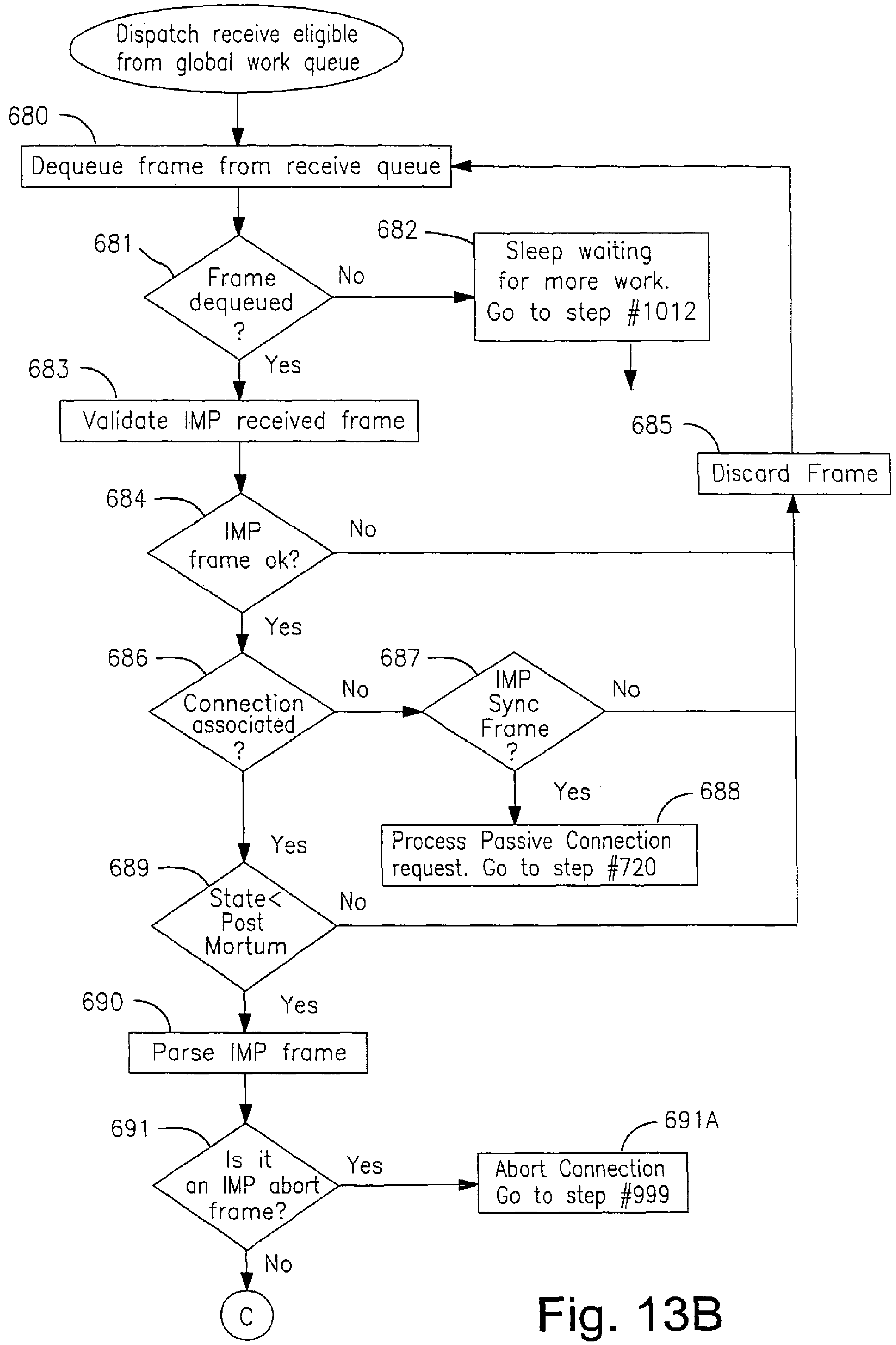

Dispatch receive eligible from global work queue
680
Dequeue frame from receive queue
681
Frame dequeued ?
No
682
Sleep waiting for more work. Go to step #1012
Yes
683
Validate IMP received frame
685
Discard Frame
684
IMP frame ok?
No
Yes
686
Connection associated ?
No
687
IMP Sync Frame ?
No
Yes
688
Process Passive Connection request. Go to step #720
Yes
689
State< Post Mortum
No
690
Yes
Parse IMP frame
691
Is it an IMP abort frame?
Yes
691A
Abort Connection Go to step #999
No
C

Fig. 13B

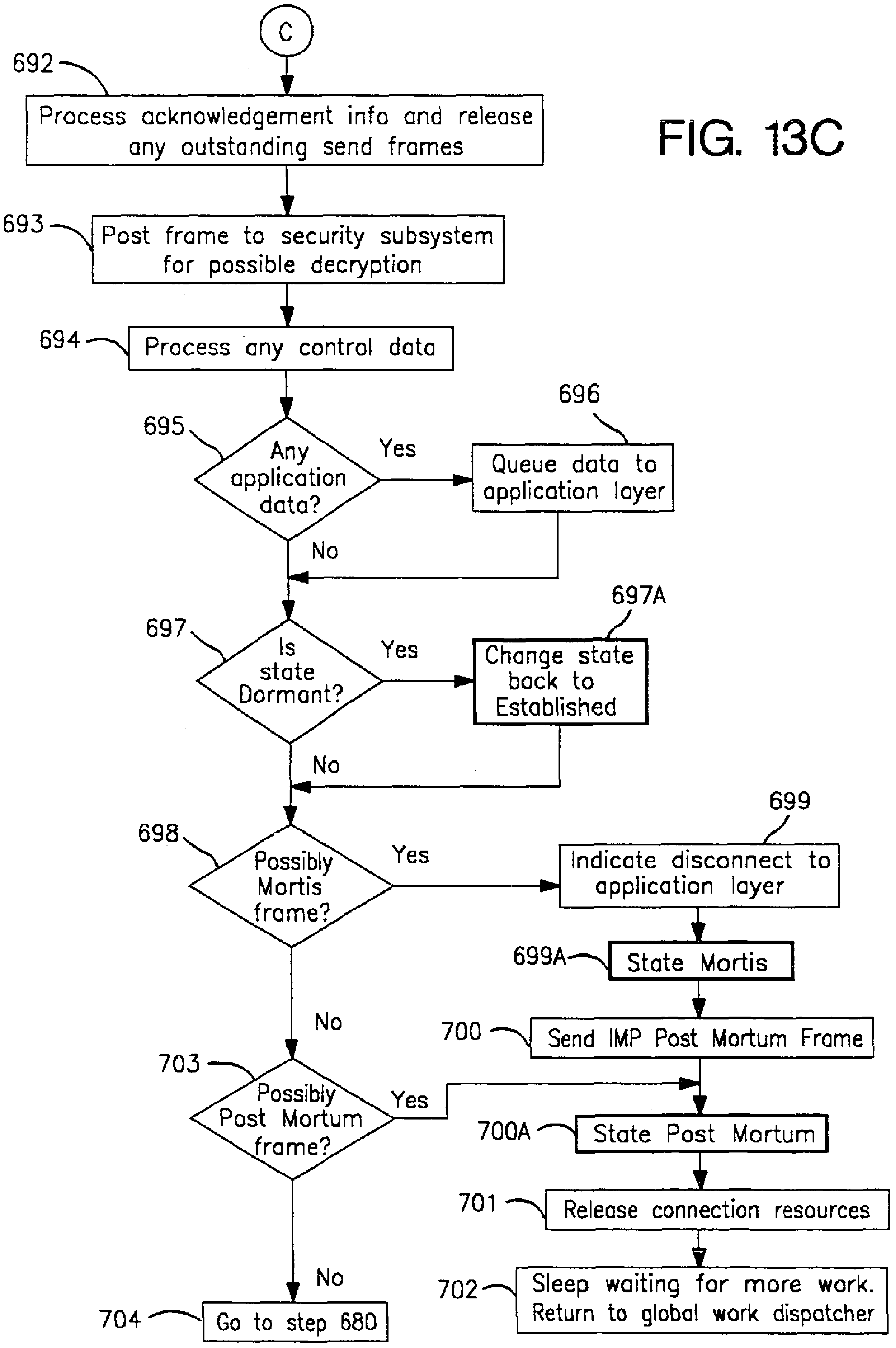

C
692
Process acknowledgement info and release any outstanding send frames
693
Post frame to security subsystem for possible decryption
694
Process any control data
695
Any application data?
Yes
No
696
Queue data to application layer
697
Is state Dormant?
Yes
No
697A
Change state back to Established
698
Possibly Mortis frame?
Yes
No
699
Indicate disconnect to application layer
699A
State Mortis
700
Send IMP Post Mortum Frame
703
Possibly Post Mortum frame?
Yes
No
700A
State Post Mortum
701
Release connection resources
702
Sleep waiting for more work. Return to global work dispatcher
704
Go to step 680

FIG. 13C

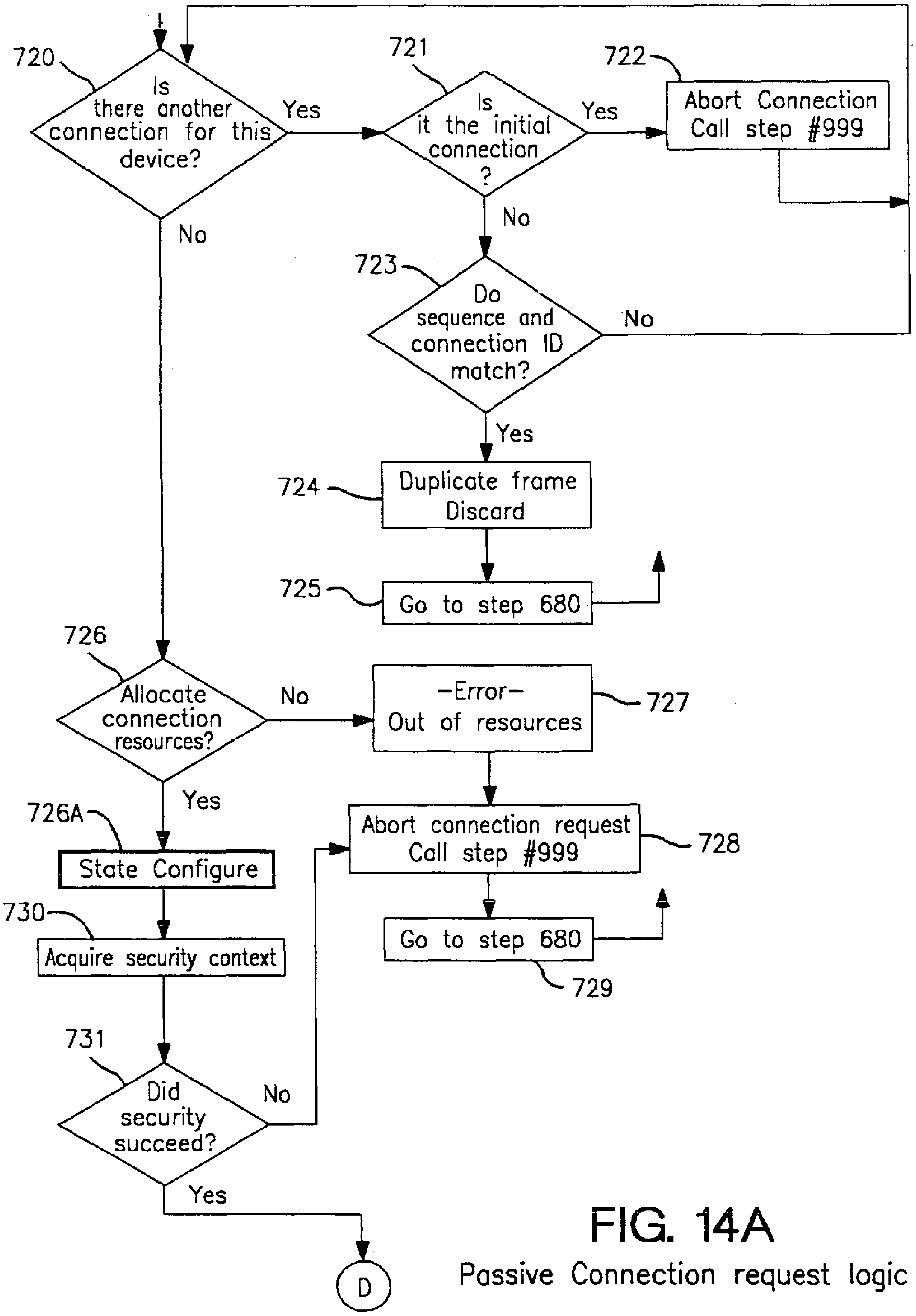


FIG. 14A

Passive Connection request logic

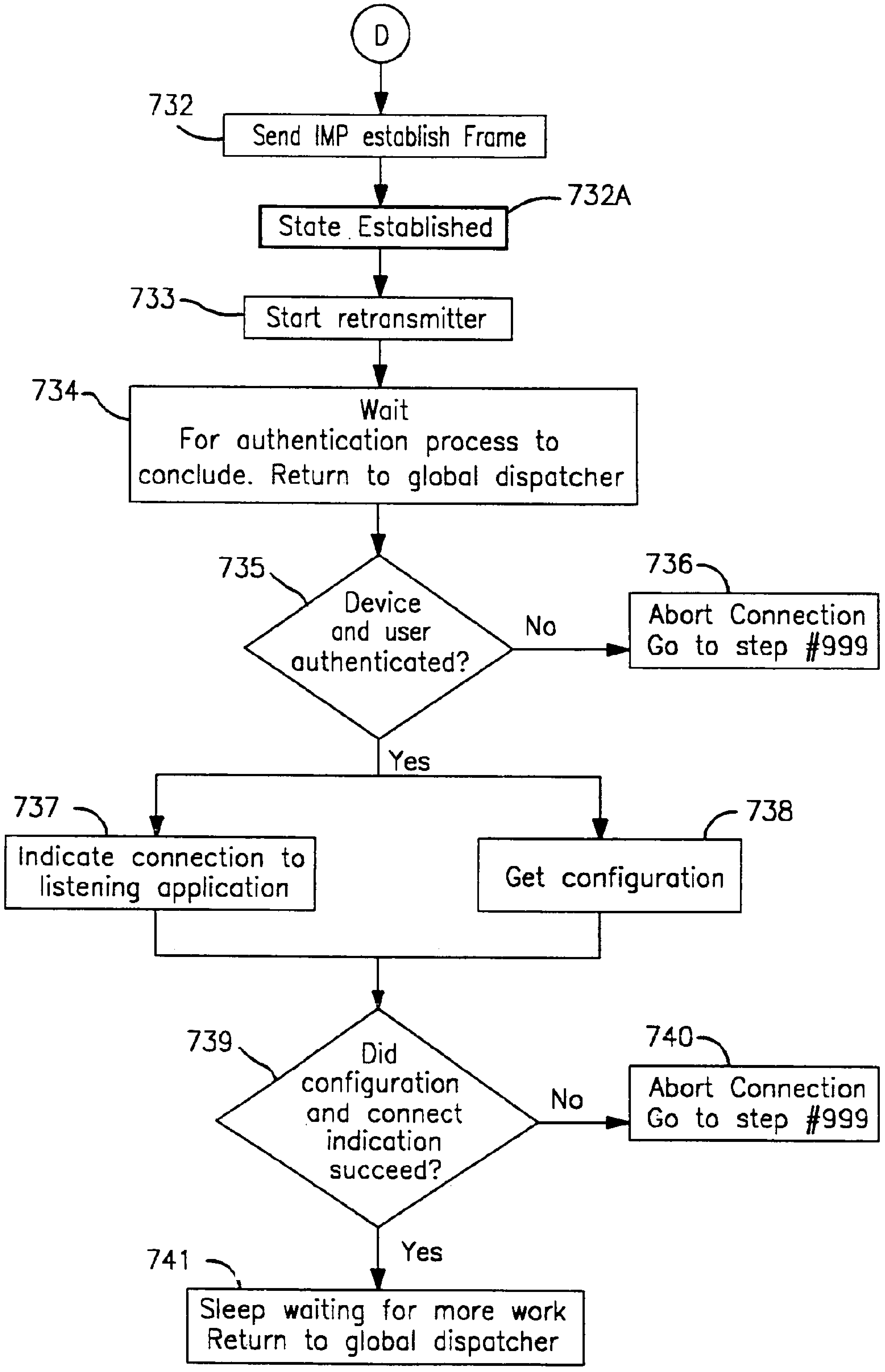

D
732
Send IMP establish Frame
732A
State Established
733
Start retransmitter
734
Wait
For authentication process to conclude. Return to global dispatcher
735
Device and user authenticated?
No
736
Abort Connection
Go to step #999
Yes
737
Indicate connection to listening application
738
Get configuration
739
Did configuration and connect indication succeed?
No
740
Abort Connection
Go to step #999
Yes
741
Sleep waiting for more work
Return to global dispatcher

FIG. 14B

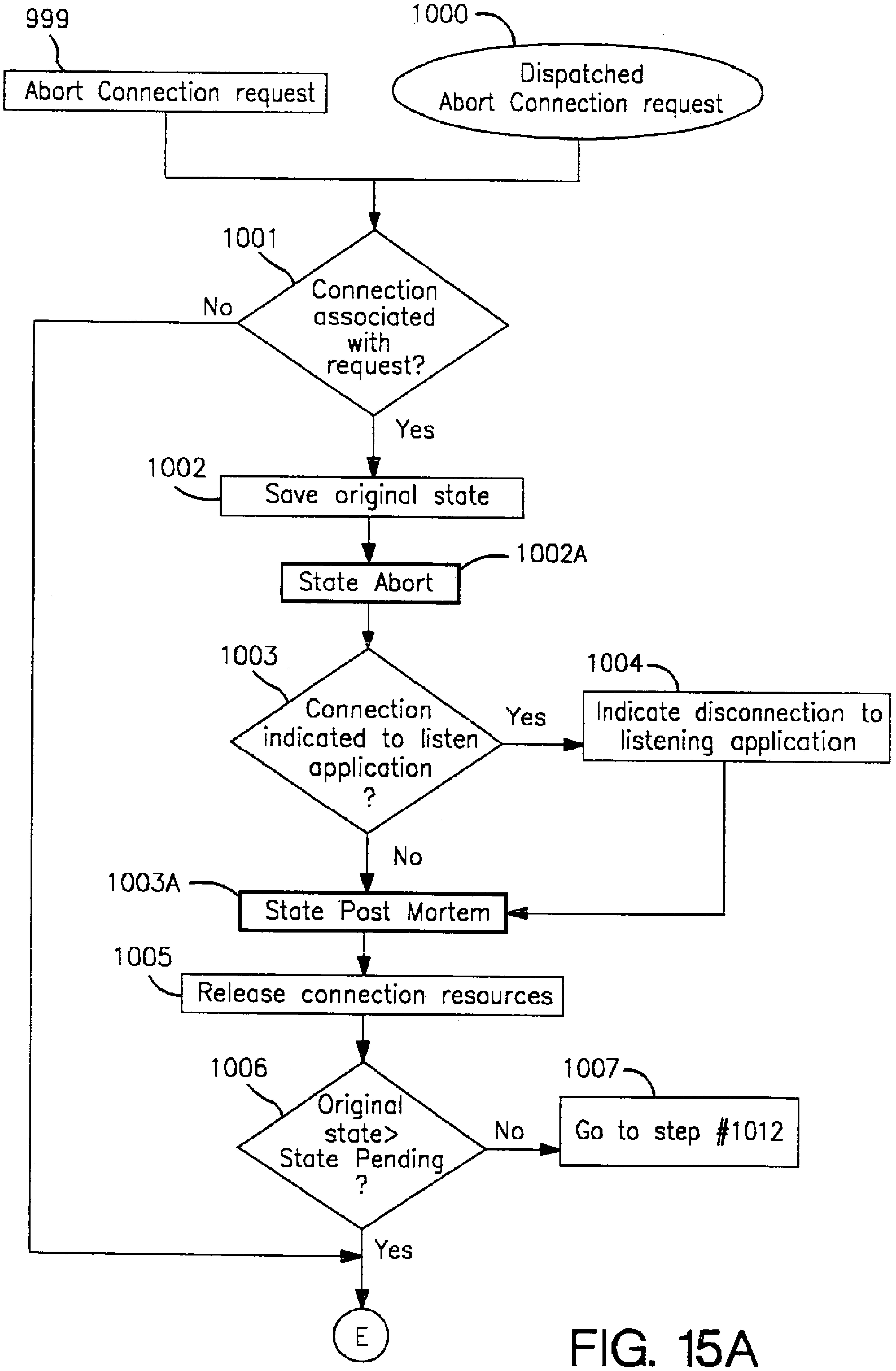


FIG. 15A

Abort Connection request logic

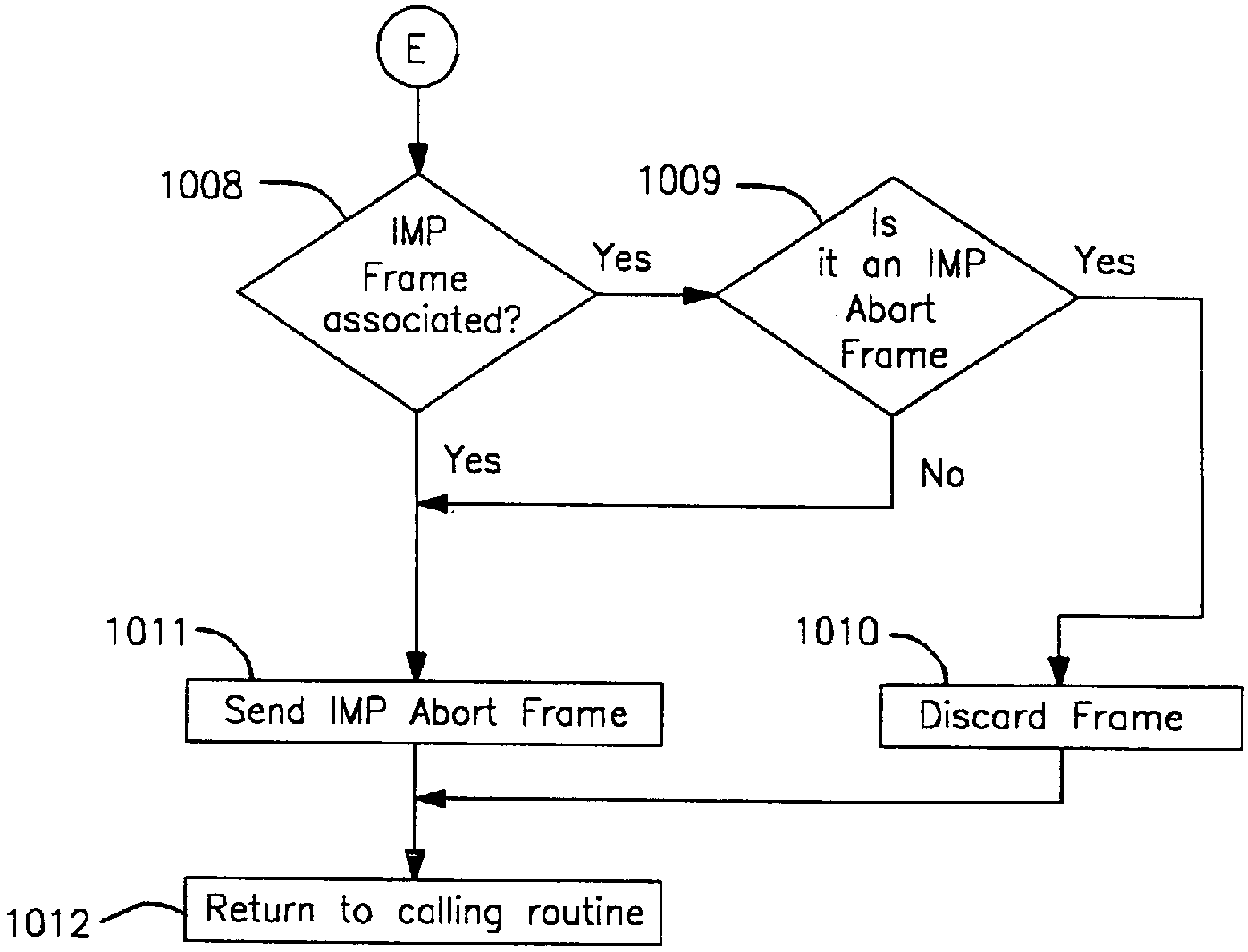
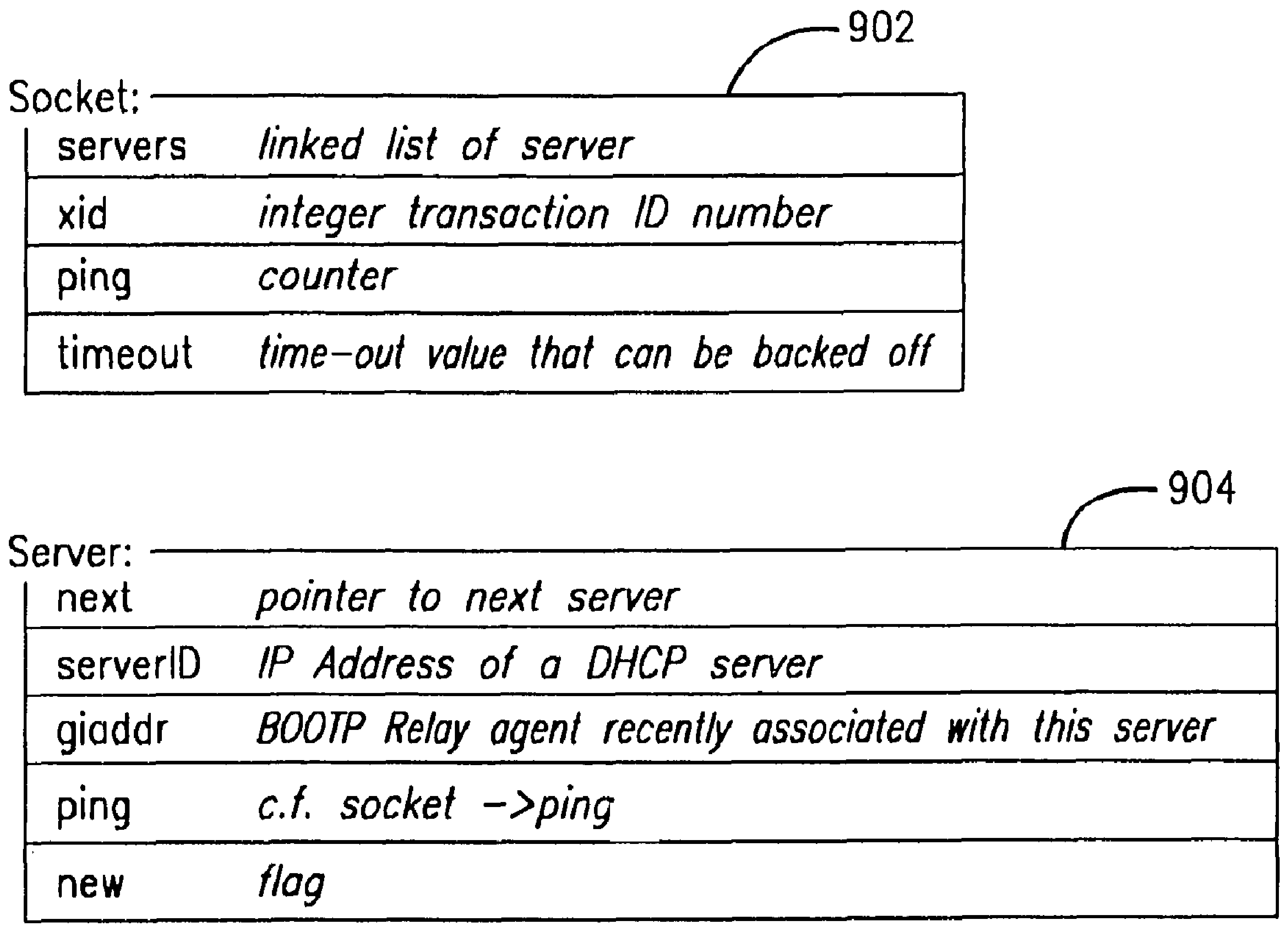

E
1008
IMP Frame associated?
Yes
1009
Is it an IMP Abort Frame
Yes
Yes
No
1011
Send IMP Abort Frame
1010
Discard Frame
1012
Return to calling routine

FIG. 15B



Socket:

servers	*linked list of server*
xid	*integer transaction ID number*
ping	*counter*
timeout	*time-out value that can be backed off*

Server:

next	*pointer to next server*
serverID	*IP Address of a DHCP server*
giaddr	*BOOTP Relay agent recently associated with this server*
ping	*c.f. socket ->ping*
new	*flag*

FIG. 16

DHCP Listener Data Structures

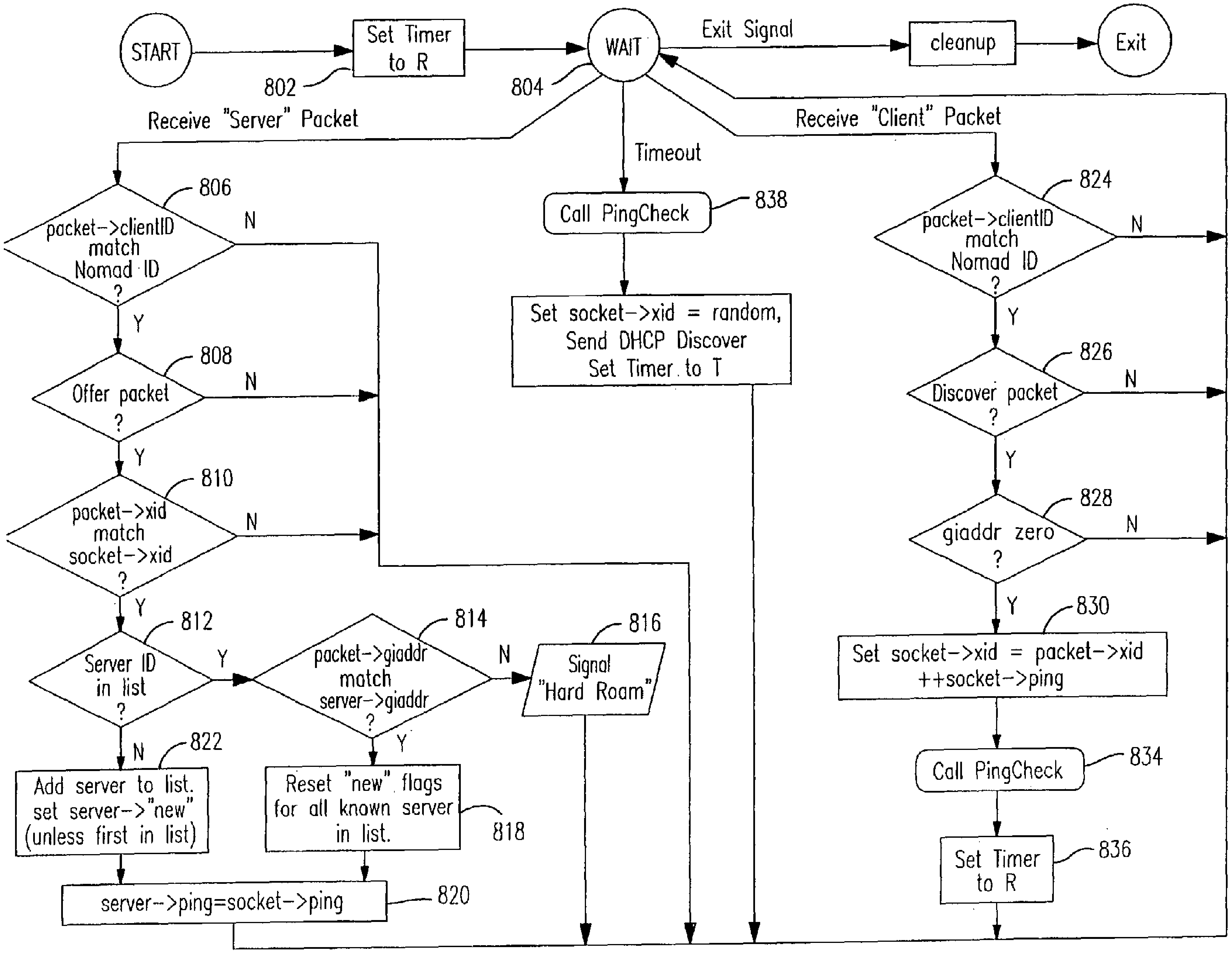

START
Set Timer to R
802
WAIT
804
Exit Signal
cleanup
Exit
Receive "Server" Packet
Timeout
Receive "Client" Packet
806
packet->clientID match Nomad ID ?
N
Y
808
Offer packet ?
N
Y
810
packet->xid match socket->xid ?
N
Y
812
Server ID in list ?
Y
N
814
packet->giaddr match server->giaddr ?
N
Y
816
Signal "Hard Roam"
822
Add server to list. set server->"new" (unless first in list)
Reset "new" flags for all known server in list.
818
server->ping=socket->ping
820
Call PingCheck
838
Set socket->xid = random, Send DHCP Discover Set Timer to T
824
packet->clientID match Nomad ID ?
N
Y
826
Discover packet ?
N
Y
828
giaddr zero ?
N
Y
830
Set socket->xid = packet->xid ++socket->ping
Call PingCheck
834
Set Timer to R
836

Fig. 17

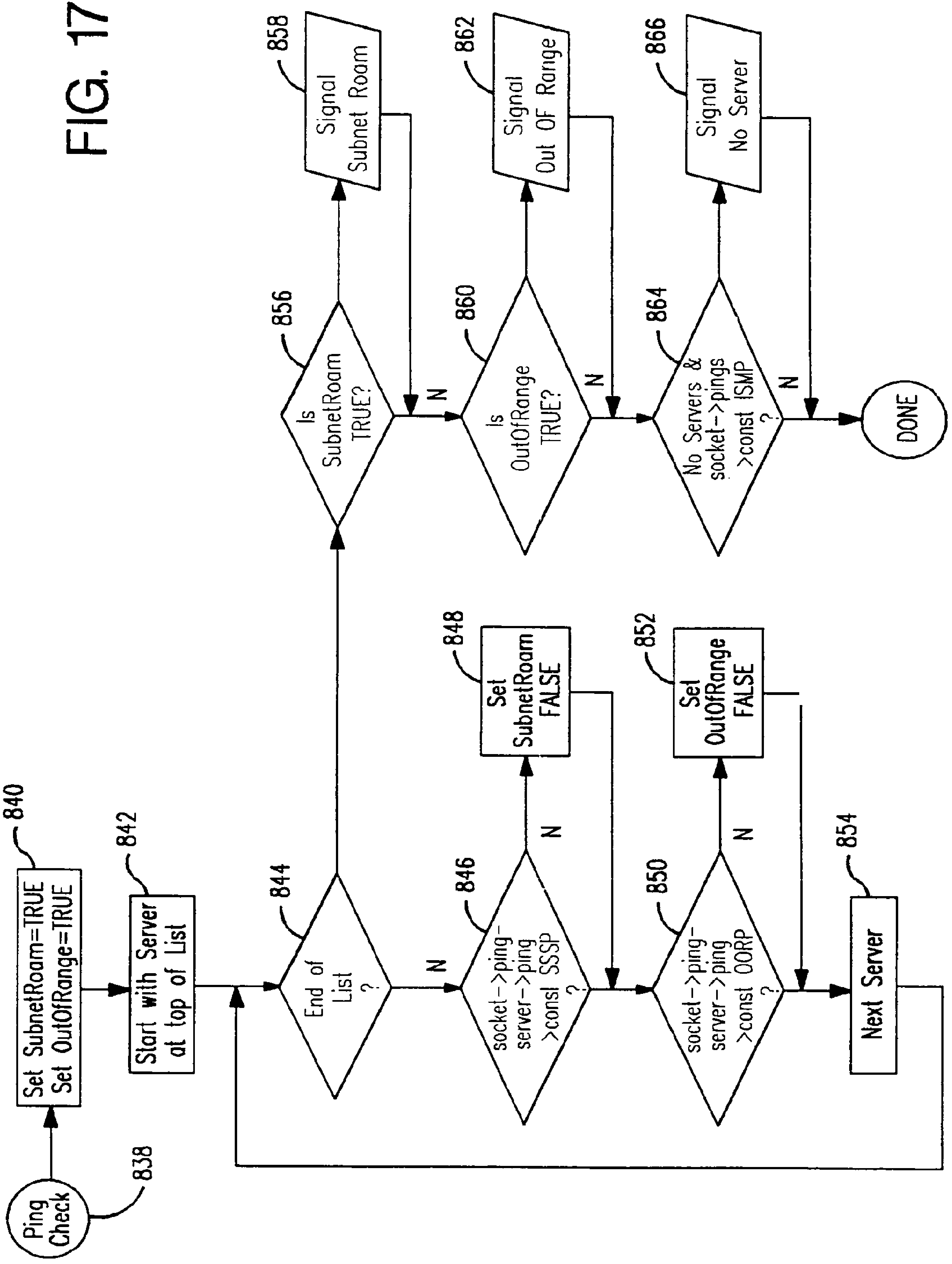

Ping Check
838
Set SubnetRoam=TRUE
Set OutOfRange=TRUE
840
Start with Server at top of List
842
End of List ?
844
N
socket->ping-server->ping >const SSSP ?
846
N
Set SubnetRoam FALSE
848
socket->ping-server->ping >const OORP ?
850
N
Set OutOfRange FALSE
852
Next Server
854
Is SubnetRoam TRUE?
856
Signal Subnet Roam
858
N
Is OutOfRange TRUE?
860
Signal Out OF Range
862
N
No Servers & socket->pings >const ISMP ?
864
Signal No Server
866
N
DONE

FIG. 17A

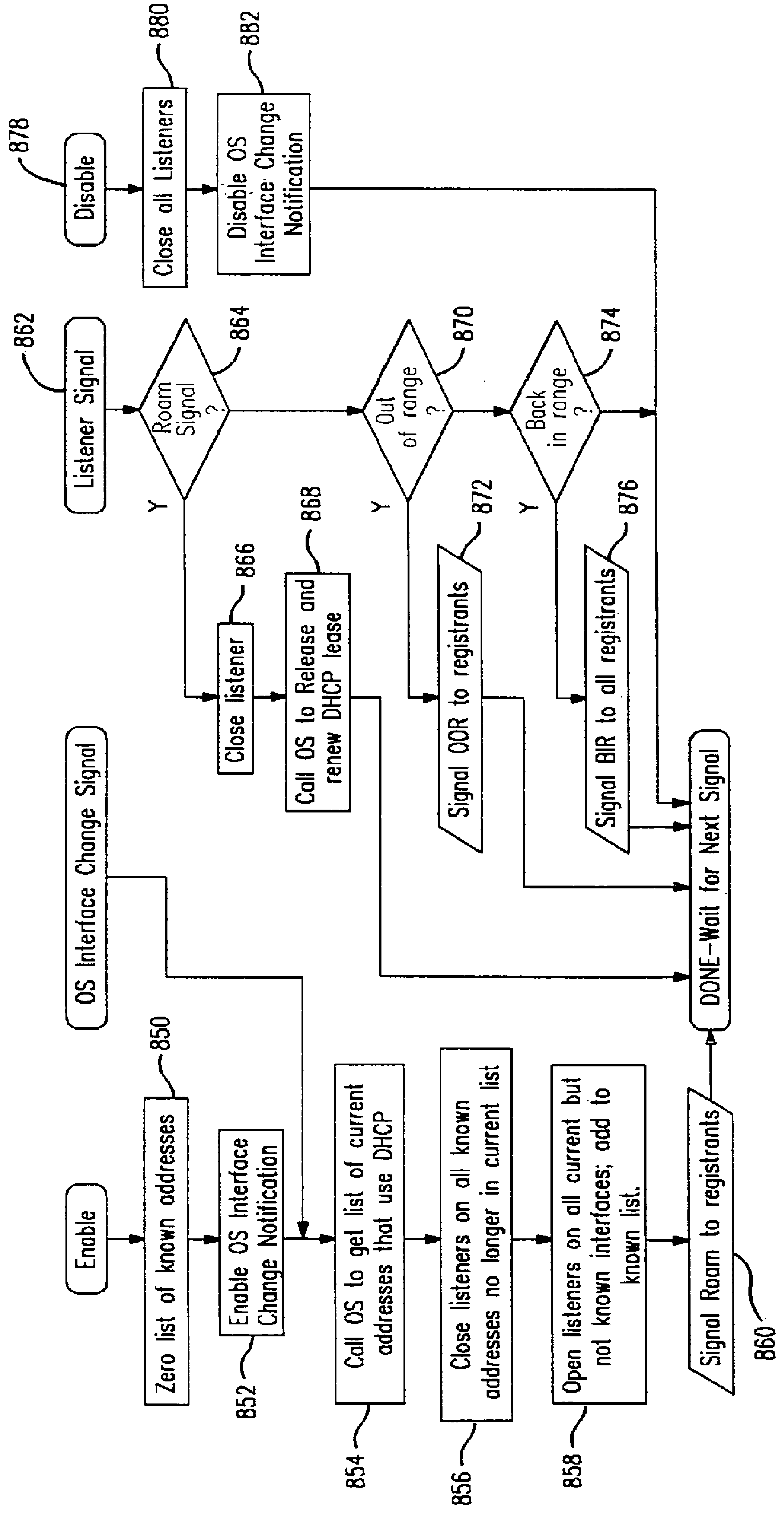


FIG. 18

ROAMING CONTROL CENTER–
Mobile End System

METHOD AND APPARATUS FOR PROVIDING MOBILE AND OTHER INTERMITTENT CONNECTIVITY IN A COMPUTING ENVIRONMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a divisional application of application Ser. No. 10/307,480, filed Dec. 2, 2002, entitled "Method and Apparatus for Providing Mobile and Other Intermittent Connectivity in a Computing Environment," now allowed; which is a division of application Ser. No. 09/330,310, filed Jun. 11, 1999, entitled "Method And Apparatus For Providing Mobile And Other Intermittent Connectivity In A Computing Environment," now U.S. Pat. No. 6,546,425, which claims the benefit of provisional application No. 60/103,598 filed Oct. 9, 1998 entitled "Method and Apparatus For Providing Wireless Connectivity In A Computing Environment" the entire content of each of which is hereby incorporated by reference in this application.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not applicable.

FIELD

The present invention relates to connectivity between networked computing devices. More particularly, the present invention relates to methods and systems that transparently address the characteristics of nomadic systems, and enable existing network applications to run reliably in the associated mobile environments. Still more particularly, the invention relates to techniques and systems for providing a continuous data stream connection between intermittently-connected devices such as handheld data units and personal computing devices.

BACKGROUND AND SUMMARY

Increasingly, companies are seeing rapid access to key information as the way to maintaining a competitive advantage. To provide immediate access to this information, mobile and other intermittently-connected computing devices are quietly and swiftly becoming an essential part of corporate networks—especially with the proliferation of inexpensive laptops and hand-held computing devices. However, integrating these nomadic devices into existing network infrastructures has created a challenge for the information manager.

Many problems in mobile networking parallel the difficulties in early local area networks (LANs) before the adoption of Ethernet. There are a variety of mobile protocols and interfaces, and because standards are just developing, there is little interoperability between systems. In addition, performance over these network technologies has been typically slow and bandwidth limited. Implementation costs to date have been high due the specialized nature of deployed systems.

Along with these issues, mobile technologies present a category of problems unto their own. Interconnects back into the main network may travel over and through a public network infrastructure, thus allowing sensitive information to possibly be tapped into. Furthermore, if any of the intermediary interconnects are via a wireless interface, the information is actually broadcast, and anyone with a similar interface can eavesdrop without much difficulty.

But, perhaps even more significantly, mobile networking has generally in the past been limited to mostly message-oriented or stateless applications—and thus has not been readily adaptable for existing or new corporate applications that use client/server, host-terminal, web-based or shared file systems models. This is because such commonly used applications need stateful sessions that employ a continuous stream of data—not just a stateless packet exchange—to work effectively and reliably.

To this end, many or most popular off-the-shelf networking applications require TCP/IP sessions, or private virtual circuits. These sessions cannot continue to function if they encounter network interruptions, nor can they tolerate roaming between networks (i.e., a change of network addresses) while established. Yet, mobile networking is, by its nature, dynamic and unreliable. Consider these common scenarios encountered in mobile networks:

Disconnected or Out of Range User

When a mobile device disconnects from a given network or loses contact (e.g., through an outage or "hole" in the coverage of a wireless interconnect), the session-oriented application running on the mobile device loses its stateful connection with its peer and ceases to operate. When the device is reattached or moves back into contact, the user must re-connect, log in again for security purposes, find the place in the application where work was left off, and possibly re-enter lost data. This reconnection process is time consuming, costly, and can be very frustrating.

Moving to a Different Network or Across a Router Boundary (Network Address Change)

Mobile networks are generally segmented for manageability purposes. But the intent of mobile devices is to allow them to roam. Roaming from one network interconnect to another can mean a change of network address. If this happens while the system is operational, the routing information must be changed for communications to continue between the associated peers. Furthermore, acquiring a new network address may require all of the previously established stateful application sessions to be terminated—again presenting the reconnection problems noted above.

Security

As mentioned before, companies need to protect critical corporate data. Off-the-shelf enterprise applications are often written with the assumption that access to the physical network is controlled (i.e., carried within cables installed inside a secure facility), and security is maintained through an additional layer of authentication and possible encryption. These assumptions have not been true in the nomadic computing world—where data is at risk for interception as it travels over public airways or public wire-line infrastructures.

SUMMARY

It would be highly desirable to provide an integrated solution that transparently addresses the characteristics of nomadic systems, and enables existing network applications to run reliably in these mobile environments.

A presently preferred non-limiting implementation solves this problem by providing a seamless solution that extends the enterprise network, letting network managers provide mobile users with easy access to the same applications as stationary users without sacrificing reliability or centralized management. The solution combines advantages of present-day wire-line network standards with emerging mobile standards to create a solution that works with existing network applications.

In accordance with one aspect of a presently preferred non-limiting implementation, a Mobility Management Server (MMS) coupled to the mobile interconnect maintains the state of each of any number of Mobile End Systems (MES) and handles the complex session management required to maintain persistent connections to the network and to peer application processes. If a Mobile End System becomes unreachable, suspends, or changes network address (e.g., due to roaming from one network interconnect to another), the Mobility Management Server maintains the connection to the associated peer—allowing the Mobile End System to maintain a continuous virtual connection even though it may temporarily lose its actual physical connection.

A presently preferred exemplary non-limiting implementation also provides the following (among others) new and advantageous techniques and arrangements:

- a Mobility Management Server providing user configurable session priorities for mobile clients;
- per-user mobile policy management for managing consumption of network resources;
- a roaming methodology making use of the industry standard Dynamic Host Configuration Protocol (DHCP) in coordination with a Mobility Management Server;
- automatic system removal of unreliable datagrams based on user configurable timeouts; and
- automatic system removal of unreliable datagrams based on user configurable retries.

In more detail, a presently preferred exemplary non-limiting implementation in one of its aspects provides a Mobility Management Server that is coupled to the mobile interconnect (network). The Mobility Management Server maintains the state of each of any number of Mobile End Systems and handles the complex session management required to maintain persistent connections to the network and to other processes (e.g., running on other network-based peer systems). If a Mobile End System becomes unreachable, suspends, or changes network address (e.g., due to roaming from one network interconnect to another), the Mobility Management Server maintains the connection to the associated peer, by acknowledging receipt of data and queuing requests. This proxying by the Mobility Management Server allows the application on the Mobile End System to maintain a continuous connection even though it may temporarily lose its physical connection to a specific network medium.

In accordance with another aspect of a presently preferred exemplary non-limiting implementation, a Mobility Management Server manages addresses for Mobile End Systems. Each Mobile End System is provided with a proxy address on the primary network. This highly available address is known as the "virtual address" of the Mobile End System. The Mobility Management Server maps the virtual addresses to current "point of presence" addresses of the nomadic systems. While the point of presence address of a Mobile End System may change when the mobile system changes from one network interconnect to another, the virtual address stays constant while any connections are active or longer if the address is statically assigned.

In accordance with yet another aspect of a presently preferred exemplary non-limiting implementation, a Mobility Management Server provides centralized system management of Mobile End Systems through a console application and exhaustive metrics. A presently preferred exemplary non-limiting implementation also provides user configurable session priorities for mobile clients running through a proxy server, and per-user mobile policy management for managing consumption of network resources.

In accordance with yet another aspect of a presently preferred exemplary non-limiting implementation, a Remote Procedure Call protocol and an Internet Mobility Protocol are used to establish communications between the proxy server and each Mobile End System.

Remote procedure calls provide a method for allowing a process on a local system to invoke a procedure on a remote system. The use of the RPC protocol allows Mobile End Systems to disconnect, go out of range or suspend operation without losing active network sessions. Since session maintenance does not depend on a customized application, off-the-shelf applications will run without modification in the nomadic environment.

The Remote Procedure Call protocol generates transactions into messages that can be sent via the standard network transport protocol and infrastructure. These RPC messages contain the entire network transaction initiated by an application running on the Mobile End System—enabling the Mobility Management Server and Mobile End System to keep connection state information synchronized at all times—even during interruptions of the physical link connecting the two. In the preferred implementation of a presently preferred exemplary non-limiting implementation providing RPC's, the proxy server and the Mobile End Systems share sufficient knowledge of each transaction's state to maintain coherent logical database about all shared connections at all times.

The Internet Mobility Protocol provided in accordance with a presently preferred exemplary non-limiting implementation compensates for differences between wired local area network interconnects and other less reliable networks such as a wireless LAN or WAN. Adjusted frame sizes and protocol timing provide significant performance improvements over non-mobile-aware transports—dramatically reducing network traffic. This is important when bandwidth is limited or when battery life is a concern. The Internet Mobility Protocol provided in accordance with a presently preferred exemplary non-limiting implementation also ensures the security of organizational data as it passes between the Mobile End System and the Mobility Management Server over public network interconnects or airways. The Internet Mobility Protocol provides a basic firewall function by allowing only authenticated devices access to the organizational network. The Internet Mobility Protocol can also certify and encrypt all communications between the Mobility Management Server and the Mobile End System.

In accordance with yet another aspect of a presently preferred exemplary non-limiting implementation, mobile interconnectivity is built on standard transport protocols (e.g., TCP/IP, UDP/IP and DHCP, etc) to extend the reach of standard network application interfaces. A presently preferred exemplary non-limiting implementation efficiently integrates transport, security, address management, device management and user management needs to make nomadic computing environments effectively transparent. The Internet Mobility Protocol provides an efficient mechanism for multiplexing multiple streams of data (reliable and unreliable) through a single virtual channel provided by such standard transport protocols over standard network infrastructure.

With the help of the RPC layer, the Internet Mobility Protocol coalesces data from different sources targeted for the same or different destinations, together into a single stream and forwards it over a mobile link. At the other end of the mobile link, the data is demultiplexed back into multiple distinct streams, which are sent on to their ultimate destination(s). The multiplexing/demultiplexing technique allows for maximum use of available bandwidth (by generating the maximum sized network frames possible), and allows multiple channels to be established (thus allowing prioritization and possibly providing a guaranteed quality of service if the underlying network provides the service).

The Internet Mobility Protocol provided in accordance with a presently preferred exemplary non-limiting implementation provides the additional features and advantages, for example:

Transport protocol independence.

Allows the network point of presence (POP) or network infrastructure to change without affecting the flow of data (except where physical boundary, policy or limitations of bandwidth may apply).

Minimal additional overhead.

Automatic fragment resizing to accommodate the transmission medium. (When the protocol data unit for a given frame is greater then the available maximum transmission unit of the network medium, the Internet Mobility Protocol will fragment and reassemble the frame to insure that it can traverse the network. In the event of a retransmit, the frame will again be assessed. If the network infrastructure or environment changes, the frame will be refragmented or in the case that the maximum transmission unit actually grew, sent as a single frame.)

Semantics of unreliable data are preserved, by allowing frames to discard unreliable data during retransmit.

Provides a new semantic of Reliable Datagram service. (Delivery of datagrams can now be guaranteed to the peer terminus of the Internet Mobility Protocol connection. Notification of delivery can be provided to a requesting entity.)

Considers the send and receive transmission path separately, and automatically tailors its operating parameters to provided optimum throughput. (Based on hysteresis, it adjusts such parameters as frame size/fragmentation threshold, number of frames outstanding (window), retransmit time, and delayed acknowledgement time to reduce the amount of duplicate data sent through the network.)

Network fault tolerant (since the expected usage is in a mobile environment, temporary loss of network medium connectivity does not result in a termination of the virtual channel or application based connection).

Provides an in-band signaling method to its peer to adjust operating parameters (each end of the connection can alert its peer to any changes in network topology or environment).

Employs congestion avoidance algorithms and gracefully decays throughput when necessary.

Employs selective acknowledgement and fast retransmit policies to limit the number of gratuitous retransmissions, and provide faster handoff recovery in nomadic environments. (This also allows the protocol to maintain optimum throughput in a lossy network environment.)

Employs sliding window technology to allow multiple frames to be outstanding. (This parameter is adjustable in each direction and provides for streaming frames up to a specified limit without requiring an acknowledgement from its peer.)

Sequence numbers are not byte oriented, thus allowing for a single sequence number to represent up to a maximum payload size.

Security aware. (Allows for authentication layer and encryption layer to be added in at the Internet Mobility Protocol layer.)

Compression to allow for better efficiency through bandwidth limited links.

Balanced design, allowing either peer to migrate to a new point of presence.

Either side may establish a connection to the peer.

Allows for inactivity timeouts to be invoked to readily discard dormant connections and recover expended resources.

Allows for a maximum lifetime of a given connection (e.g., to allow termination and/or refusal to accept connections after a given period or time of day).

A presently preferred exemplary non-limiting implementation also allows a system administrator to manage consumption of network resources. For example, the system administrator can place controls on Mobile End Systems, the Mobility Management Server, or both. Such controls can be for the purpose, for example, of managing allocation of network bandwidth or other resources, or they may be related to security issues. It may be most efficient to perform management tasks at the client side for clients with lots of resources. However, thin clients don't have many resources to spare, so it may not be practical to burden them with additional code and processes for performing policy management. Accordingly, it may be most practical to perform or share such policy management functions for thin clients at a centralized point such as the Mobility Management Server. Since the Mobility Management Server proxies the distinct data streams of the Mobile End Systems, it provides a central point from which to conduct policy management. Moreover, the Mobility Management Server provides the opportunity to perform policy management of Mobile End Systems on a per user and/or per device basis. Since the Mobility Management Server is proxying on a per user basis, it has the ability to control and limit each user's access to network resources on a per-user basis as well as on a per-device basis.

As one simple example, the Mobility Management Server can "lock out" certain users from accessing certain network resources. This is especially important considering that interface network is via a mobile interconnect, and may thus "extend" outside of the boundaries of a locked organizational facility (consider, for example, an ex-employee who tries to access the network from outside his former employer's building). However, the policy management provided by the Mobility Management Server can be much more sophisticated. For example, it is possible for the Mobility Management Server to control particular Web URL's particular users can visit, filter data returned by network services requests, and/or compress data for network bandwidth conservation. This provides a way to enhance existing and new application-level services in a seamless and transparent manner.

A presently preferred exemplary non-limiting implementation thus extends the enterprise network, letting network managers provide mobile users with easy access to the same applications as stationary users without sacrificing reliability or centralized management. The solution combines advantages of existing wire-line network standards with emerging mobility standards to create a solution that works with existing network applications.

BRIEF DESCRIPTION OF THE DRAWINGS

These, as well as other features and advantages will be more completely understood and appreciated by careful study of the following more detailed description of presently preferred non-limiting exemplary implementations in conjunction with the accompanying drawings, of which:

FIG. **1** is a diagram of an overall mobile computing network provided in accordance with a presently preferred exemplary non-limiting implementation;

FIG. **2** shows an example software architecture for a Mobile End System and a Mobility Management Server;

FIG. **2**A shows example steps performed to transfer information between a Mobile End System and a Mobility Management Server;

FIG. **3** shows an example mobile interceptor architecture;

FIG. **3**A is a flowchart of example steps performed by the mobile interceptor;

FIG. **3**B is a flowchart of example steps performed by an RPC engine to handle RPC work requests;

FIGS. **4**-**5**C are flowcharts of example steps to process RPC work requests;

FIG. **6** is a diagram of an example received work request;

FIG. **7** is a diagram showing how a received work request can be dispatched onto different priority queues;

FIGS. **8** and **9** show processing of the contents of the different priority queues;

FIGS. **10**A-**15**B show example steps performed to provide an Internet Mobility Protocol;

FIG. **16** shows example listener data structures; and

FIGS. **17**, **17**A and **18** are flowcharts of example steps performed to provide for mobile interconnect roaming.

DETAILED DESCRIPTION OF PRESENTLY PREFERRED EXAMPLE IMPLEMENTATIONS

FIG. **1** is an example of mobile enhanced networked computer system **100** provided in accordance with a presently preferred exemplary non-limiting implementation. Networked computer system **100** includes a Mobility Management Server **102** and one or more Mobile End Systems **104**. Mobile End Systems **104** can communicate with Mobility Management Server **102** via a local area network (LAN) **108**. Mobility Management Server **102** serves as network level proxy for Mobile End Systems **104** by maintaining the state of each Mobile End System, and by handling the complex session management required to maintain persistent connections to any peer systems **110** that host network applications—despite the interconnect between Mobile End Systems **104** and Mobility Management Server **102** being intermittent and unreliable. In the preferred implementation, Mobility Management Server **102** communicates with Mobile End Systems **104** using Remote Procedure Call and Internet Mobility Protocols in accordance with a presently preferred exemplary non-limiting implementation.

In this particular example, Mobile End Systems **104** are sometimes but not always actively connected to Mobility Management Server **102**. For example:

- Some Mobile End Systems **104***a*-**104***k* may communicate with Mobility Management Server **102** via a mobile interconnect (wirelessly in this case), e.g., conventional electromagnetic (e.g., radio frequency) transceivers **106** coupled to wireless (or wire-line) local area or wide area network **108**. Such mobile interconnect may allow Mobile End Systems **104***a*-**104***k* to "roam" from one cover area **107***a* to another coverage area **107***k*. Typically, there is a temporary loss of communications when a Mobile End System **104** roams from one coverage area **107** to another, moves out of range of the closest transceiver **106**, or has its signal temporarily obstructed (e.g., when temporarily moved behind a building column or the like).
- Other Mobile End Systems **104***l*, **104***m*, . . . may communicate with Mobility Management Server **102** via non-permanent wire-based interconnects **109** such as docking ports, network cable connectors, or the like. There may be a temporary loss of communications when Mobile End Systems **104** are temporarily disconnected from LAN **108** by breaking connection **109**, powering off the Mobile End Systems, etc.
- Still other Mobile End Systems (e.g., **104***n*) may be nomadically coupled to Mobility Management Server **102** via a further network topography **111** such as a wide area network, a dial-up network, a satellite network, or the Internet, to name a few examples. In one example, network **111** may provide intermittent service. In another example, Mobile End Systems **104** may move from one type of connection to another (e.g., from being connected to Mobility Management Server **102** via wire-based interconnect **109** to being connected via network **111**, or vice versa)—its connection being temporarily broken during the time it is being moved from one connection to another.

Mobile End Systems **104** may be standard mobile devices and off the shelf computers. For example, Mobile End System **104** may comprise a laptop computer equipped with a conventional radio transceiver and/or network cards available from a number of manufacturers. Mobile End Systems **104** may run standard network applications and a standard operating system, and communicate on the transport layer using a conventionally available suite of transport level protocols (e.g., TCP/IP suite.) In accordance with the present non-limiting exemplary implementation, Mobile End Systems **104** also execute client software that enables them to communicate with Mobility Management Server **102** using Remote Procedure Call and Internet Mobility Protocols that are transported using the same such standard transport level protocols.

Mobility Management Server **102** may comprise software hosted by a conventional Windows NT or other server. In the preferred implementation, Mobility Management Server **102** is a standards-compliant, client-server based intelligent server that transparently extends the enterprise network **108** to a nomadic environment. Mobility Management Server **102** serves as network level proxy for each of any number of Mobile End Systems **104** by maintaining the state of each Mobile End System, and by handling the complex session management required to maintain persistent connections to any peer systems **110** that host network applications—despite the mobile interconnect between Mobile End Systems **104** and transceivers **106** being intermittent and unreliable.

For example, server **102** allows any conventional (e.g., TCP/IP based) network application to operate without modification over mobile connection. Server **102** maintains the sessions of Mobile End Systems **104** that disconnect, go out of range or suspend operation, and resumes the sessions when the Mobile End System returns to service. When a Mobile End System **104** becomes unreachable, shuts down or changes its point of presence address, the Mobility Management Server **102** maintains the connection to the peer system **110** by acknowledging receipt of data and queuing requests until the Mobile End System once again becomes available and reachable.

Server **102** also extends the management capabilities of wired networks to mobile connections. Each network software layer operates independently of others, so the solution can be customized to the environment where it is deployed.

As one example, Mobility Management Server **102** may be attached to a conventional organizational network **108** such as a local area network or wide area network. Network **108** may be connected to a variety of fixed-end systems **110** (e.g., one or most host computers **110**). Mobility Management Server **102** enables Mobile End Systems **104** to communicate with Fixed End System(s) **110** using continuous session type data streams even though Mobile End Systems **104** sometimes lose contact with their associated network interconnect or move from one network interconnect **106**, **109**, **111** to another (e.g., in the case of wireless interconnect, by roaming from one wireless transceiver **106** coverage area **107** to another).

A Mobile End System **104** establishes an association with the Mobility Management Server **102**, either at startup or when the Mobile End System requires network services. Once this association is established, the Mobile End System **104** can start one or more network application sessions, either serially or concurrently. The Mobile End System **104**-to-Mobility Management Server **102** association allows the Mobile End System to maintain application sessions when the Mobile End System, disconnects, goes out of range or suspends operation, and resume sessions when the Mobile End System returns to service. In the preferred implementation, this process is entirely automatic and does not require any intervention on the user's part.

In accordance with an aspect of a presently preferred exemplary non-limiting implementation, Mobile End Systems **104** communicate with Mobility Management Server **102** using conventional transport protocols such as, for example, UDP/IP. Use of conventional transport protocols allows Mobile End Systems **104** to communicate with Mobility Management Server **102** using the conventional routers **112** and other infrastructure already existing on organization's network **108**. In accordance with a presently preferred exemplary non-limiting implementation, a higher-level Remote Procedure Call protocol generates transactions into messages that are sent over the mobile enhanced network **108** via the standard transport protocol(s). In this preferred implementation, these mobile RPC messages contain the entire network transaction initiated by an application running on the Mobile End System **104**, so it can be completed in its entirety by the Mobility Management Server. This enables the Mobility Management Server **102** and Mobile End System **104** to keep connection state information synchronized at all times—even during interruptions of network medium connectivity.

Each of Mobile End Systems **104** executes a mobility management software client that supplies the Mobile End System with the intelligence to intercept all network activity and relay it via the mobile RPC protocol to Mobility Management Server **102**. In the preferred implementation, the mobility management client works transparently with operating system features present on Mobile End Systems **104** (e.g., Windows NT, Windows 98, Windows 95, Windows CE, etc.) to keep client-site application sessions active when contact is lost with the network.

Mobility Management Server **102** maintains the state of each Mobile End System **104** and handles the complex session management required to maintain persistent connections to associated peer **108** such as host computer **110** attached to the other end of the connection end point. If a Mobile End System **104** becomes unreachable, suspends, or changes network address (e.g., due to roaming from one network interconnect to another), the Mobility Management Server **102** maintains the connection to the host system **110** or other connection end-point, by acknowledging receipt of data and queuing requests. This proxy function means that the peer application never detects that the physical connection to the Mobile End System **104** has been lost—allowing the Mobile End System's application(s) to effectively maintain a continuous connection with its associated session end point (by simply and easily resuming operations once a physical connection again is established) despite the mobile system temporarily losing connection or roaming from one network interconnect **106**A to another network interconnect **106**K within coverage area **107**K.

Mobility Management Server **102** also provides address management to solve the problem of Mobile End Systems **104** receiving different network addresses when they roam to different parts of the segmented network. Each Mobile End System **104** is provided with a virtual address on the primary network. Standard protocols or static assignment determine these virtual addresses. For each active Mobile End System **104**, Mobility Management Server **102** maps the virtual address to the Mobile End System's current actual ("point of presence") address. While the point of presence address of a Mobile End System **104** may change when the device changes from one network segment to another, the virtual address stays constant while any connections are active or longer if the address is assigned statically.

Thus, the change of a point of presence address of a Mobile End System **104** remains entirely transparent to an associated session end point on host system **110** (or other peer) communicating with the Mobile End System via the Mobility Management Server **102**. The peer **110** sees only the (unchanging) virtual address proxied by the server **102**.

In the preferred implementation, Mobility Management Server **102** can also provide centralized system management through console applications and exhaustive metrics. A system administrator can use these tools to configure and manage remote connections, and troubleshoot remote connection and system problems.

The proxy server function provided by Mobility Management Server **102** allows for different priority levels for network applications, users and machines. This is useful because each Mobility Management Server **102** is composed of finite processing resources. Allowing the system manager to configure the Mobility Management Server **102** in this way provides enhanced overall system and network performance. As one example, the system manager can configure Mobility Management Server **102** to allow real time applications such as streaming audio or video to have greater access to the Mobility Management Server **102**'s resources than other less demanding applications such as email.

In more detail, Mobility Management Server **102** can be configured via an application or application interface; standard network management protocols such as SNMP; a Web-based configuration interface; or a local user interface. It is possible to configure association priority and/or to configure application priority within an association. For example, the priority of each association relative to other associations running through the Mobility Management Server **102** is configurable by either the user name, or machine name (in the preferred implementation, when the priority is configured for both the user and the machine that a user is logged in on, the configuration for the user may have higher precedence). In addition or alternatively, each association may have several levels of application priority, which is configured based on network application name. The system allows for any number of priority levels to exist. In one particular implementation, three priority levels are provided: low, medium and high.

Server and Client Example Software Architecture

FIG. **2** shows an example software architecture for Mobile End System **104** and Mobility Management Server **102**. In accordance with one aspect of a presently preferred exemplary non-limiting implementation, Mobile End System **104** and Mobility Management Server **102** run standard operating system and application software—with only a few new components being added to enable reliable and efficient persistent session connections over an intermittently connected mobile network **108**. As shown in FIG. **2**, Mobile End System **104** runs conventional operating system software including network interface drivers **200**, TCP/UDP transport support **202**, a transport driver interface (TDI) **204**, and a socket API **206** used to interface with one or more conventional network applications **208**. Conventional network file and print services **210** may also be provided to communicate with conventional TDI **204**. Server **102** may include similar conventional network interface drivers **200'**, TCP/UDP transport support **202'**, a transport driver interface (TDI) **204'**, and a socket API **206'** used to interface with one or more conventional network applications **208'**. Mobile End System **104** and Mobility Management Server **102** may each further include conventional security software such as a network/security provider **236** (Mobile End System) and a user/security database **238** (server).

In accordance with one exemplary aspect of the present non-limiting exemplary implementation, a new, mobile interceptor component **212** is inserted between the TCP/UDP transport module **202** and the transport driver interface (TDI) **204** of the Mobile End System **104** software architecture. Mobile interceptor **212** intercepts certain calls at the TDI **204** interface and routes them via RPC and Internet Mobility Protocols and the standard TCP/UDP transport protocols **202** to Mobility Management Server **102** over network **108**. Mobile interceptor **212** thus can intercept all network activity and relay it to server **102**. Interceptor **212** works transparently with operating system features to allow client-side application sessions to remain active when the Mobile End System **104** loses contact with network **108**.

While mobile interceptor **212** could operate at a different level than the transport driver interface **204** (e.g., at the socket API level **206**), there are advantages in having mobile interceptor **212** operate at the TDI level. Many conventional operating systems (e.g., Microsoft Windows 95, Windows 98, Windows NT and Windows CE) provide TDI interface **204**—thus providing compatibility without any need to change operating system components. Furthermore, because the transport driver interface **204** is a kernel level interface, there is no need to switch to user mode—thus realizing performance improvements. Furthermore, mobile interceptor **212** working at the level of TDI interface **204** is able to intercept from a variety of different network applications **208** (e.g., multiple simultaneously running applications) as well as encompassing network file and print services **210** (which would have to be handled differently if the interceptor operated at the socket API level **206** for example).

FIG. **2A** shows an example high level flowchart of how mobile interceptor **212** works. A call to the TDI interface **204** of Mobile End System **104** (block **250**) is intercepted by mobile interceptor **212** (block **252**). Mobile interceptor **212** packages the intercepted RPC call in a fragment in accordance with an Internet Mobility Protocol, and sends the fragment as a datagram via a conventional transport protocol such as UDP or TCP over the LAN, WAN or other transport **108** to Mobility Management Server **102** (block **252**). The Mobility Management Server **102** receives and unpackages the RPC datagram (block **254**), and provides the requested service (for example, acting as a proxy to the Mobile End System application **208** by passing data or a response to an application server process running on Fixed End System **110**).

Referring once again to FIG. **2**, Mobility Management Server **102** includes an address translator **220** that intercepts messages to/from Mobile End Systems **104** via a conventional network interface driver **222**. For example, address translator **230** recognizes messages from an associated session peer (Fixed End System **110**) destined for the Mobile End System **104** virtual address. These incoming Mobile End System messages are provided to proxy server **224**, which then maps the virtual address and message to previously queued transactions and then forwards the responses back to the current point of presence addresses being used by the associated Mobile End System **104**.

As also shown in FIG. **2**, Mobility Management Server **102** includes, in addition to address translation (intermediate driver) **220**, and proxy server **224**, a configuration manager **228**, a control/user interface **230** and a monitor **232**. Configuration management **228** is used to provide configuration information and parameters to allow proxy server **224** to manage connections. Control, user interface **230** and monitor **232** allow a user to interact with proxy server **214**.

Mobile Interceptor

FIG. **3** shows an example software architecture for mobile interceptor **212** that support the RPC Protocol and the Internet Mobility Protocol in accordance with a presently preferred exemplary non-limiting implementation. In this example, mobile interceptor **212** has two functional components:

a Remote Procedure Call protocol engine **240**; and

an Internet Mobility Protocol engine **244**.

Mobile interceptor **212** in the preferred implementation thus supports Remote Procedure Call protocol and Internet Mobility Protocol to connect Mobility Management Server **102** to each Mobile End System **104**. Remote procedure calls provide a method for allowing a process on a local system to invoke a procedure on a remote system. Typically, the local system is not aware that the procedure call is being executed on a remote system. The use of RPC protocols allows Mobile End System **104** to go out of range or suspend operation without losing active network sessions. Since session maintenance does not depend on a customized application, off-the-shelf applications will run without modification in the mobile environment of network **108**.

Network applications typically use application-level interfaces such as Windows sockets. A single call to an application-level API may generate several outgoing or incoming data packets at the transport, or media access layer. In prior mobile networks, if one of these packets is lost, the state of the entire connection may become ambiguous and the session must be dropped. In the preferred exemplary non-limiting implementation providing RPCs, the Mobility Management Server **102** and the Mobile End Systems **104** share sufficient knowledge of the connection state to maintain a coherent logical link at all times—even during physical interruption.

The Internet Mobility Protocol provided in accordance with a presently preferred exemplary non-limiting implementation compensates for differences between wire-line and other less reliable networks such as wireless. Adjusted frame sizes and protocol timing provide significant performance improvements over non-mobile-aware transports—dramatically reducing network traffic. This is important when bandwidth is limited or when battery life is a concern.

The Internet Mobility Protocol provided in accordance with a presently preferred non-limiting implementation also ensure the security of organization's data as it passes between the Mobile End System **104** and the Mobility Management Server **102** on the public wire-line networks or airway. The Internet Mobility Protocol provides a basic firewall function by allowing only authenticated devices access to the organizational network. The Internet Mobility Protocol can also certify and encrypt all communications between the mobility management system **102** and the Mobile End System **104**.

The Remote Procedure Call protocol engine **240** on Mobile End System **104** of FIG. **3** marshals TDI call parameters, formats the data, and sends the request to the Internet Mobility Protocol engine **244** for forwarding to Mobility Management Server **102** where the TDI Remote Procedure Call engine **240'** executes the calls. Mobile End Systems **104** martial TDI call parameters according to the Remote Procedure Call protocol. When the Mobility Management Server **102** TDI Remote Procedure Call protocol engine **240'** receives these RPCs, it executes the calls on behalf of the Mobile End System **104**. The Mobility Management Server **102** TDI Remote Procedure Call protocol engine **240'** shares the complete network state for each connected Mobile End System with the peer Mobile End System **104**'s RPC engine **240**. In addition to performing remote procedure calls on behalf of the Mobile End Systems **104**, the server RPC engine **240'** is also responsible for system flow control, remote procedure call parsing, virtual address multiplexing (in coordination with services provided by address translator **220**), remote procedure call transaction prioritization, scheduling, and coalescing.

The Internet Mobility Protocol engine **244** performs reliable datagram services, sequencing, fragmentation, and re-assembly of messages. It can, when configured, also provide authentication, certification, data encryption and compression for enhanced privacy, security and throughput. Because the Internet Mobility Protocol engine **244** functions in power-sensitive environments using several different transports, it is power management aware and is transport independent.

FIG. **3**A shows an example process mobile interceptor **212** performs to communicate a TDI call to Mobility Management Server **102**. Generally, the mobile interceptor RPC protocol engine **240** forwards marshaled TDI calls to the Internet Mobility Protocol engine **244** to be transmitted to the Mobility Management Server **102**. RPC protocol engine **240** does this by posting the RPC call to a queue maintained by the Internet Mobility Protocol engine **244** (block **302**). To facilitate bandwidth management, the Internet Mobility Protocol engine **244** delays sending received RPC calls for some period of time (“the RPC coalesce time out period”) (block **304**). Typically, the RPC coalesce timeout is set between five and fifteen milliseconds as one example but is user configurable. This delay allows the RPC engine **240** to continue posting TDI calls to the Internet Mobility Protocol engine **244** queue so that more than one RPC call can be transmitted to the Mobility Management Server **102** in the same datagram (fragment).

When the coalesce timer expires, or the RPC protocol engine **240** determines that it will not be receiving more RPC calls (decision block **306**), the RPC engine provides the Internet Mobility Protocol engine **244** with a request to flush the queue, coalesce the RPC calls into a single frame, and forward the frame to its peer (block **308**). This coalescing reduces the number of transmissions—enhancing protocol performance.

As mentioned above, Mobility Management Server **102** proxy server also has an RPC protocol engine **212'** and an Internet Mobility Protocol engine **244'**. FIG. **3**B shows an example process performed by Mobility Management Server **102** upon receipt of an Internet Mobility Protocol message frame from Mobile End System **104**. Once the frame is received by the Mobility Management Server **102**, the Internet Mobility Protocol engine **244'** reconstructs the frame if fragmented (due to the maximum transmission size of the underlying transport) and then demultiplexes the contents of the message to determine which Mobile End System **104** it was received from. This demultiplexing allows the Internet Mobility Protocol **244'** to provide the Remote Procedure Call engine **240'** with the correct association-specific context information.

The Internet Mobility Protocol engine **244'** then formulates the received message into a RPC receive indication system work request **354**, and provides the Mobility Management Server **102** RPC engine **240'** with the formulated work request and association-specific context information. When RPC protocol engine **240'** receives work request **352**, it places it into an association-specific work queue **356**, and schedules the association to run by providing a scheduled request to a global queue **358**. The main work thread of RPC engine **240'** is then signaled that work is available. Once the main thread is awake, it polls the global queue **358** to find the previously queued association scheduled event. It then de-queues the event and begins to process the association-specific work queue **356**.

On the association specific work queue **356** it finds the previously queued RPC receive indication work request The main thread then de-queues the RPC receive indication work request **356** and parses the request. Because of the coalescing described in connection with FIG. **3**A, the Mobility Management Server **102** often receives several RPC transactions bundled in each datagram. It then demultiplexes each RPC transaction back into distinct remote procedure calls and executes the requested function on behalf of Mobile End System **104**. For performance purposes RPC engine **240'** may provide a look ahead mechanism during the parsing process of the RPC messages to see if it can execute some of the requested transactions concurrently (pipelining).

How RPC Protocol Engine 240' Runs RPC Associations

FIG. **4** is a flowchart of an example process for running RPC associations placed on an association work queue **356**. When an RPC association is scheduled to run, the main thread for the RPC protocol engine **240'** (which may be implemented as a state machine) de-queues the work request from global work queue **358** and determines the type of work request.

There are six basic types of RPC work requests in the preferred implementation:

- schedule request;
- connect indication;
- disconnect indication;
- local terminate association;
- “resources available” request; and
- ping inactivity timeout.

RPC protocol engine **240'** handles these various types of requests differently depending upon their type. RPC protocol engine **240'** tests the request type (indicated by information associated with the request as stored on global queue **358**) in order to determine how to process the request.

If the type of work request is a “schedule request” (decision block **360**), the RPC engine **240'** determines which association is being scheduled (block **362**). RPC engine **240'** can determine this information from what is stored on global queue **358**. Once the association is known, RPC engine **240'** can identify the particular one of association work queues **356**(**1**) . . . **356**(*n*) the corresponding request is stored on. RPC engine **362** retrieves the corresponding association control block (block **362**), and calls a Process Association Work task **364** to begin processing the work in a specific association's work queue **356** as previously noted.

FIG. **5** shows example steps performed by the “process association work” task **364** of FIG. **4**. Once the specific association has been determined, this “process association work” task **364** is called to process the work that resides in the corresponding association work queue **356**. If the de-queued work request (block **390**) is an RPC receive request (decision block **392**), it is sent to the RPC parser to be processed (block **394**). Otherwise, if the de-queued work request is a pending receive request (decision block **396**), the RPC engine **240'** requests TDI **204'** to start receiving data on behalf of the application's connection (block **398**). If the de-queued work request is a pending connect request (decision block **400**), RPC engine **240'** requests TDI **204'** to issue an application specified TCP (or other transport protocol) connect request (block **402**). It then waits for a response from the TDI layer **204'**. Once the request is completed by TDI **204'**, its status is determined and then reported back to the original requesting entity. As a performance measure, RPC engine **240'** may decide to retry the connect request process some number of times by placing the request back on the associations-specific work queue (**356**) before actually reporting an error back to the requesting peer. This again is done in an effort to reduce network bandwidth and processing consumption.

The above process continues to loop until a "scheduling weight complete" test (block **404**) is satisfied. In this example, a scheduling weight is used to decide how many work requests will be de-queued and processed for this particular association. This scheduling weight is a configuration parameter set by configuration manager **228**, and is acquired when the association connect indication occurs (FIG. **4**, block **372**). This value is configurable based on user or the physical identification of the machine.

Once the RPC engine is finished with the association work queue **356** (for the time at least), it may proceed to process dispatch queues (block **406**) (to be discussed in more detail below). If, after processing work on the association's work queue **356**, more work remains in the association work queue, the RPC engine **240'** will reschedule the association to run again at a later time by posting a new schedule request to the global work queue **358** (FIG. **4**, decision block **366**, block **368**; FIG. **5**, decision block **408**, block **410**).

Referring once again to FIG. **4**, if the RPC work request is a "connect indication" (decision block **370**), RPC engine **240'** is being requested to instantiate a new association with a mobile peer (usually, but not always, the Mobile End System **104**). As one example, the connect indication may provide the RPC engine **240'** with the following information about the peer machine which is initiating the connection:

physical identifier of the machine,
name of the user logged into the machine,
address of the peer machine, and
optional connection data from the peer RPC engine **240**.

In response to the connect indication (decision block **370**), the RPC engine **240** calls the configuration manager **228** with these parameters. Configuration manager **228** uses these parameters to determine the exact configuration for the new connection. The configuration (e.g., association scheduling weight and the list of all applications that require non-default scheduling priorities along with those priorities) is then returned to the RPC engine **240'** for storage and execution. RPC engine **240'** then starts the new association, and creates a new association control block (block **372**). As shown in FIG. **5**A the following actions may be taken:

allocate and association control block (block **372**A);
initialize system wide resources with defaults (block **372**B);
get configuration overrides with current configuration settings (block **372**C);
initialize flags (block **372**D);
initialize the association-specific work queue (block **372**E);
initialize association object hash table (block **372**F);
initialize the coalesce timer (block **372**G); and
insert association control block into session table (block **372**H).

A "disconnect indication" is issued by the Internet Mobility Protocol engine **244'** to the RPC engine **240'** when the Internet Mobility Protocol engine has determined that the association must be terminated. The RPC engine **240'** tests for this disconnect indication (block **374**), and in response, stops the association and destroys the association control block (block **376**). As shown in FIG. **5**B, the following steps may be performed:

mark the association as deleted to prevent any further processing of work that may be outstanding (block **376**A);
close all associated association objects including process, connection and address objects (block **376**B);
free all elements on work queue (block **376**C);
stop coalesce timer if running (block **376**D);
decrement association control block reference count (block **376**E); and
if the reference count is zero (tested for by block **376**F):
destroy association specific work queue,
destroy object hash table,
destroy coalesce timer,
remove association control block from association table, and
free control block (**376**G).

A "terminate session" request is issued when system **100** has determined that the association must be terminated. This request is issued by the system administrator, the operating system or an application. RPC engine **240'** handles a terminate session request in the same way it handles a disconnect request (decision block **378**, block **376**).

In the preferred implementation, the interface between the RPC engine **240'** and the Internet Mobility Protocol engine **244'** specifies a flow control mechanism based on credits. Each time one thread posts a work request to another thread, the call thread returns the number of credits left in the work queue. When a queue becomes full, the credit count goes to zero. By convention, the calling thread is to stop posting further work once the credit count goes to zero. Therefore, it is necessary to have a mechanism to tell the calling thread that "resources are available" once the queued work is processed and more room is available by some user configurable/predetermined low-water mark in the queue. This is the purpose of the "resources available" work indication (tested for by decision block **380**). As shown in FIG. **5**C, the following steps may be performed when the credit count goes to zero:

mark association as "low mark pending" by setting the RPC_LMPQ_SEND_FLAG (block **379**A). Once in this state:
all received datagrams are discarded (block **379**B);
all received stream events are throttled by refusing to accept the data (block **379**C) (this causes the TCP or other transport receive window to eventually close, and provides flow control between the Fixed End System **110** and the Mobility Management Server **102**; before returning, the preferred implementation jams a "pending receive request" to the front of the association specific work queue **356** so that outstanding stream receive event processing will continue immediately once resources are made available).
all received connect events are refused for passive connections (block **379**D).

When the "resources available" indication is received by the RPC engine **240'** (FIG. **4**, decision block **380**), the RPC engine determine whether the association has work pending in its associated association work queue **356**; if it does, the RPC engine marks the queue as eligible to run by posting the association to the global work queue **358** (block **382**). If a pending receive request has been posted during the time the association was in the low mark pending state, it is processed at this time (in the preferred implementation, the RPC engine **240'** continues to accept any received connect requests during this processing).

Referring once again to FIG. **4**, if RPC engine **240'** determines that the Mobility Management Server **102** channel used for "ping" has been inactive for a specified period of time (decision block **384**), the channel is closed and the resources are freed back to the system to be used by other processes (block **386**).

RPC Parsing and Priority Queuing

Referring back to FIG. **5**, it was noted above that RPC engine parsed an RPC receive request upon receipt (see blocks **392**, block **394**). Parsing is necessary in the preferred implementation because a single received datagram can contain multiple RPC calls, and because RPC calls can span multiple Internet Mobility Protocol datagram fragments. An example format for an RPC receive work request **500** is shown in FIG. **6**. Each RPC receive work request has at least a main fragment **502(1)**, and may have any number of additional fragments **502(2)** . . . **502**(N). Main fragment **502(1)** contains the work request structure header **503** and a receive overlay **504**. The receive overlay **504** is a structure overlay placed on top of the fragment **502(1)** by the Internet Mobility Protocol engine **244**. Within this overlay **504** is a structure member called pUserData that points to the first RPC call **506(1)** within the work request **500**.

The FIG. **6** example illustrates a work request **500** that contains several RPC calls **506(1)**, **506(2)** . . . **506(8)**. As shown in the FIG. **6** example, an RPC work request **500** need not be contained in a contiguous block of memory or in a single fragment **502**. In the example shown, a second fragment **502(2)** and a third fragment **502(3)** that are chained together to the main fragment **502(1)** in a linked list.

Thus, RPC parser **394** in this example handles the following boundary conditions:

- each RPC receive request **500** may contain one or more RPC calls;
- one or more RPC calls **506** may exist in a single fragment **502**;
- each RPC call **506** may exist completely contained in a fragment **502**; and
- each RPC call **506** may span more than one fragment **502**.

FIG. **7** shows an example RPC parser process **394** to parse an RPC receive work request **500**. In this example, the RPC parser **394** gets the first fragment **502(1)** in the work request, gets the first RPC call **506(1)** in the fragment, and parses that RPC call. Parser **394** proceeds through the RPC receive work request **500** and processes each RPC call **506** in turn. If the number of fragment bytes remaining in the RPC receive work request **500** fragment **502(1)** is greater than the size of the RPC header **503**, parser **394** determines whether the RPC call is fully contained within the RPC fragment **502** and thus may be processed (this may be determined by testing whether the RPC call length is greater than the number of fragment bytes remaining). If the RPC call type is a chain exception, then the RPC call will handle the updating of the RPC parser **394** state. In the proxy server **224**, the only RPC calls using the chain exception are the "datagram send" and "stream send" calls. This chain exception procedure is done to allow the RPC engine to avoid fragment copies by chaining memory descriptor lists together for the purpose of RPC send calls.

Once the parser **394** identifies an RPC call type, a pointer to the beginning of the RPC information is passed to the RPC engine **240** for execution. The RPC engine divides all TDI procedure calls into different priorities for execution. The highest priority calls are immediately executed by passing them to an RPC dispatcher **395** for immediate execution. All lower priority calls are dispatched to dispatch queues **510** for future processing. Each dispatch queue **510** represents a discrete priority.

In the preferred implementation, mobile applications call the "open address" object and "open connection" object functions before executing other TDI networking functions. Therefore, the system assigns application level priorities during the "open address" object and "open connection" object calls. In the example implementation, once an address or connection object is assigned a priority, all calls that are associated with that object are executed within that assigned priority.

If, for example, the RPC call is a TDI Open Address Object request or a TDI Open Connection Object Request, it is sent to the RPC dispatcher **395** for immediate execution. The Open Address and Open Connection object RPC calls provide access to a process ID or process name that are used to match against the information provided by the configuration manager **228** during the configuration requests that occurs within the association connect indication described earlier. This is used to acquire configuration for the address or connection object.

In the preferred implementation, all RPC calls have at least an address object or connection object as a parameter. When the call is made, the priority assigned to that specific object is used as the priority for the RPC call. The configuration assigned to the address or connection object determines which priority all associated RPC calls will be executed in. For example, if the assigned priority is "high," all RPC calls will be executed immediately without being dispatched to a dispatch queue **510**. If the assigned priority is "1," all RPC calls will be placed into dispatch queue **510(1)**.

Referring once again to FIG. **5**, once the "process association work" task **364** process has completed executing its scheduled amount of association work (decision block **404**), it checks to see if the dispatch queues require servicing (block **406**). FIG. **8** is a flowchart of example steps performed by the "process dispatch queues" block **406** of FIG. **5** to process the dispatch queues **510** shown in FIG. **7**.

In this example, dispatch queues **510** are processed beginning with the highest priority queue (**510(1)** in this example) (block **408**). Each queue **510** is assigned a weight factor. The weight factor is a configuration parameter that is returned by the configuration manager **228** when a Mobile End System **104** to Mobility Management Server **102** association is created. As one example, low priority dispatch queues **510** can have a weight factor of 4, and medium priority queues can have a weight factor of 8. High priority RPC calls do not, in this example, use weight factors because they are executed immediately as they are parsed.

RPC engine **240'** loops through the de-queuing of RPC calls from the current queue until either the queue is empty or the queue weight number of RPC calls has been processed (blocks **412-416**). For each de-queued RPC call, the RPC dispatcher **395** is called to execute the call. The RPC dispatcher **395** executes the procedural call on behalf of the Mobile End System **104**, and formulates the Mobile End System response for those RPC calls that require responses.

If, after exiting the loop, the queue still has work remaining (decision block **418**), the queue will be marked as eligible to run again (block **420**). By exiting the loop, the system yields the processor to the next lower priority queue (blocks **424**, **410**). This ensures that all priority levels are given an opportunity to run no matter how much work exists in any particular queue. The system gets the next queue to service, and iterates the process until all queues have been processed. At the end of processing all queues, the system tests to see if any queues have been marked as eligible to run—and if so, the association is scheduled to run again by posting a schedule request to the global work queue. The association is scheduled to run again in the "process global work" routine shown in FIG. **4** above. This approach yields the processor to allow other associations that have work to process an opportunity run. By assigning each queue a weight factor, the system may be tuned to allow different priority levels unequal access to the Mobility Management Server **102**'s CPU. Thus, higher priority queues are not only executed first, but may also be tuned to allow greater access to the CPU.

Mobility Management Server RPC Responses

The discussion above relates explains how remote procedure calls are sent from the Mobile End System **104** to the Mobility Management Server **102** for execution. In addition to this type of RPC call, the Mobility Management Server **102** RPC engine **240'** also supports RPC events and RPC receive responses. These are RPC messages that are generated asynchronously as a result of association specific connection peer activity (usually the Fixed End System **110**). Mobility Management Server **102** RPC engine **240'** completes RPC transactions that are executed by the RPC dispatcher **395**. Not all RPC calls require a response on successful completion. Those RPC calls that do require responses on successful completion cause the RPC dispatcher **395** to build the appropriate response and post the response to the Internet Mobile Protocol engine **244'** to be returned to the peer Mobile End System **104**. All RPC calls generate a response when the RPC call fails (the RPC receive response is the exception to above).

RPC events originate as a result of network **108** activity by the association specific connection (usually the Fixed End System **110**). These RPC event messages are, in the preferred implementation, proxied by the Mobility Management Server **102** and forwarded to the Mobile End System **104**. The preferred implementation Mobility Management Server **102** supports the following RPC event calls:

- Disconnect Event (this occurs when association-specific connected peer (usually the Fixed End System **110**) issues a transport level disconnect request; the disconnect is received by the proxy server **224** on behalf of the Mobile End System **104**, and the proxy server then transmits a disconnect event to the Mobile End System);
- Stream Receive Event (this event occurs when the association-specific connected peer (usually the Fixed End System **110**) has sent stream data to the Mobile End System **104**; the proxy server **224** receives this data on behalf of the Mobile End System **104**, and sends the data to the Mobile End System in the form of a Receive Response);
- Receive Datagram Event (this event occurs when any association-specific portal receives datagrams from a network peer (usually the Fixed End System **110**) destined for the Mobile End System **104** through the Mobility Management Server **102**; the proxy server **224** accepts these datagrams on behalf of the Mobile End System, and forwards them to the Mobile End System in the form of receive datagram events; and
- Connect Event (this event occurs when the association-specific listening portal receives a transport layer connect request (usually from the Fixed End System **110**) when it wishes to establish a transport layer end-to-end connection with a Mobile End System **104**; the proxy server **224** accepts the connect request on behalf of the Mobile End System, and then builds a connect event RPC call and forwards it to the Mobile End System).

FIG. **9** shows how the RPC engine **240'** handles proxy server-generated RPC calls. For high priority address and connection objects, the RPC engine **240'** dispatches a send request to the Internet Mobility Protocol engine **244'** immediately. The send request results in forwarding the RPC message to the peer Mobile End System **104**. For lower priority objects, the Internet Mobility Protocol engine **244** send request is posted to an appropriate priority queue **510'**. If the association is not scheduled to run, a schedule request is also posted to the global queue **358'**. The Internet Mobility Protocol send request is finally executed when the dispatch queues are processed as described earlier in connection with FIGS. **5** & **8**.

Internet Mobility Protocol

Internet Mobility Protocol provided in accordance with an example non-limiting implementation is a message oriented connection based protocol. It provides guaranteed delivery, (re)order detection, and loss recovery. Further, unlike other conventional connection oriented protocols (i.e. TCP), it allows for multiple distinct streams of data to be combined over a single channel; and allows for guaranteed, unreliable, as well as new message oriented reliable data to traverse the network through the single virtual channel simultaneously. This new message oriented level of service can alert the requester when the Internet Mobility Protocol peer has acknowledged a given program data unit.

The Internet Mobility Protocol provided in accordance with a presently preferred exemplary non-limiting implementation is designed to be an overlay on existing network topologies and technologies. Due to its indifference to the underlying network architecture, it is transport agnostic. As long as there is a way for packetized data to traverse between two peers, Internet Mobility Protocol can be deployed. Each node's network point of presence (POP) or network infrastructure can also be changed without affecting the flow of data except where physical boundary, policy or limitations of bandwidth apply.

With the help of the layer above, Internet Mobility Protocol coalesces data from many sources and shuttles the data between the peers using underlying datagram facilities. As each discrete unit of data is presented from the upper layer, Internet Mobility Protocol combines into a single stream and subsequently submits it for transmission. The data units are then forwarded to the peer over the existing network where upon reception, with the help from the layer above, the stream is demultiplexed back into multiple distinct data units. This allows for optimum use of available bandwidth, by generating the maximum sized network frames possible for each new transmission. This also has the added benefit of training the channel once for maximum bandwidth utilization and have its parameters applied to all session level connections.

In rare instances where one channel is insufficient, the Internet Mobility Protocol further allows multiple channels to be established between the peers—thus allowing for data prioritization and possibly providing a guaranteed quality of service (if the underlying network provides the service).

The Internet Mobility Protocol also provides a dynamically selectable guaranteed or unreliable levels of service. For example, each protocol data unit that is submitted for transmission can be queued with either a validity time period or a number of retransmit attempts or both. Internet Mobility Protocol will expire a data unit when either threshold is reached, and remove it from subsequent transmission attempts.

Internet Mobility Protocol's additional protocol overhead is kept minimal by use of a variable length header. The frame type and any optional fields determine the size of the header. These optional fields are added in a specific order to enable easy parsing by the receiving side and bits in the header flag field denote their presence. All other control and configuration information necessary for the peers to communicate can be passed through the in-band control channel. Any control information that needs to be sent is added to the frame prior to any application level protocol data unit. The receiving side processes the control information and then passes the rest of the payload to the upper layer.

Designed to run over relatively unreliable network links where the error probability is relatively high, Internet Mobility Protocol utilizes a number of techniques to insure data integrity and obtain optimum network performance. To insure data integrity, a Fletcher checksum algorithm is used to detect errant frames. This algorithm was selected due to the fact of its efficiency as well as its detection capability. It can determine not only bit errors, but also bit reordering.

Sequence numbers are used to insure ordered delivery of data. Internet Mobility Protocol sequence numbers do not, however, represent each byte of data as in TCP. They represent a frame of data that can be, in one example implementation, as large as 65535 bytes (including the Internet Mobility Protocol header). They are 32 bits or other convenient length in one example to insure that wrap-around does not occur over high bandwidth links in a limited amount of time.

Combining this capability along with the expiration of data, retransmitted (retried) frames may contain less information than the previous version that was generated by the transmitting side. A frame id is provided to enable detection of the latest versioned frame. However, since data is never added in the preferred implementation and each element removed is an entire protocol data unit, this is not a necessity. In one example, the Internet Mobility Protocol will only process the first instance of a specific frame it receives—no matter how many other versions of that frame are transmitted. Each frame created that carries new user payload is assigned its own unique sequence number.

Performance is gained by using of a sliding window technique—thus allowing for more then one frame to be outstanding (transmitted) at a time before requiring the peer to acknowledge reception of the data. To insure timely delivery of the data, a positive acknowledgement and timer based retransmit scheme is used. To further optimize the use of the channel, a selective acknowledgement mechanism is employed that allows for fast retransmission of missing frames and quick recovery during lossy or congested periods of network connectivity. In one example, this selective acknowledgement mechanism is represented by an optional bit field that is included in the header.

A congestion avoidance algorithm is also included to allow the protocol to back off from rapid retransmission of frames. For example, a round trip time can be calculated for each frame that has successfully transfer between the peers without a retransmit. This time value is averaged and then used as the basis for the retransmission timeout value. As each frame is sent, a timeout is established for that frame. If an acknowledgement for that frame is not received, and the frame has actually been transmitted, the frame is resent. The timeout value is then increased and then used as the basis for the next retransmission time. This retransmit time-out is bounded on both the upper and lower side to insure that the value is within a reasonable range.

Internet Mobility Protocol also considers the send and receive paths separately. This is especially useful on channels that are asymmetric in nature. Base on hysteresis, the Internet Mobility Protocol automatically adjusts parameters such as frame size (fragmentation threshold), number of frames outstanding, retransmit time, and delayed acknowledgement time to reduce the amount of duplicate data sent through the network.

Due to the fact that Internet Mobility Protocol allows a node to migrate to different points of attachment on diverse networks, characteristics (e.g., frame size) of the underlying network may change midstream. An artifact of this migration is that frames that have been queued for transmission on one network may no longer fit over the new medium the mobile device is currently attached to. Combining this issue with the fact that fragmentation may not be supported by all network infrastructures, fragmentation is dealt with at the Internet Mobility Protocol level. Before each frame is submitted for transmission, Internet Mobility Protocol assesses whether or not it exceeds the current fragmentation threshold. Note that this value may be less than the current maximum transmission unit for performance reason (smaller frames have a greater likelihood of reaching its ultimate destination then larger frames). The tradeoff between greater protocol overhead versus more retransmissions is weighed by Internet Mobility Protocol, and the frame size may be reduced in an attempt to reduce overall retransmissions). If a given frame will fit, it is sent in its entirety. If not, the frame is split into maximum allowable size for the given connection. If the frame is retransmitted, it is reassessed, and will be refragmented if the maximum transmission unit has been reduced (or alternatively, if the maximum transmission unit actually grew, the frame may be resent as a single frame without fragmentation).

The protocol itself is orthogonal in its design as either side may establish or terminate a connection to its peer. In a particular implementation, however, there may be a few minor operational differences in the protocol engine depending on where it is running. For example, based on where the protocol engine is running, certain inactivity detection and connection lifetime timeouts may be only invoked on one side. To allow administrative control, Internet Mobility Protocol engine running on the Mobility Management Server **102** keeps track of inactivity periods. If the specified period of time expires without any activity from the Mobile End System **104**, the Mobility Management Server **102** may terminate a session. Also, an administrator may want to limit the overall time a particular connection may be established for, or when to deny access base on time of day. Again these policy timers may, in one example implementation, be invoked only on the Mobility Management Server **102** side.

In one example implementation, the software providing the Internet Mobility Protocol is compiled and executable under Windows NT, 9x, and CE environments with no platform specific modification. To accomplish this, Internet Mobility Protocol employs the services of a network abstraction layer (NAL) to send and receive Internet Mobility Protocol frames. Other standard utility functions such as memory management, queue and list management, event logging, alert system, power management, security, etc are also used. A few runtime parameters are modified depending on whether the engine is part of an Mobile End System **104** or Mobility Management Server **102** system. Some examples of this are:

Certain timeouts are only invoked on the Mobility Management Server **102**

Direction of frames are indicated within each frame header for echo detection

Inbound connections may be denied if Mobile End System **104** is so configured

Alerts only signaled on Mobility Management Server **102**

Power management enabled on Mobile End System **104** but is not necessary on the Mobility Management Server **102**

The Internet Mobility Protocol interface may have only a small number of "C" callable platform independent published API functions, and requires one O/S specific function to schedule its work (other then the aforementioned standard utility functions). Communications with local clients is achieved through the use of defined work objects (work requests). Efficient notification of the completion of each work element is accomplished by signaling the requesting entity through the optional completion callback routine specified as part of the work object.

The Internet Mobility Protocol engine itself is queue based. Work elements passed from local clients are placed on a global work queue in FIFO order. This is accomplished by local clients calling a published Internet Mobility protocol function such as "ProtocolRequestwork( )". A scheduling function inside of Internet Mobility Protocol then removes the work and dispatches it to the appropriate function. Combining the queuing and scheduling mechanisms conceal the differences between operating system architectures—allowing the protocol engine to be run under a threaded based scheme (e.g., Windows NT) or in a synchronous fashion (e.g., Microsoft Windows 9x & Windows CE). A priority scheme can be overlaid on top of its queuing, thus enabling a guaranteed quality of service to be provided (if the underlying network supports it).

From the network perspective, the Internet Mobility Protocol uses scatter-gather techniques to reduce copying or movement of data. Each transmission is sent to the NAL as a list of fragments, and is coalesced by the network layer transport. If the transport protocol itself supports scatter-gather, the fragment list is passed through the transport and assembled by the media access layer driver or hardware. Furthermore, this technique is extensible in that it allows the insertion or deletion of any protocol wrapper at any level of the protocol stack. Reception of a frame is signaled by the NAL layer by calling back Internet Mobility Protocol at a specified entry point that is designated during the NAL registration process.

Internet Mobility Protocol Engine Entry Points

Internet Mobility Protocol in the example implementation exposes four common entry points that control its startup and shutdown behavior. These procedures are:

1. Internet Mobility ProtocolCreate( )
2. Internet Mobility ProtocolRun( )
3. Internet Mobility ProtocolHalt( )
4. Internet Mobility ProtocolUnload( )

Internet Mobility ProtocolCreate( )

The Internet Mobility ProtocolCreateo function is called by the boot subsystem to initialize the Internet Mobility Protocol. During this first phase, all resource necessary to start processing work must be acquired and initialized. At the completion of this phase, the engine must be in a state ready to accept work from other layers of the system. At this point, Internet Mobility Protocol initializes a global configuration table. To do this, it employs the services of the Configuration Manager **228** to populate the table.

Next it registers its suspend and resume notification functions with the APM handler. In one example, these functions are only invoked on the Mobile End System **104** side—but in another implementation it might be desirable to allow Mobility Management Server **102** to suspend during operations. Other working storage is then allocated from the memory pool, such as the global work queue, and the global NAL portal list.

To limit the maximum amount of runtime memory required as well as insuring Internet Mobility Protocol handles are unique, Internet Mobility Protocol utilizes a 2-tier array scheme for generating handles. The globalConnectionArray table is sized based on the maximum number of simultaneous connection the system is configured for, and allocated at this time. Once all global storage is allocated and initialized, the global Internet Mobility Protocol state is change to _STATE_INITIALIZE_.

Internet Mobility ProtocolRun( )

The Internet Mobility ProtocolRun( ) function is called after all subsystems have been initialized, and to alert the Internet Mobility Protocol subsystem that it is okay to start processing any queued work. This is the normal state that the Internet Mobility Protocol engine is during general operations. A few second pass initialization steps are taken at this point before placing the engine into an operational state.

Internet Mobility Protocol allows for network communications to occur over any arbitrary interface(s). During the initialization step, the storage for the interface between Internet Mobility Protocol and NAL was allocated. Internet Mobility Protocol now walks through the global portal list to start all listeners at the NAL. In one example, this is comprised of a two step process:

Internet Mobility Protocol requests the NAL layer to bind and open the portal based on configuration supplied during initialization time; and

Internet Mobility Protocol then notifies the NAL layer that it is ready to start processing received frames by registering the Internet Mobility ProtocolRCVFROMCB call back.

A local persistent identifier (PID) is then initialized.

The global Internet Mobility Protocol state is change to _STATE_RUN_.

Internet Mobility ProtocolHalt

The Internet Mobility ProtocolHalt( ) function is called to alert the engine that the system is shutting down. All resources acquired during its operation are to be release prior to returning from this function. All Internet Mobility Protocol sessions are abnormally terminated with the reason code set to administrative. No further work is accepted from or posted to other layers once the engine has entered into _STATE_HALTED_ state.

Internet Mobility ProtocolUnload( )

The Internet Mobility ProtocolUnload( ) function is the second phase of the shutdown process. This is a last chance for engine to release any allocated system resources still being held before returning. Once the engine has returned from this function, no further work will be executed as the system itself is terminating

Internet Mobility Protocol Handles

In at least some examples, using just the address of the memory (which contains the Internet Mobility Protocol state information) as the token to describe an Internet Mobility Protocol connection may be insufficient. This is mainly due to possibility of one connection terminating and a new one starting in a short period of time. The probability that the memory allocator will reassign the same address for different connections is high—and this value would then denote both the old connection and a new connection. If the original peer did not hear the termination of the session (i.e. it was off, suspended, out of range, etc.), it could possibly send a frame on the old session to the new connection. This happens in TCP and will cause a reset to be generated to the new session if the peer's IP addresses are the same. To avoid this scenario, Internet Mobility Protocol uses manufactured handle. The handles are made up of indexes into two arrays and a nonce for uniqueness. The tables are laid out as follows.

Table 1: an array of pointers to an array of connection object.

Table 2: an array of connection objects that contains the real pointers to the Internet Mobility Protocol control blocks.

This technique minimizes the amount of memory being allocated at initialization time. Table 1 is sized and allocated at startup. On the Mobile End System **104** side this allows allocation of a small amount of memory (the memory allocation required for this Table 1 on the Mobility Management Server **102** side is somewhat larger since the server can have many connections).

Table 1 is then populated on demand. When a connection request is issued, Internet Mobility Protocol searches through Table 1 to find a valid pointer to Table 2. If no entries are found, then Internet Mobility Protocol will allocate a new Table 2 with a maximum of 256 connection objects—and then stores the pointer to Table 2 into the appropriate slot in Table 1. The protocol engine then initializes Table 2, allocates a connection object from the newly created table, and returns the manufactured handle. If another session is requested, Internet Mobility Protocol will search Table 1 once again, find the valid pointer to Table 2, and allocate the next connection object for the session. This goes on until one of two situations exist:

If all the connection objects are exhausted in Table 2, a new Table 2 will be allocated, initialized, and a pointer to it will be placed in the next available slot in Table 1; and

If all connection objects have been released for a specific Table 2 instance and all elements are unused for a specified period of time, the storage for that instance of Table 2 is released back to the memory pool and the associated pointer in Table 1 is zeroed to indicate that that entry is now available for use when the next connection request is started (if and only if no other connection object are available in other instances of Table 2).

Two global counters are maintained to allow limiting the total number of connections allocated. One global counter counts the number of current active connections; and the other keeps track of the number of unallocated connection objects. The second counter is used to govern the total number of connection object that can be created to some arbitrary limit. When a new Table 2 is allocated, this counter is adjusted downward to account for the number of objects the newly allocated table represents. On the flip side, when Internet Mobility Protocol releases a Table 2 instance back to the memory pool, the counter is adjusted upward with the number of connection objects that are being released.

Work Flow

Work is requested by local clients through the Internet Mobility ProtocolRequestWork( ) function. Once the work is validated and placed on the global work queue, the Internet Mobility ProtocolWorkQueueEligible( ) function is invoked. If in a threaded environment, the Internet Mobility Protocol worker thread is signaled (marked eligible) and control is immediately returned to the calling entity. If in a synchronous environment, the global work queue is immediately run to process any work that was requested. Both methods end up executing the Internet Mobility ProtocolProcessWork( ) function. This is the main dispatching function for processing work.

Since only one thread at a time may be dispatching work from the global queue in the example implementation, a global semaphore may be used to protect against reentrancy. Private Internet Mobility Protocol work can post work directly to the global work queue instead of using the Internet Mobility ProtocolRequestWork( ) function.

A special case exists for SEND type work objects. To insure that the semantics of Unreliable Datagrams is kept, each SEND type work object can be queued with an expiry time or with a retry count. Work will be aged based on the expiry time. If the specified timeout occurs, the work object is removed from the connection specific queue, and is completed with an error status. If the SEND object has already been coalesced into the data path, the protocol allows for the removal of any SEND object that has specified a retry count. Once the retry count has been exceeded, the object is removed from the list of elements that make up the specific frame, and then returned to the requester with the appropriate error status.

Connection Startup

Internet Mobility Protocol includes a very efficient mechanism to establish connections between peers. Confirmation of a connection can be determined in as little as a three-frame exchange between peers. The initiator sends an IMP SYNC frame to alert its peer that it is requesting the establishment of a connection. The acceptor will either send an IMP ESTABLISH frame to confirm acceptance of the connection, or send an IMP ABORT frame to alert the peer that its connection request has been rejected. Reason and status codes are passed in the IMP ABORT frame to aid the user in decipher the reason for the rejection. If the connection was accepted, an acknowledgement frame is sent (possibly including protocol data unit or control data) and is forwarded to the acceptor to acknowledge receipt of its establish frame.

To further minimize network traffic, the protocol allows user and control data to be included in the initial handshake mechanism used at connection startup. This ability can be used in an insecure environment or in environments where security is dealt with by a layer below, such that the Internet Mobility Protocol can be tailored to avert the performance penalties due to double security authentication and encryption processing being done over the same data path.

Data Transfer

Internet Mobility Protocol relies on signaling from the NAL to detect when a frame has been delivered to the network. It uses this metric to determine if the network link in question has been momentarily flow controlled, and will not submit the same frame for retransmission until the original request has been completed. Some network drivers however lie about the transmission of frames and indicate delivery prior to submitting them to the network. Through the use of semaphores, the Internet Mobility Protocol layer detects this behavior and only will send another datagram until the NAL returns from the original send request

Once a frame is received by Internet Mobility Protocol, the frame is quickly validated, then placed on an appropriate connection queue. If the frame does not contain enough information for Internet Mobility Protocol to discern its ultimate destination, the frame is placed on the Internet Mobility Protocol socket queue it frame was received on, and then that socket queue is place on the global work queue for subsequence processing. This initial demultiplexing allows received work to be dispersed rapidly with limited processing overhead.

Acquiescing

To insure minimal use of network bandwidth during periods of retransmission and processing power on the Mobility Management Server **102**, the protocol allows the Mobility Management Server **102** to "acquiesce" a connection. After a user configurable period of time, the Mobility Management Server **102** will stop retransmitting frames for a particular connection if it receives no notification from the corresponding Mobile End System **104**. At this point, the Mobility Management Server **102** assumes that the Mobile End System **104** is in some unreachable state (i.e. out of range, suspended, etc), and places the connection into a dormant state. Any further work destined for this particular connection is stored for future delivery. The connection will remain in this state until one of the following conditions are met:

Mobility Management Server **102** receives a frame from the Mobile End System **104**, thus returning the connection to its original state;

a lifetime timeout has expired;

an inactivity timeout has expired; or

the connection is aborted by the system administrator.

In the case that the Mobility Management Server **102** receives a frame from the Mobile End System **104**, the connection continues from the point it was interrupted. Any work that was queued for the specific connection will be forwarded, and the state will be resynchronized. In any of the other cases, the Mobile End System **104** will be apprised of the termination of the connection once it reconnects; and work that was queued for the Mobile End System **104** will be discarded.

Connect and Send Requests

FIGS. **10**A-**10**C together are a flowchart of example connect and send request logic formed by Internet mobility engine **244**. In response to receipt from a command from RPC engine **240**, the Internet Mobility Protocol engine **244** determines whether the command is a "connect" request (decision block **602**). If it is, engine **244** determines whether connection resources can be allocated (decision block **603**). If it is not possible to allocate sufficient connection resources ("no" exit to decision block **603**), engine **244** declares an error (block **603***a*) and returns. Otherwise, engine **244** performs a state configuration process in preparation for handling the connect request (block **603***b*).

For connect and other requests, engine **244** queues the connect or send request and signals a global event before return to the calling application (block **604**).

To dispatch a connect or send request from the Internet Mobility Protocol global request queue, engine **244** first determines whether any work is pending (decision block **605**). If no work is pending ("no" exit to decision block **605**), engine **244** waits for the application to queue work for the connection by going to FIG. **10**C, block **625** (block **605***a*). If there is work pending ("yes" exit to decision block **605**), engine **244** determines whether the current state has been established (block **606**). If the state establish has been achieved ("yes" exit to decision block **606**), engine **244** can skip steps used to transition into establish state and jump to decision block **615** of FIG. **10**B (block **606***a*). Otherwise, engine **244** must perform a sequence of steps to enter establish state ("no" exit to decision block **606**).

In order to enter establish state, engine **244** first determines whether the address of its peer is known (decision block **607**). If not, engine **244** waits for the peer address while continuing to queue work and transitions to FIG. **10**C block **625** (block **607***a*). If the peer address is known ("yes" exit to decision block **607**), engine **244** next tests whether the requisite security context has been acquired (decision block **608**). If not, engine **244** must wait for the security context while continuing to queue work and transitioning to block **625** (block **608***a*). If security context has already been acquired ("yes" exit to decision block **608**), engine **244** declares a "state pending" state (block **608***b*), and then sends an Internet Mobility Protocol sync frame (block **609**) and starts a retransmit timer (block **610**). Engine **244** determines whether the corresponding established frame was received (block **611**). If it was not ("no" exit to decision block **611**), engine **244** tests whether the retransmit time has expired (decision block **612**). If the decision block has not expired ("no" exit to decision block **612**), engine **244** waits and may go to step **625** (block **613**). Eventually, if the established frame is never received (as tested for by block **611**) and a total retransmit time expires (decision block **614**), the connection may be aborted (block **614***a*). If the established is eventually received ("yes" exit to decision block **611**), engine **244** declares a "state established" state (block **611***a*).

Once state establish has been achieved, engine **244** tests whether the new connection has been authenticated (decision block **615**). If it has not been, engine **244** may wait and transition to step **625** (block **616**). If the connection has been authenticated ("yes" exit to decision block **615**), engine **244** tests whether authentication succeeded (decision block **617**). If it did not ("no" exit to decision block **617**), the connection is aborted (block **614***a*). Otherwise, engine **244** tests whether the peer transmit window is full (decision block **618**). If it is ("yes" exit to decision block **618**), engine **244** waits for acknowledgment and goes to step **625** (decision block **619**). If the window is not full ("no" exit to decision block **618**), engine **244** creates an Internet Mobility Protocol data frame (block **620**) and sends it (block **621**). Engine **244** then determines if the retransmit timer has started (decision block **622**). If no, engine **244** starts the retransmit timer (block **623**). Engine **244** loops through blocks **618**-**623** until there is no more data to send (as tested for by decision block **624**). Engine **244** then returns to a sleep mode waiting for more work and returns to the global dispatcher (block **625**).

Termination

FIG. **11** is a flowchart of example steps performed by Internet Mobility Protocol engine **244** to terminate a connection. In response to a "terminate connection" request (block **626**), the engine queues the request to its global work queue and returns to the calling application (block **626***a*). The terminate request is eventually dispatched from the Internet Mobility Protocol process global work queue for execution (block **627**). Engine **244** examines the terminate request and determines whether the terminate request should be immediate or graceful (decision block **628**). If immediate ("abort" exit to decision block **628**), engine **244** immediately aborts the connection (block **629**). If graceful ("graceful" exit to decision block **628**), engine **244** declares a "state close" state (block **628***a*), and sends an Internet Mobility Protocol "Mortis" frame (block **630**) to indicate to the peer that the connection is to close. Engine **244** then declares a "Mortis" state (block **630***a*) and starts the retransmit timer (block **631**). Engine **244** tests whether the response of "post mortem" frame has been received from the peer (decision block **632**). If not ("no" exit to decision block **632**), engine **244** determines whether a retransmit timer has yet expired (decision block **633**). If the retransmit timer is not expired ("no" exit to decision block **633**), engine **244** waits and proceeds to step **637** (block **634**). If the retransmit timer has expired ("yes" exit to decision block **633**), engine **244** determines whether the total retransmit time has expired (decision block **635**). If the total time is not yet expired ("no" exit to decision block **635**), control returns to block **630** to resent the Mortis frame. If the total retransmit time has expired ("yes" exit to decision block **635**), engine **244** immediately aborts the connection (block **635***a*).

Once a "post mortem" responsive frame has been received from the peer ("yes" exit to decision block **632**), engine **244** declares a "post mortem" state (block **632***a*), releases connection resources (block **636**), and returns to sleep waiting for more work (block **637**).

Retransmission

FIG. **12** is a flowchart of example "retransmit" events logic performed by Internet Mobility Protocol engine **244**. In the event that the retransmit timer has expired (block **650**), engine **244** determines whether any frames are outstanding (decision block **651**). If no frames are outstanding ("no" exit to decision block **651**), engine **244** dismisses the timer (block **652**) and returns to sleep (block **660**). If, on the other hand, frames are outstanding ("yes" exit to decision block **651**), engine **244** determines whether the entire retransmit period has expired (decision block **653**). If it has not ("no" exit to decision block **653**), the process returns to sleep for the difference in time (block **654**). If the entire retransmit time period has expired ("yes" exit to decision block **653**), engine **244** determines whether a total retransmit period has expired (decision block **655**). If it has ("yes" exit to decision block **655**) and this event has occurred in the Mobility Management Server engine **244'** (as opposed to the Mobile End System engine **244**), a dormant state is declared (decision block **656**, block **656***a*). Under these same conditions, the Internet Mobility Protocol engine **244** executing on the Mobile End System **104** will abort the connection (block **656***b*).

If the total retransmit period is not yet expired ("no" exit to decision block **655**), engine **244** reprocesses the frame to remove any expired data (block **657**) and then retransmits it (block **658**)—restarting the retransmit timer as it does so (block **659**). The process then returns to sleep (block **660**) to wait for the next event.

Internet Mobility Protocol Expiration of a PDU

FIG. **12** block **657** allows for the requesting upper layer interface to specify a timeout or retry count for expiration of any protocol data unit (i.e. a SEND work request) submitted for transmission to the associated peer. By use of this functionality, Internet Mobility Protocol engine **244** maintains the semantics of unreliable data and provides other capabilities such as unreliable data removal from retransmitted frames. Each PDU (protocol data unit) **506** submitted by the layer above can specify a validity timeout and/or retry count for each individual element that will eventually be coalesced by the Internet Mobility Protocol engine **244**. The validity timeout and/or retry count (which can be user-specified for some applications) are used to determine which PDUs **506** should not be retransmitted but should instead be removed from a frame prior to retransmission by engine **244**.

The validity period associated with a PDU **506** specifies the relative time period that the respective PDU should be considered for transmission. During submission, the Internet Mobility Protocol RequestWork function checks the expiry timeout value. If it is non-zero, an age timer is initialized. The requested data is then queued on the same queue as all other data being forwarded to the associated peer. If the given PDU **506** remains on the queue for longer than the time period specified by the validity period parameter, during the next event that the queue is processed, the given (all) PDU(s) that has an expired timeout is removed and completed locally with a status code of "timeout failure" rather than being retransmitted when the frame is next retransmitted. This algorithm ensures that unreliable data being queued for transmission to the peer will not grow stale and/or boundlessly consume system resources.

In the example shown in FIG. **12**A, three separate PDUs **506** are queued to Internet Mobility Protocol engine **244** for subsequent processing. PDU **506(1)** is queued without an expiry time denoting no timeout for the given request. PDU **506(2)** is specified with a validity period of 2 seconds and is chronologically queued after PDU **506(1)**. PDU **506(***n***)** is queued 2.5 seconds after PDU **506(2)** was queued. Since the act of queuing PDU **506(***n***)** is the first event causing processing of the queue and PDU **506(2)** expiry time has lapsed, PDU **506(2)** is removed from the work queue, completed locally and then PDU **506(***n***)**, is placed on the list. If a validity period was specified for PDU **506(***n***)** the previous sequence of events would be repeated. Any event (queuing, dequeuing, etc) that manipulates the work queue will cause stale PDUs to be removed and completed.

As described above, PDUs **506** are coalesced by the Internet Mobility Protocol Engine **244** transmit logic and formatted into a single data stream. Each discrete work element, if not previously expired by the validity timeout, is gathered to formulate Internet Mobility Protocol data frames. Internet Mobility Protocol Engine **244** ultimately sends these PDUs **506** to the peer, and then places the associated frame on a Frames-Outstanding list. If the peer does not acknowledge the respective frame in a predetermined amount of time (see FIG. **12** showing the retransmission algorithm), the frame is retransmitted to recover from possibly a lost or corrupted packet exchange. Just prior to retransmission, the PDU list that the frame is comprised of is iterated through to determine if any requests were queued with a retry count. If the retry count is non zero, and the value is decremented to zero, the PDU **506** is removed from the list, and the frames header is adjusted to denote the deletion of data. In this fashion, stale data, unreliable data, or applications employing their own retransmission policy are not burdened by engine **244**'s retransmission algorithm.

In the FIG. **12**B example, again three separate PDUs **506** are queued to Internet Mobility Protocol engine **244** for subsequent processing. PDU **506(1)** is queued without a retry count. This denotes continuous retransmission attempts or guaranteed delivery level of service. PDU **506(2)** is queued with a retry count of 1 and is chronologically queued after PDU **506(1)**. PDU **506(***n***)** is queued sometime after PDU **506(2)**. At this point, some external event (e.g., upper layer coalesce timer, etc.) causes engine **244**'s send logic to generate a new frame by gathering enough PDUs **506** from the work queue to generate an Internet Mobility Protocol data frame **500**. The frame header **503** is calculated and stamped with a retry ID of 0 to denote that this is the first transmission of the frame. The frame is then handed to the NAL layer for subsequent transmission to the network. At this point a retransmit timer is started since the frame in question contains a payload. For illustration purposes it is assumed that an acknowledgement is not received from the peer for a variety of possible reasons before the retransmit timer expires. The retransmit logic of engine **244** determines that the frame **500** in question is now eligible for retransmission to the network. Prior to resubmitting the frame to the NAL layer, engine **244**'s retransmit logic iterates through the associated list of PDUs **506**. Each PDU's retry count is examined and if non-zero, the count is decremented. In the process of decrementing PDU **506(2)**'s retry count, the retry count becomes zero. Because PDU **506(2)**'s retry count has gone to zero, it is removed from the list and completed locally with a status of "retry failure." The frame header **503** size is then adjusted to denote the absence of the PDU **506(2)**'s data. This process is repeated for all remaining PDUs. Once the entire frame **500** is reprocessed to produce an "edited" frame **500'**, the retry ID in the header is incremented and the resultant datagram is then handed to the NAL layer for subsequent (re)transmission.

Reception

FIGS. **13**A-**13**D are a flowchart of example steps performed by Internet Mobility Protocol engine **244** in response to receipt of a "receive" event. Such receive events are generated when an Internet Mobility Protocol frame has been received from network **108**. In response to this receive event, engine **244** pre-validates the event (block **670**) and tests whether it is a possible Internet Mobility Protocol frame (decision block **671**). If engine **244** determines that the received frame is not a possible frame ("no" exit to decision block **671**), it discards the frame (block **672**). Otherwise ("yes" exit to decision block **671**), engine **244** determines whether there is a connection associated with the received frame (decision block **673**). If there is a connection associated with the received frame ("yes" exit to decision block **673**), engine **244** places the work on the connection receive queue (block **674**), marks the connection as eligible to receive (block **675**), and places the connection on the global work queue (block **676**). If no connection has yet been associated with the received frame ("no" exit to decision block **673**), engine **244** places the received frame on the socket receive queue (block **677**) and places the socket receive queue on the global work queue (block **678**). In either case, engine **244** signals a global work event (block **679**). Upon dispatching of a "receive eligible" event from the global work queue (see FIG. **13**B), engine **244** de-queues the frame from the respective receive queue (block **680**). It is possible that more then one IMP frame is received and queued before the Internet Mobility Protocol engine **244** can start de-queuing the messages. Engine **244** loops until all frames have been de-queue (blocks **681**, **682**). Once a frame has been de-queued ("yes" exit to decision block **681**), engine **244** validates the received frame (block **683**) and determines whether it is okay (decision block **684**). If the received frame is invalid, engine **244** discards it (block **685**) and de-queues the next frame from the receive queue (block **680**). If the received frame is valid ("yes" exit to decision block **684**), engine **244** determines whether it is associated with an existing connection (block **686**). If it is not ("no" exit to decision block **686**), engine **244** tests whether it is a sync frame (decision block **687**). If it is not a sync frame ("no" exit to decision block **687**), the frame is discarded (block **685**). If, on the other hand, a sync frame has been received ("yes" exit to decision block **687**), engine **244** processes it using a passive connection request discussed in association with FIGS. **14**A and **14**B (block **688**).

If the frame is associated with a connection ("yes" exit to decision block **686**), engine **244** determines whether the connection state is still active and not "post mortem" (decision block **689**). If the connection is already "post mortem," the frame is discarded (block **685**). Otherwise, engine **244** parses the frame (block **690**) and determines whether it is an abort frame (decision block **691**). If the frame is an abort frame, engine **244** immediately aborts the connection (block **691***a*). If the frame is not an abort frame ("yes" exit to decision block **691**), engine **244** processes acknowledgment information and releases any outstanding send frames (block **692**). Engine **244** then posts the frame to any security subsystem for possible decryption (block **693**). Once the frame is returned from the security subsystem engine **244** processes any control data (block **694**). Engine **244** then determines whether the frame contains application data (decision block **695**). If it does, this data is queued to the application layer (block **696**). Engine **244** also determines whether the connection's state is dormant (block **697** and **697***a*—this can happen on Mobility Management Server engine **244'** in the preferred implementation), and returns state back to established.

If the frame is possibly a "Mortis" frame ("yes" exit to decision block **698**), engine **244** indicates a "disconnect" to the application layer (block **699**) and enters the "Mortis" state (block **699***a*). It sends a "post mortem" frame to the peer (block **700**), and enters the "post mortem" state (block **700***a*). Engine **244** then releases connection resources (block **701**) and returns to sleep waiting for more work (block **702**). If the parsed frame is a "post mortem" frame ("yes" exit to decision block **703**), blocks **700***a*, **701**, **702** are executed. Otherwise, control returns to block **680** to dequeue the next frame from the receive queue (block **704**).

Passive Connections

Blocks **14**A-**14**B are together a flowchart of example steps performed by Internet Mobility Protocol engine **244** in response to a "passive connection" request. Engine **244** first determines whether there is another connection for this particular device (block **720**). If there is ("yes" exit to decision block **720**), the engine determines whether it is the initial connection (decision block **721**). If peer believes the new connection is the initial connection ("yes" exit to decision block **721**), engine **244** aborts the previous connections (block **722**). If not the initial connection ("no" exit to decision block **721**), engine **244** tests whether the sequence and connection ID match (decision block **723**). If they do not match ("no" exit to decision block **723**), control returns to decision block **720**. If the sequence and connection ID do match ("yes" exit to decision block **723**), engine **244** discards duplicate frames (block **724**) and returns to step **680** of FIG. **13**B (block **725**).

If there is no other connection ("no" exit to decision block **720**), engine **244** determines whether it can allocate connection resources for the connection (decision block **726**). If it cannot, an error is declared ("no" exit to decision block **726**, block **727**), and the connection is aborted (block **728**). If it is possible to allocate connection resources ("yes" exit to decision block **726**), engine **244** declares a "configure" state (block **726***a*) and acquires the security context for the connection (block **730**). If it was not possible to acquire sufficient security context ("no" exit to decision block **731**), the connection is aborted (block **728**). Otherwise, engine **244** sends an established frame (block **732**) and declares the connection to be in state "establish" (block **732***a*). Engine **244** then starts a retransmitter (block **733**) and waits for the authentication process to conclude (block **734**). Eventually, engine **244** tests whether the device and user have both been authenticated (block **735**). If either the device or the user is not authenticated, the connection is aborted (block **736**). Otherwise, engine **244** indicates the connection to the listening application (block **737**) and gets the configuration (block **738**). If either of these steps do not succeed, the connection is aborted (decision block **739**, block **740**). Otherwise, the process returns to sleep waiting for more work (block **741**).

Abnormal Termination

FIGS. **15**A and **15**B are a flowchart of example steps performed by the Internet Mobility Protocol engine **244** in response to an "abort" connection request. Upon receipt of such a request from another process (block **999**) and are dispatched via the queue (block **1000**), engine **244** determines whether the connection is associated with the request (decision block **1001**). If it is ("yes" exit to decision block **1001**), engine **244** saves the original state (block **1002**) and declares an "abort" state (block **1002***a*). Engine **244** then determines whether the connection was indicated to any listening application (decision block **1003**)—and if so, indicates a disconnect to that listening application (block **1004**). Engine **244** then declares a "post mortem" state (block **1003***a*), releases the resources previously allocated to the particular connection (block **1005**), and tests whether the original state is greater than the state pending (decision block **1006**). If not ("no" exit to decision block **1006**), the process transitions to block **1002** to return to the calling routine (block **1007**). Otherwise, engine **244** determines whether the request is associated with a received frame (decision block **1008**). If the abort request is associated with a received frame, and the received frame is an abort frame (decision block **1009**), the received frame is discarded (block **1010**). Otherwise engine **244** will send an abort frame (block **1011**) before returning to the calling routine (block **1012**).

Roaming Control

Referring once again to FIG. **1**, mobile network **108** may comprise a number of different segments providing different network interconnects (**107***a*-**107***k* corresponding to different wireless transceivers **106***a*-**106***k*). In accordance with another aspect of a presently preferred exemplary non-limiting implementation, network **108** including Mobility Management Server **102** is able to gracefully handle a "roaming" condition in which a Mobile End System **104** has moved from one network interconnect to another. Commonly, network **108** topographies are divided into segments (subnets) for management and other purposes. These different segments typically assign different network (transport) addresses to the various Mobile End Systems **104** within the given segment.

It is common to use a Dynamic Host Configuration Protocol (DHCP) to automatically configure network devices that are newly activated on such a subnet. For example, a DHCP server on the sub-net typically provides its clients with (among other things) a valid network address to "lease". DHCP clients may not have permanently assigned, "hard coded" network addresses. Instead, at boot time, the DHCP client requests a network address from the DHCP server. The DHCP server has a pool of network addresses that are available for assignment. When a DHCP client requests an network address, the DHCP server assigns, or leases, an available address from that pool to the client. The assigned network address is then "owned" by the client for a specified period ("lease duration"). When the lease expires, the network address is returned to the pool and becomes available for reassignment to another client. In addition to automatically assigning network addresses, DHCP also provides netmasks and other configuration information to clients running DHCP client software. More information concerning the standard DHCP protocol can be found in RFC2131.

Thus, when a Mobile End System **104** using DHCP roams from one subnet to another, it will appear with a new network address. In accordance with a presently preferred exemplary non-limiting implementation, Mobile End Systems **104** and Mobility Management Server **102** take advantage of the automatic configuration functionality of DHCP, and coordinate together to ensure that the Mobility Management Server recognizes the Mobile End System's "new" network address and associates it with the previously-established connection the Mobility Management Server is proxying on its behalf.

The preferred implementation uses standard DHCP Discover/Offer client-server broadcast messaging sequences as an echo request-response, along with other standard methodologies in order to determine if a Mobile End System **104** has roamed to a new subnet or is out of range. In accordance with the standard DHCP protocol, a Mobile End System **104** requiring a network address will periodically broadcast client identifier and hardware address as part of a DHCP Discover message. The DHCP server will broadcast its Offer response (this message is broadcast rather than transmitted specifically to the requesting Mobile End System because the Mobile End System doesn't yet have a network address to send to). Thus, any Mobile End System **104** on the particular subnet will pick up any DHCP Offer server response to any other Mobile End System broadcast on the same subnet.

A presently preferred exemplary implementation of present non-limiting implementation provides DHCP listeners to monitor the DHCP broadcast messages and thereby ascertain whether a particular Mobile End System **104** has roamed from one subnet to another and is being offered the ability to acquire a new network address by DHCP. FIG. **16** shows example DHCP listener data structures. For example, a Mobile End System listener data structure **902** may comprise:

a linked list of server data structures,
an integer transaction ID number (xid),
a counter ("ping"), and
a timeout value.

A server data structure **904** may comprise a linked list of data blocks each defining a different DHCP server, each data block comprising:

a pointer to next server,
a server ID (network address of a DHCP server),
an address (giaddr) of a BOOTP relay agent recently associated with this DHCP server,
a "ping" value (socket ->ping), and
a flag.

These data structures are continually updated based on DHCP broadcast traffic appearing on network **108**. The following example functions can be used to maintain these data structures:

roamCreate( ) [initialize variables]
roamDeinitialize( ) [delete all listeners]
roamStartIndications( ) [call a supplied callback routine when a Mobile End System has roamed or changed interfaces, to give a registrant roaming indications]
roamStopIndications( ) [remove the appropriate callback from the list, to stop giving a registrant roaming indications]
Interface Change [callback notification from operating system indicating an interface has changed its network address]
Listener Signal [per-interface callback from a Listener indicating a roaming or out-of-range or back-in-range condition].

Additionally, a refresh process may be used to update Listeners after interface changes.

In the preferred implementation, all Mobile End Systems **104** transmit the same Client Identifier and Hardware Address in DHCP Discover requests. This allows the listener data structures and associated processes to distinguish Mobile End System-originated Discover requests from Discover requests initiated by other network devices. Likewise, the DHCP server will broadcast its response, so any Mobile End System **104** and/or the Mobility Management Server **102** will be able to pick up the DHCP server Offer response to any other Mobile End System. Since multiple DHCP servers can respond to a single DHCP Discover message, the listener data structures shown in FIG. **16** store each server response in a separate data block, tied to the main handle via linked list.

Upon receiving a Discover request having the predetermined Client Hardware Address and Client Identifier, the preferred implementation recognizes this request as coming from a Mobile End System **104**. If the message also has a BOOTP relay address set to zero, this indicates that the message originated on the same subnet as the listener. Listeners may ignore all DHCP Offers unless they have a transaction ID (xid) matching that of a Discover message recently sent by a Mobile End System **104**. The listener can determine that a Mobile End System **104** has roamed if any response comes from a known server with a new BOOTP relay agent ID and/or offered network address masked with an offered subnet mask. Listeners add new servers to the FIG. **16** data structures only after receiving a positive response from an old server. If a listener receives responses from new server(s) but none from an old server, this may indicate roaming (this can be a configurable option). If the listener fails to receive responses from new or old servers, the listener is out of range (this determination can be used to signal an upper layer such as an application to halt or reduce sending of data to avoid buffer overflow).

If the listener never receives a response from any server, there is no point of reference and thus impossible to determine whether roaming has occurred. This condition can be handled by signaling an error after a timeout and allowing the caller to retry the process. The preferred implementation determines that a Mobile End System **104** has roamed if any response has come from a known server with a new BOOTP relay agent ID (or a new offered network address when masked with offered subnet mask). If the listener data structures see responses from new servers but none from an old server, it is possible that roaming has occurred, but there must be a delay before signaling, in order to wait for any potential responses from the old servers. If there are no responses from new or old servers, then the Mobile End System **104** is probably out of range and Mobility Management Server **102** waits for it to come back into range.

FIG. **17** is a flowchart of example steps of a Listener process of the preferred implementation. Referring to FIG. **17**, a DHCP listener process is created by allocating appropriate memory for the handle, opening NAL sockets for the DHCP client and server UDP ports, and setting receive callbacks for both. A timer is then set (block **802**) and then the process enters the "Wait" state to wait for a roaming related event (block **804**). Three external inputs can trigger an event:

a DHCP server packet is received;

a DHCP client packet sent by another Mobile End System is received

a timer timeout occurs.

If a DHCP server packet has been received, the packet is examined to determine whether its client identifier matches the predetermined client ID (decision block **806**). If it does not, it is discarded. However, if the packet does contain the predetermined ID, a test is performed to determine whether the packet is a DHCP Offer packet (decision block **808**). Offer packets are rejected unless they contain a transaction ID matching a recently sent DHCP Discover sequence.

If the packet transaction ID matches (block **810**), then a test is made as to whether the server sending the DHCP offer packet is known (i.e., the server ID is in the listener data structure shown in FIG. **16**) (block **812**). If the server ID is not on the list ("no" exit to decision block **812**), it is added to the list and marked as "new" (or "first" if it is the first server on the list) (block **822**). If the server is already on the list ("Y" exit to decision block **812**), a further test is performed to determine whether the packet BOOTP relay address ("GIADDR") matches the server address ("GIADDR") (decision block **814**). If there is no match, then the Offer packet must be originating from a different subnet, and it is determined that a "hard roam" has occurred (block **816**). The caller application is signaled that there has been a roam. If, on the other hand, decision block **814** determines there is a match in BOOTP relay addresses, then no roam has occurred, the listener process stamps the server receive time, resets "new" flags for all other servers on the list, and stores the current ping number with the server (block **818**, **820**). The process then returns to "wait" period.

If the event is a received client packet, the listener process determines whether the packet has the predetermined client ID, is a DHCP Discover packet and has a BOOTP relay address (GIADDR) of 0 (blocks **824**, **826**, **828**). These steps determine whether the received packet is DHCP Discover message sent by another Mobile End System **104** on the same sub-net as the listener. If so, the listener process then sets the transaction ID to the peer's transaction ID (block **830**) for use in comparing with later-received DHCP Offer packets, calls a ping check (block **834**) and resets the timer (block **836**).

In response to a timer timeout, the process calls a "ping check" (block **838**). "Pings" in the preferred implementation are DHCP Discover packets with a random new xid. Example steps for this ping check **838** are shown in FIG. **17**A. The purpose of the ping check routine is to determine if a "soft roam" condition has occurred (i.e., a Mobile End System has temporarily lost and then regained contact with a sub-net, but has not roamed to a different sub-net). The process determines whether there is a sub-net roam condition, an out-of-range condition, or a "no server" condition. In other words:

Has a Mobile End System roamed from one sub-net to another?

Is a Mobile End System out of range?

Is a DHCP server absent?

These conditions are determined by comparing Mobile End System prior "ping" response with the current "ping" response (decision blocks **846**, **850**). For example, if the current ping number minus the old server's last ping response is greater than the sub-net server pings and there is at least one server marked "new," there has been a sub-net roam to a different server. The result of this logic is to either signal a subset roam, and out of range condition or a no server condition (or none of these) to the calling process.

FIG. **18** shows a flowchart of example steps performed by a Mobile End System **104** roaming control center. To enable roaming at the Mobile End System **104**, the list of known addresses is initialized to zero (block **850**) and an operating system interface change notification is enabled (block **852**). The process then calls the operating system to get a list of current addresses that use DHCP (block **854**). All known addresses no longer in the current list have their corresponding listeners closed (block **856**). Similarly, the process opens listeners on all current but not known interfaces (block **858**). The process then signals "roam" to registrants (block **860**).

When the listener process of FIG. **17** signals (block **862**), the process determines whether the signal indicates a "roam", "out of range" or "back in range" condition (decision block **864**, **870**, **874**). A roam signal ("yes" exit to decision block **864**) causes the process to close corresponding listener **866** and call the operating system to release and renew DHCP lease to a network address (block **868**). If the listener signals "out of range" (decision block **870**), the process signals this condition to registrants (block **872**). If the signal is a "back in range" (decision block **874**), then this condition is signaled to all registrants (block **876**). Upon receiving a disabled roam command (block **878**), the process closes all listeners (block **880**) and disables the operating system interface change notification (block **882**).

EXAMPLES

A presently preferred exemplary implementation of present non-limiting implementation finds application in a variety of real-world situations. For example:

Intermittently Connected Portable Computer

Many businesses have employees who occasionally telecommute or work from home. Such employees often use laptop computers to get their work done. While at work, the employees typically connect their laptop computers to a local area network such as an Ethernet through use of a docking port or other connector. The LAN connection provides access to network services (e.g., printers, network drives) and network applications (e.g., database access, email services).

Now suppose an employee working on a project needs to go home for the evening and wants to resume working from home. The employee can "suspend" the operating system and applications running on the laptop computer, pack up the laptop computer, and bring the laptop computer home.

Once home, the employee can "resume" the operating system and applications running on the laptop computer, and reconnect to the office LAN via a dialup connection and/or over the Internet. The Mobility Management Server (which continued to proxy the laptop computer vis-a-vis the network and its applications during the time the laptop computer was temporarily suspended) can re-authenticate the laptop computer and resume communicating with the laptop computer.

From the perspective of the employee now working from home, all of the network drive mappings, print services, email sessions, database queries, and other network services and applications, are exactly where the employee left them at the office. Furthermore, because the Mobility Management Service continued to proxy the laptop computer's sessions, none of those network applications terminated the laptop computer's sessions during the time the employee was traveling from the office to home. The exemplary implementation thus provides efficient persistence of session across the same or multiple network mediums that is very powerful and useful in this and other contexts.

Mobile Inventory and Warehouse Application

Imagine a large warehouse or retail chain. Within this campus, inventory workers use vehicle mounted (i.e., trucks and forklifts) personal laptop computers and handheld data collection units and terminals to perform inventory management of goods. Warehouse and retail workers are often inexperienced computer users that do not understand network sub-nets and require management supervision. A presently preferred exemplary implementation allows the creation of a turnkey system that hides the complexity of the mobile network from the warehouse users. The users can move in and out of range of access points, suspend and resume their Mobile End Systems **104**, and change locations without concern for host sessions, network addresses, or transport connections. In addition, the management software on the Mobility Management Server **102** provides management personnel with metrics such as number of transactions, which may be used to gauge worker productivity. Management can also use the network sub-net and access points to determine worker's last known physical location.

Mobile Medical Application

Imagine a large hospital using radio LAN technology for network communications between several buildings. Each building is on a unique sub-net. A presently preferred exemplary implementation enables nurses and doctors to move from room to room with handheld personal computers or terminals—reading and writing patient information in hospital databases. Access to the most recent articles on medication and medical procedures is readily available through the local database and the World Wide Web. While in the hospital, pagers (one and two way) are no longer required since a presently preferred exemplary implementation of the present invention allows continuous connection to the Mobile End System **104**. Messages can be sent directly to medical personnel via the Mobile End System **104**. As in the case with warehouse workers, medical personnel are not required to understand the mobile network they are using. In addition, the Mobile End System **104** allows medical personnel to disable radio transmission in area where radio emissions are deemed undesirable (e.g., where they might interfere with other medical equipment)—and easily resume and reconnect where they left off.

Trucking and Freight

Freight companies can a presently preferred exemplary implementation of use the present invention to track inventory. While docked at a warehouse, the Mobile End System **104** may use LAN technology to update warehouse inventories. While away from local services, the Mobile End System **104** can use Wide Area WAN services such as CDPD and ARDIS to maintain real time status and location of inventory. The Mobile End System **104** automatically switches between network infrastructures—hiding the complexity of network topology from vehicle personnel.

Mobile Enterprise

Corporate employees may use the system in accordance with a presently preferred exemplary implementation for access to E-mail, web content and messaging services while within an enterprise campus that has invested in an infrastructure such as 802.11. The cost of ownership is reduced since pager service and other mobile device services are no longer required. The purchase of mobile infrastructure is a one time capital expense as opposed to the costly "pay-per-use" model offered by many existing mobile device services.

IP Multiplication

If an organization has a LAN that needs to be connected to the Internet, the administrator of the LAN has two choices: get enough globally assigned addresses for all computers on the LAN, or get just a few globally assigned addresses and use the Mobility Management Server **102** in accordance with a presently preferred exemplary non-limiting implementation as an address multiplier. Getting a large number of IP addresses tends to be either expensive or impossible. A small company using an Internet Service Provider (ISP) for access to the Internet can only use the IP addresses the ISP assigns—and the number of IP addresses limits the number of computers that can be on the Internet at the same time. An ISP also charges per connection, so the more computers that need to be on the Internet, the more expensive this solution becomes.

Using the Mobility Management Server **102** in accordance with the present non-limiting exemplary implementation as an address multiplier could solve many of these problems. The enterprise could put the Mobility Management Server **102** on hardware that is connected to the Internet via an ISP. Mobile End Systems **104** could then easily connect. Because all connection to the Internet would go through the Mobility Management Server **102**, only one address from the ISP is required. Thus, using a presently preferred exemplary non-limiting implementation as an address multiplier allows the enterprise to get just a few (in many cases one) addresses and accounts from the ISP, and allows the entire LAN to have simultaneous connections to the Internet (assuming enough bandwidth is provided).

While the has been described in connection with what is presently considered to be the most practical and preferred implementation, it is to be understood that the invention is not to be limited to the disclosed implementation, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the scope of the appended claims.

What is claimed is:

1. A mobile computing environment comprising:
at least one proxy server; and
at least one mobile computing device that includes:
  a signal transmitter,
  a transport driver interface, and
  a mobile interceptor coupled to said transport driver interface,
said mobile interceptor intercepting requests for network services at said transport driver interface, generating

Remote Procedure Calls responsive to said requests for network services, and forwarding said Remote Procedure Calls from the at least one mobile device via the signal transmitter to said at least one proxy server; and

said at least one proxy server includes: at least one work dispatcher that receives and handles said Remote Procedure Calls forwarded by said mobile interceptor; and a prioritized queue that proxies communication sessions on behalf of said mobile computing device even when the mobile computing device becomes temporarily disconnected from said mobile computing environment.

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