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(72) DUGAS, PIERRE, CA
(72) LOEWEN, JON, CA
(71) NORTEL NETWORKS CORPORATION, CA

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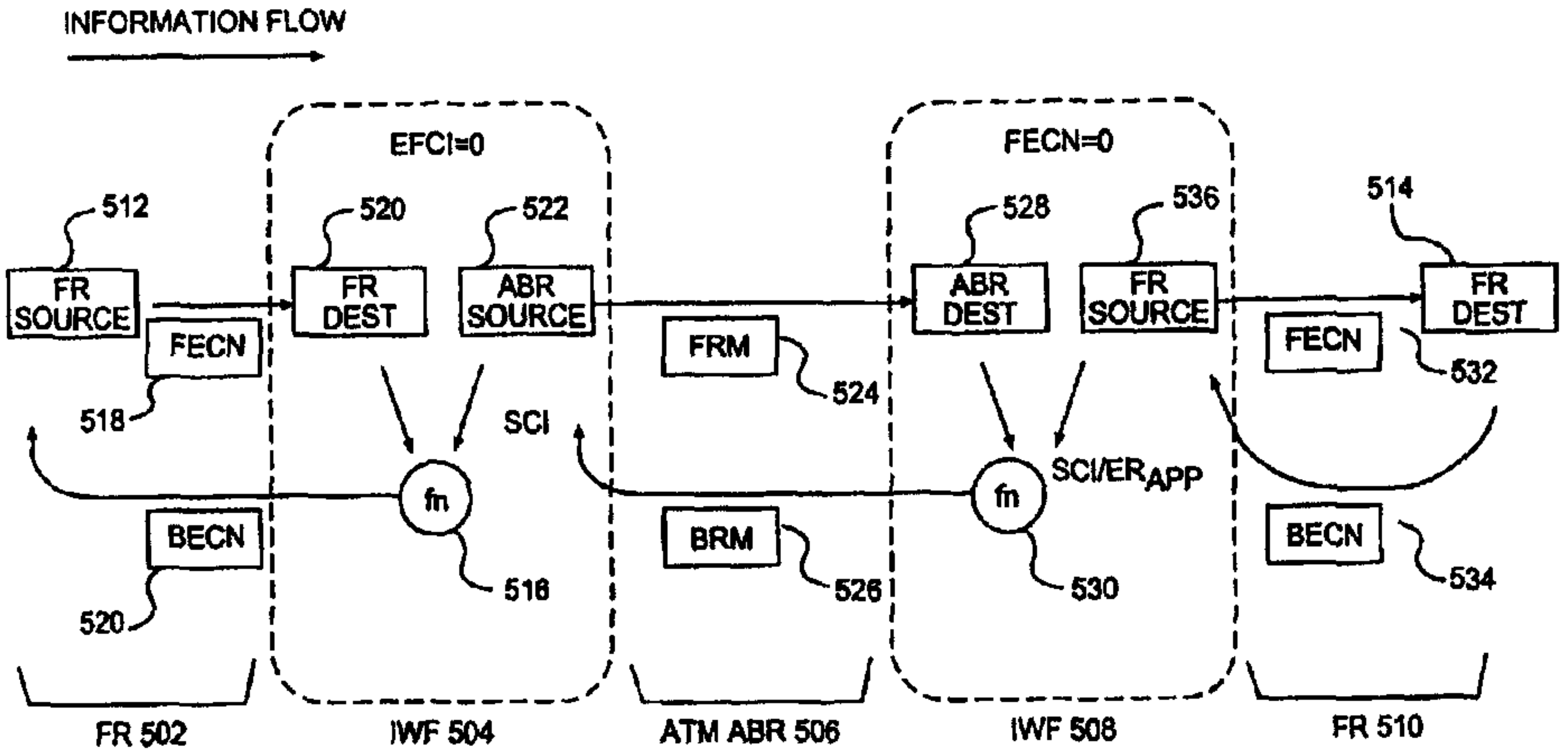
(54) PROCEDE ET APPAREIL POUR LE CONTROLE DE L'ENGORGEMENT DE RELAIS DE TRAMES EN INTERFONCTIONNEMENT AVEC DES BOUCLES DE COMMANDE DU DEBIT BINAIRE DISPONIBLE

(54) METHOD AND APPARATUS FOR FRAME RELAY CONGESTION INTERWORKING WITH ABR FLOW-CONTROL LOOPS



(57) Dans un réseau hybride comprenant des segments de réseau caractérisés par des protocoles de données Niveau 2 (p. ex. relais de trames) et des segments de réseau ATM avec des catégories de service ABR, un procédé d'interfonctionnement de chaque engorgement du segment de réseau assure un contrôle de l'engorgement à boucle fermée de bout-en-bout, comme par exemple, à travers tout le réseau hybride. Le réseau hybride est divisé en segments de régulation du débit et des notifications précédentes concernant l'engorgement sont mises en correspondance dans des réseau précédents, réduisant de ce fait l'engorgement.

(57) In a hybrid network including network segments characterized by Layer 2 data protocols (e.g. frame relay) and ATM network segments with ABR service categories, a method for interworking each network segment's congestion controls provides closed-loop congestion control end-to-end, i.e., across the entire hybrid network. The hybrid network is divided into flow-control segments, and backward congestion notifications are mapped into preceding networks, which improves congestion.

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(71) Applicant: NORTHERN TELECOM LIMITED [CA/CA]; P.O. Box 6123, Station A, Montreal, Quebec H3C 3J5 (CA).

(72) Inventors: LOEWEN, Jon; 108–101 Parkside Drive, Port Moody, British Columbia V3H 4W6 (CA). DUGAS, Pierre; 598 McConnell Road, Aylmer, Quebec J9J 2N8 (CA).

(74) Agents: McGRAW, James et al.; Smart & Biggar, 900–55 Metcalfe Street, P.O. Box 2999, Station D, Ottawa, Ontario K1P 5Y6 (CA).

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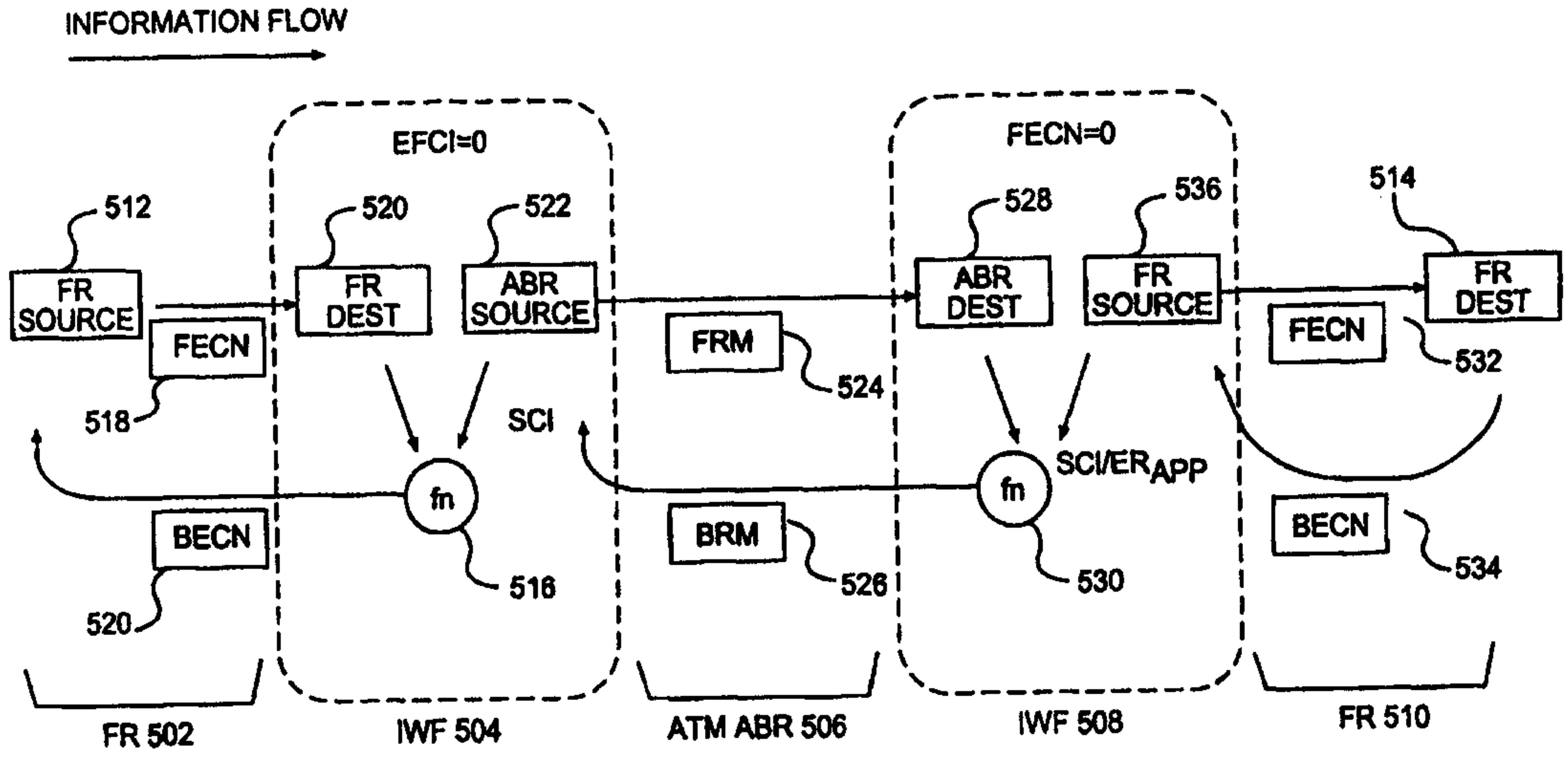


(57) Abstract

In a hybrid network including network segments characterized by Layer 2 data protocols (e.g. frame relay) and ATM network segments with ABR service categories, a method for interworking each network segment's congestion controls provides closed–loop congestion control end–to–end, i.e., across the entire hybrid network. The hybrid network is divided into flow–control segments, and backward congestion notifications are mapped into preceding networks, which improves congestion.

METHOD AND APPARATUS FOR FRAME RELAY CONGESTION INTERWORKING WITH ABR FLOW-CONTROL LOOPS

Background of the Invention

The present invention relates generally to congestion control in communications networks and, more particularly, to a method and apparatus for implementing hybrid network congestion control when interconnecting networks of differing types, such as frame relay networks and asynchronous transfer mode (ATM) networks with an available bit rate (ABR) service category.

The widespread proliferation of communications, data processing, and other networks has led to a demand for improved efficiency in the way interconnected networks communicate with each other. As networks evolve, the various associated protocols used to operate the networks similarly change. Today, certain networks commonly use a transfer protocol known as "frame relay." The frame relay (hereinafter "FR") protocol, which is one of the most widely used protocols, transfers data in the form of "frames," *i.e.*, groups of bytes of varying length. One disadvantage of the frame relay protocol, however, is the unacceptably long transmission times associated with particularly large frames. In certain applications, such as voice and video applications, transmission time is more critical than in other applications.

Asynchronous transfer mode (hereinafter "ATM") networks emerged to satisfy some of these problems. ATM networks pass data in the form of fixed-size (*i.e.*, 53 bytes) "cells." The structure of ATM networks creates several benefits, not the least of which is a reduction in data transmission time due to the shorter cell length, a benefit of particular importance to multimedia applications. Generally, ATM is considered an improved way of operating a data processing network given current and future needs.

Regardless of their type, networks generally need to control congestion to allow efficient communication and avoid the loss of, or the unacceptable delay in the transmission of, information. For congestion control, frames have bits specifically allocated for use in congestion control. For example, when a frame relay network component experiences congestion, it can set a bit in the frames about to be transmitted from the component to notify downstream components in the network of the congestion problem. Conversely, a network component may receive one or more frames with a set congestion bit indicating congestion upstream in the network. This component can then act accordingly by, for example, either reducing the rate at which it thereafter transmits frames or simply passing along the congestion information to the next network component.

Figure 1 shows a general network segment including a source 100, a plurality of network components 102, and a destination 104. The source generates data 106, which is relayed through the network by network components 102 toward destination 104. When, in the presence of network congestion, destination 104 receives an indication of that congestion, it forwards or routes the congestion data back to the source while adding its own congestion information. Upon receipt of this congestion information, source 100 may then reduce its transmission rate to reduce network congestion. This congestion control loop, shown generally by reference numeral 108, thus gives the entire end-to-end network segment "closed-loop flow control." Such closed-loop control allows the entire network segment to react to changing traffic conditions by notifying the source of network traffic congestion. The congestion notification that travels back to the source is commonly referred to as "back pressure" since it forces congestion back to the edge of the network segment.

The components making up a frame relay network can only indicate congestion information through "binary notification," *i.e.*, through the use of the congestion bits in a frame. Although binary notification allows the network components to know whether there is congestion, the network cannot determine exactly how much to adjust the transmission rate.

One of the main advantages of ATM networks over frame relay networks is the way ATM networks handle network traffic congestion control. ATM has a known service protocol or category called "Available Bit Rate" (hereinafter "ABR") that uses specialized cells, called "Resource Management" (hereinafter "RM") cells, that carry information regarding the state of the network. These RM cells contain more network status information than frames or normal user ATM cells and, in addition to binary notification, can specify to a network component the exact rate at which the component should be transmitting cells to help alleviate the congestion. This "explicit rate" notification allows the network components to transmit at the proper rate much more rapidly. Consequently, ATM networks can respond to changing traffic conditions much faster than frame relay networks.

As time progresses, more people are expected to use the ATM network format. As more and more ATM networks are deployed, the number of interconnections with between, for example, ATM networks and FR networks will rise, yielding "hybrid networks" characterized by both ATM and FR interworking functions. Successful linkage of the networks will be accomplished only if there is an efficient interworking of the different forms of congestion control. Although prior art congestion control interworking solutions illustrate ways to connect the two types of networks, each suffers from a deficiency in the way congestion is controlled over the entire hybrid network. These implementations include FRF.5 and FRF.8 of the Frame Relay Forum. These prior art solutions are described in papers titled "Frame Relay/ATM PVC Network Interworking Implementation Agreement," December 20, 1994 (D. O'Leary, editor), and "Frame Relay/ATM PVC Network Interworking Implementation Agreement," April 14, 1995 (D. O'Leary, editor), respectively.

In the FRF.8 implementation, the congestion notification generated in the frame relay network is not mapped into the ATM networks, *i.e.*, the congestion notification bits in the frames traveling from the destination back toward the source are not mapped into the ATM portion of the preceding interconnected network. As such, this implementation does not achieve end-to-end, closed-loop flow control in the hybrid network, eliminating the possibility for the end-to-end hybrid network to quickly adapt to changing transfer characteristics.

While FRF.5 also defines a flow control interworking between FR and ATM networks, the resulting hybrid network does not make efficient use of the ATM ABR segments to provide backward notification of congestion. Rather, FRF.5 relies on the end-to-end FR congestion loop to provide back pressure. For example, if there is congestion at the end of a FR network segment, the congestion will pass through the ATM segment and appear on the other side in the next FR segment. As a result, the network is slow in reacting to changing transfer characteristics.

It is, therefore, desirable to provide a method for interworking non-ABR Layer 2 data protocol congestion controls with ATM ABR networks.

Summary of the Invention

Systems and methods consistent with the present invention satisfy this desire and other desires by providing a method for interworking a non-ABR layer 2 data protocol with rate flow-control to an ATM network with an ABR service category. More particularly, the present invention provides a method for connecting frame relay networks to ATM ABR networks while providing closed-loop back pressure (congestion control) across the entire hybrid network.

A method, consistent with the present invention for use in a hybrid network including a first network segment interconnected with a second network segment, for interworking congestion controls of each segment across the hybrid network includes the steps of transmitting information in a first format from a source in the first network segment toward a destination in the second network segment, and translating the information to a second format associated with the second network segment. The method also includes the step of receiving the translated information in a source in the second network segment, and generating a congestion indicator if congestion occurs at the source in the second network segment. The method also includes the steps of mapping the congestion indicator to a backward congestion indicator associated with the first network segment, and transmitting the backward congestion indicator toward the source in the first network segment so as to control congestion in the hybrid network.

Another method, consistent with the present invention for use in a hybrid network including a first network segment interconnected with a second network segment, for interworking congestion controls of each segment across the hybrid network includes the steps of transmitting information in a first format from a source in the first network segment toward a destination in the second network segment, and translating the information to a second format associated with the second network segment. The method also includes the steps of generating a backward congestion indicator associated with the second network segment if congestion occurs in the second network segment, mapping the backward congestion indicator associated with the second network segment to a backward congestion indicator associated with the first network segment, and transmitting the backward congestion indicator associated with the first network segment toward the source in the first network segment so as to control congestion in the hybrid network.

A network consistent with the present invention includes a first network segment including a backward congestion indicator to control congestion in the segment; and a second network segment positioned downstream from the first network segment and having an associated source that receives information from the first network segment, the source having a congestion indicator. The network also includes means for mapping the congestion indicator associated with the second network segment into the backward congestion indicator in the first network to apply back pressure to the first network segment.

Another network consistent with the present invention includes a first network segment having a destination that generates a backward congestion indicator to control congestion in the segment, and a second network segment positioned downstream from the first network segment and including a backward congestion indicator to control congestion in the segment. The network also includes means for mapping the backward congestion indicator in the second network segment into the backward congestion indicator associated with the first network segment. In one network implementation, the means for mapping includes means for mapping the backward congestion indicator in the second network segment into one of either a congestion bit field or an explicit rate field of the backward congestion indicator associated with the first network segment.

Several advantages accrue to systems and methods consistent with the present invention. For example, the segmented congestion control in the hybrid network and the backward congestion notification between each segment leads to faster congestion response time and lower packet loss for the total hybrid network. It also allows the hybrid network to benefit from ATM ABR's faster response to network congestion. More particularly, the interworking enables the closed-loop flow-control of ABR to be extended beyond ATM, allowing the hybrid network to respond dynamically to changing transfer characteristics. The closed-loop is extended by making the layer 2 data protocol network a virtual ABR segment with binary notification from the ATM network's perspective. Moreover, the transport of FR data packets over ABR (rather than VBR-nrt or UBR) results in better utilization of the ATM backbone and better quality of service.

The above desires, other desires, features, and advantages of the present invention will be readily appreciated by one of ordinary skill in the art from the following detailed description.

Brief Description of the Drawings

Figure 1 is a diagram illustrating a network segment;

Figure 2 is a diagram of a frame relay network frame suitable for use with the present invention;

Figure 3 is a diagram of an ATM cell suitable for use with the present invention;

Figure 4 is a diagram of a Resource Management ATM cell suitable for use with the present invention;

Figure 5 is a diagram of a first frame relay and ATM hybrid network connection with congestion interworking consistent with the present invention; and

Figure 6a-6d are diagrams of a second frame relay and ATM hybrid network connection with congestion interworking consistent with the present invention.

Detailed Description of the Preferred Embodiments

Reference will now be made in detail to embodiments consistent with this invention that are illustrated in the accompanying drawings. The same reference numbers in different drawings generally refer to the same or like parts.

A frame relay network consistent with the present invention may be connected with an ATM network with ABR to form a hybrid network including interworked congestion controls providing closed-loop flow-control across the entire hybrid network. In an exemplary embodiment consistent with the present invention, each individual network segment, *i.e.*, frame relay or ATM ABR, employs its own closed-loop congestion notification. This segmentation restricts the slower binary notification to the FR networks, thereby allowing the ATM ABR networks to use the more efficient explicit rate notification. Thus, the faster congestion response speed of the ATM ABR network segments increases the congestion response speed of the entire hybrid network. In addition, a preceding network segment may be notified by a downstream segment of congestion in the downstream segment. This interconnected segmented loop approach yields a faster network level response time because the congestion notification inside each loop travels a shorter distance and takes less time than a congestion notification required to travel from one end of the entire system to the other end.

Figure 2 portrays a frame relay frame structure shown generally by reference numeral 200. Frame 200 typically includes a 2-byte header portion 202 followed by a variable length information portion 204. Alternatively, the frame may include a 3- or 4-byte header portion as is known. Header portion Header 202 includes two bits, a Forward Explicit Congestion Notification (FECN) bit 206 and a Backward Explicit Congestion Notification (BECN) bit 208. These FECN and BECN bits, which function as forward and backward congestion indicators, respectively, are used to inform network components of network congestion, *i.e.*, that frames are encountering congestion.

Congestion information in a FR network is carried in the FECN and BECN bits of frames traveling between a source and a destination. In the network segment shown in Figure 1, the FECN and BECN bits follow the path of the congestion control loop 108. Network elements experiencing congestion set the FECN bit 206 in frames traveling in the forward direction of congestion control loop 108 to warn destination 104 that the frames it will be receiving have encountered congestion along the way. As destination 104 receives this congestion information, it will, in turn, generally relay this information to source 100. This is accomplished through the BECN bit 208. Thus, the destination 104 sets BECN bit 208 in frames traveling in the other direction to warn source 100 in a network segment that frames it is transmitting will encounter congestion. In response to receipt of a frame with a set BECN bit, source 100 will generally adjust its transmission rate so as to help control congestion.

Figure 3 depicts an ATM cell 300. As is known, ATM cells include a 5-byte header (header portion 302) and a 48-byte payload (information portion 304). The cell also carries bits commonly referred to as the payload type identifier (PTI) 306 that serves multiple functions. PTI 306 identifies whether a cell is a resource management (RM) cell or a normal user cell. Cell 300 also includes a bit called the Explicit Forward Congestion Indicator (EFCI) bit, which is used by normal user cells to perform binary congestion notification much like the FECN bit 206 does in a frame.

RM cells are specialized cells used to notify network components of cell transmission rates and congestion information. Figure 4 illustrates a typical RM cell 400 which, as shown, includes *inter alia* a direction (DIR) bit 402, congestion bits (congestion indication (CI)/no increase (NI)) 404, an explicit rate (ER) field 406, and a current cell rate (CCR) field 408. DIR bit 402 is used to indicate the direction in which the cell is traveling, *i.e.*, forward (toward the destination) or backward (toward the source). A network component may be informed of network congestion via congestion bits 404, and may use the CCR field 408 to notify other network components of its transmission rate. Although the CI congestion bit is typically used, the NI congestion bit may also be used. A network component may request a specific transmission rate using ER field 406. Systems and methods consistent with the present invention make use of both forward resource management (FRM) cells generated by an ABR source, and backward resource management (BRM) cells generated by an ABR destination and travel back toward the ABR source.

ATM ABR works in generally the same way as FR congestion control, using a closed-loop to notify network components of congestion, but adds the benefit of using an explicit transmission rate carried in RM cells. ER field 408 can be used by a source component to determine what its transmission rate should be. Without the benefit of explicit rate notification, as in a FR network, a source 100 only knows that it should alter its transmission rate, not by how much. Source 100 can only keep incrementally altering its transmission rate until it receives no more binary congestion notifications. Thus, the network's response to changing transfer characteristics, *i.e.*, changing traffic conditions, is dictated by the time it takes for the source to incrementally alter its transmission rate to a rate acceptable to the network segment.

ATM ABR, through the ER field, provides network components with the ability to specify an acceptable transmission rate to a source 100 in a BRM cell. This way, the source can instantly change (*i.e.*, increase or decrease) its transmission rate to the explicit rate without the latency of incremental reductions. As a result, the network reacts much faster to changing network traffic conditions and thus experiences reduced packet loss. Although ATM ABR can also effect congestion control through the use of binary notification via the EFCI bit in PTI 306 of a normal user cell (*e.g.*, Figure 3) or the CI bit 404 in an RM cell 400 (*e.g.*, Figure 4), the explicit rate capability of the RM cell is the main congestion control advantage of ATM ABR over FR networks.

Figure 5 shows a hybrid network 500 within which systems and methods consistent with the present invention may function. Network 500 includes a pair of FR networks 502 and 510 interconnected by an ATM ABR network 506, and a pair of interworking functions (IWFs) 504 and 508. One of ordinary skill will appreciate that IWFs 504 and 508 may be implemented either in hardware or in software. As shown, information flows in the direction of the arrow from an FR source 512 toward an FR destination 514. For purposes of this discussion, it shall be assumed that FR network segments implement some type of source-based dynamic rate adaptation mechanism using FECN and BECN according to ITU-T recommendation I.370.

Moreover, it shall be assumed that ATM networks implement ABR functionality including VS/VD support according to ATM Forum's TM4.0.

Generally consistent with the present invention, where a preceding FR network segment is connected to a succeeding ATM ABR network segment (*i.e.*, where data flow is toward the ATM ABR segment), the forward binary congestion notification of the FR segment may be mapped to the backward binary congestion notification of the same FR segment as in normal closed-loop FR systems. However, if the ABR source or node at the beginning of the succeeding ATM ABR network segment is congested, a congestion indication from that ABR source may be mapped into the backward binary congestion notification of the preceding FR network. Hence, in the FR segment, the backward binary congestion notification may be set if there is either forward congestion notification in that FR network segment or if there is congestion at the beginning of the following ATM segment (*i.e.*, in the ABR source).

Regarding the connection between a preceding ATM segment and a succeeding FR network segment, consistent with the present invention the forward congestion notification of the ATM segment may be mapped into the backward congestion notification of the same ATM segment. In addition, a congestion indication from the FR source may be mapped into the backward congestion notification of the ATM segment.

Frame Relay to ATM ABR Network Interworking

With continuing reference to Figure 5, IWF 504 connects FR network segment 502 to ATM ABR network segment 506, translating FR frames into ATM cells. IWF 504 includes a mapping function 516 which, consistent with the present invention, maps congestion indications between these interconnected network segments.

If IWF 504 receives congestion information from a frame with the FECN bit 518 set (signifying that an element within FR network segment 502 became congested), FR mapping function 516 maps the congestion information into a BECN bit 520 in at least one frame traveling back toward source 512. FR source 512 may respond to this back pressure by appropriately reducing its transmission rate in an effort to help alleviate the congestion in the FR network segment.

Despite the presence of congestion in the FR network segment 502, IWF 504 sets the EFCI bit in the translated ATM cell to a value of zero to help segment the closed-loop flow control into individual network segments. Since any congestion indication carried in FECN bits 518 reaching the end of the FR network segment is turned around at the end by the mapping into the BECN bits, carrying that congestion indication into the succeeding ATM network by setting the EFCI bits in the translated ATM cells would only increase the size of the loop and create greater latency in the hybrid network response (since the indication of congestion in FR network segment 502 would have to loop through the entire ATM network 506 segment). In short, it is assumed that there will be no incoming congestion indication from FR network segment 502.

Nevertheless, ABR source 522 may in fact experience congestion caused by, for example, variable bit rate (VBR) traffic taking the maximum bandwidth, or by other connections which are exceeding their bandwidth. If this congestion occurs, systems and methods consistent with the present invention contemplate a congestion indicator from the ABR source 522 (*i.e.*, SCI) being mapped back into the preceding FR network segment 502. SCI may, for example, be mapped by mapping function 516 into a BECN bit 520 in at least one frame traveling back toward FR source 512. In response, source 512 may appropriately reduce its transmission rate to help control congestion across the hybrid network.

As the information proceeds through ATM network segment 506, congestion may arise in one or more network elements. To combat this congestion, segment 506 may use FRM cells 524 as a forward congestion notification and BRM cells 526 as backward congestion notification to effect closed-loop traffic flow control. When ABR destination 528 is notified of congestion from one or more FRM cells 524, it may return at least one BRM cell 526 with an appropriate congestion indication to ABR source 522. ABR destination 528 can either simply give an indication of congestion by setting one or more of the congestion bits 404, or can specify a particular transmission rate through the explicit rate field 408 (see Figure 4). ABR source 522 can thereafter respond to this back pressure by appropriately altering its transmission rate to control congestion in the ATM ABR network segment.

ATM ABR to Frame Relay Network Interworking

As shown in Figure 5, IWF 508 interconnects ATM ABR network segment 506 to FR network segment 510, translating ATM cells into FR frames. As with IWF 504, to help segment the closed-loop congestion control, IWF 508 sets the FECN bit in the translated frame to a value of zero, regardless of the presence of congestion in the preceding network segment. If an element in segment 510 becomes congested, a FECN bit 532 in a frame will be set by that element. Such a FECN bit 532 may be mapped into a BECN bit 534 by FR destination 514. Destination 514 could represent the end of the hybrid network. Of course, if network segment 510 was followed by some other network segment, then destination 514 could be similar to destination 520 of IWF 504.

Consistent with the present invention, when a frame with a set FECN bit 532 reaches FR destination 514, a frame with a BECN bit may be generated by the destination. When a frame with a set BECN bit 534 reaches IWF 508, FR source 536 may consider the congestion notification and execute a rate adaptation algorithm, such as that proposed in the Q.922 FR standard, for purposes of controlling congestion in the FRM segment. Once FR source starts adjusting its transmission rate, congestion in FR 510 segment should start to ease.

FR source may nevertheless experience congestion. As a result, systems and methods consistent with the present invention also contemplate mapping a congestion indicator from FR source 536 into the preceding ATM ABR segment 506 to help control congestion across the hybrid network. FR source may, for example, send either an approximation of an explicit rate (ER_{APP}) or a binary congestion notification to mapping function 530, which maps the congestion indicator into at least one BRM cell 526 traveling back toward ABR source 522. The approximated ER is mapped into the ER field, whereas the binary congestion notification would be mapped into one or more of the CI/NI bits of the BRM cell. In one embodiment, mapping function 530 maps the smaller of the explicit rate received from ABR destination 528 and the explicit rate approximation received from FR source 536 into BRM cell 526. This mapping serves as an indication to the ATM ABR network segment 506 that the succeeding FR segment 510 is experiencing congestion and that transmission rates should be reduced. Mapping in this scenario (as in the other scenarios described herein) does not have to follow a 1:1 relationship.

Rather, the mapping may occur after some predetermined number of congestion indicators are received.

Figure 6a shows a diagram of a second frame relay and ATM hybrid network connection with congestion interworking consistent with the present invention. In this example, the hybrid network includes two FR network segments (*i.e.*, FR Hop A and FR Hop B) and three ATM ABR network segments (*i.e.*, ABR Hop 1, ABR Hop 2, and ABR Hop 3) interconnected as shown through two interworking functions (*i.e.*, IWF 1 and IWF 2). Information passes from the FR source of FR Hop A through IWF 1 toward ABR Hop 1, in a manner similar to the interworking of FR 502, IWF 504, and ABR 506 discussed above in regard to Figure 5. In short, the IWF clears the explicit forward congestion indication (EFCI) bits as part of the translation process. A mapping function ("fn") maps set FECN bits into set BECN bits to note the presence of any congestion in FR Hop A. When appropriate, the FR mapping function also maps congestion indicators (SCI) from ABR source into BECN bits.

With continuing reference to Figure 6a, ATM cells (translated from frames) then proceed along ABR Hops 1-3 to IWF 2. These cells are translated back into frames by IWF 2, which sets the FECN bits to zero, as described above in relation to Figure 5. The mapping function of IWF 2 operates under three possible modes in interworking congestion control between FR Hop B and ABR Hop 3. In the first mode, shown in Figure 6b, the frame source associated with FR Hop B applies rate adaptation based on the receipt of set BECN bits. This results in discards or congestion at the FR source, which is not coupled to ATM ABR Hop 3. However, without a means for relaying the congestion information back toward the FR source of FR Hop A, no real benefit is obtained across the hybrid network.

The second mode, shown in Figure 6c, has a congestion indicator generated by a congested FR source being mapped to one or more of the congestion bits (*i.e.*, CI/NI bits) in an ABR destination-generated BRM cell. This makes ABR Hop 3 binary and generally requires knowledge of the congestion indicator to avoid discarding (see similar discussion above regarding IWF 508 of Figure 5). The third mode is shown in Figure 6d. In this mode, an approximated explicit rate generated according to a rate adaptation algorithm similar that described in the Q.922 specification is mapped to the ER field of a BRM cell. This makes ABR

Hop 3 explicit rate and generally requires knowledge of the congestion indicator to avoid discarding (see similar discussion above regarding IWF 508 of Figure 5).

In summary, the hybrid networks of Figures 5 and 6 are exemplary and depict possible the connections between FR network segments and ATM ABR network segments. Of course, the present invention is equally useful in any hybrid network having any number of interconnected FR and ATM ABR segments, as well as hybrid networks including network segments of each type connected back-to-back. Consistent with the present invention, each network segment performs its own closed-loop flow control while notifying the preceding network segment of any congestion in the succeeding, or notifying, network. In general, the present invention provides a method for the interworking of a non-ABR Layer 2 data protocol with rate flow-control to an ATM network with an ABR service category. More particularly, the interworking functions and segmentation approach described herein permit the interconnection of frame relay networks to ATM ABR networks while improving the traffic congestion response time in the hybrid network. However, the fact that the embodiments described involved frame relay as the non-ABR data protocol should in no way be construed as a limitation on the scope of the invention.

It will be appreciated by those skilled in this art that various modifications and variations can be made to the network interworking strategy consistent with the present invention described herein without departing from the spirit and scope of the invention. Other embodiments of the invention will be apparent to those skilled in this art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered exemplary only, with a true scope and spirit of the invention being indicated by the following claims.

What is claimed is:

1. A hybrid network comprising:

a first network segment including a backward congestion indicator to control congestion in the segment;

a second network segment positioned downstream from the first network segment and having an associated source that receives information from the first network segment, the source having a source congestion indicator; and

means for mapping the source congestion indicator associated with the second network segment into the backward congestion indicator in the first network.

2. The hybrid network of claim 1 further including a hybrid network interface interconnecting the first network segment and the second network segment, the hybrid network interface including the means for mapping and

means for translating information from a first format associated with the first network segment into a second format associated with the second network segment.

3. The hybrid network of claim 2 wherein the first network segment also includes a forward congestion indicator being mapped into the backward congestion indicator by the means for mapping.

4. The hybrid network of claim 2 wherein the second network segment includes a forward congestion indicator mapped into a backward congestion indicator.

5. The hybrid network of claim 2 wherein the translated information includes a congestion indication bit and the hybrid network interface includes

means for clearing the congestion indication bit.

6. The hybrid network of claim 3 wherein the forward congestion indicator is mapped into the backward congestion indicator as an explicit rate.

7. The hybrid network of claim 4 wherein the forward congestion indicator is mapped into the backward congestion indicator as an explicit rate.

8. The hybrid network of claim 1 wherein the source congestion indicator associated with the second network is one of either an approximated explicit rate or a binary congestion indication.

9. The hybrid network of claim 8 wherein the backward congestion indicator in the first network includes a first field and the means for mapping includes

means for mapping the approximated explicit rate into the first field.

10. The hybrid network of claim 8 wherein the backward congestion indicator in the first network includes a second field, and the means for mapping includes

means for mapping the binary congestion indication into the second field.

11. The hybrid network of claim 8 wherein the source determines the approximated explicit rate using a rate adaptation algorithm.

12. The hybrid network of claim 1 wherein the first network segment is characterized by a Layer 2 data protocol and the second network segment is an asynchronous transfer mode network with an available bit rate service category.

13. The hybrid network of claim 12 wherein the Layer 2 data protocol is frame relay.

14. The hybrid network of claim 1 wherein the first network segment is an asynchronous transfer mode network with an available bit rate service category and the second network segment is characterized by a Layer 2 data protocol.

15. The hybrid network of claim 14 wherein the Layer 2 data protocol is frame relay.

16. A method, for use in a hybrid network including a first network segment interconnected with a second network segment, for interworking congestion controls of each segment across the hybrid network, the method comprising the steps of:

transmitting information in a first format from a source in the first network segment toward a destination in the second network segment;

translating the information to a second format associated with the second network segment;

receiving the translated information in a source in the second network segment;

generating a source congestion indicator if congestion occurs at the source in the second network segment;

mapping the source congestion indicator to a backward congestion indicator associated with the first network segment; and

transmitting the backward congestion indicator toward the source in the first network segment.

17. The method of claim 16 further comprising the step of

generating a forward congestion indicator associated with the first network segment if congestion occurs in the first network segment.

18. The method of claim 17 further comprising the steps of

mapping the forward congestion indicator to the backward congestion indicator associated with the first network segment; and

transmitting the backward congestion indicator toward the source in the first network segment.

19. The method of claim 16 further comprising the step of

clearing a congestion indication bit in the translated information received by the source.

20. The method of claim 18 further comprising the step of

generating a forward congestion indicator associated with the second network segment if congestion occurs in the second network segment.

21. The method of claim 20 further comprising the steps of

mapping the forward congestion indicator associated with the second network segment into a backward congestion indicator associated with the second network segment; and

transmitting the backward congestion indicator toward the source in the second network segment.

22. The method of claim 18 wherein the step of mapping the forward congestion indicator to the backward congestion indicator includes the substep of

mapping the forward congestion indicator to the backward congestion indicator as an explicit rate.

23. The method of claim 21 wherein the step of mapping the forward congestion indicator to the backward congestion indicator includes the substep of

mapping the forward congestion indicator to the backward congestion indicator as an explicit rate.

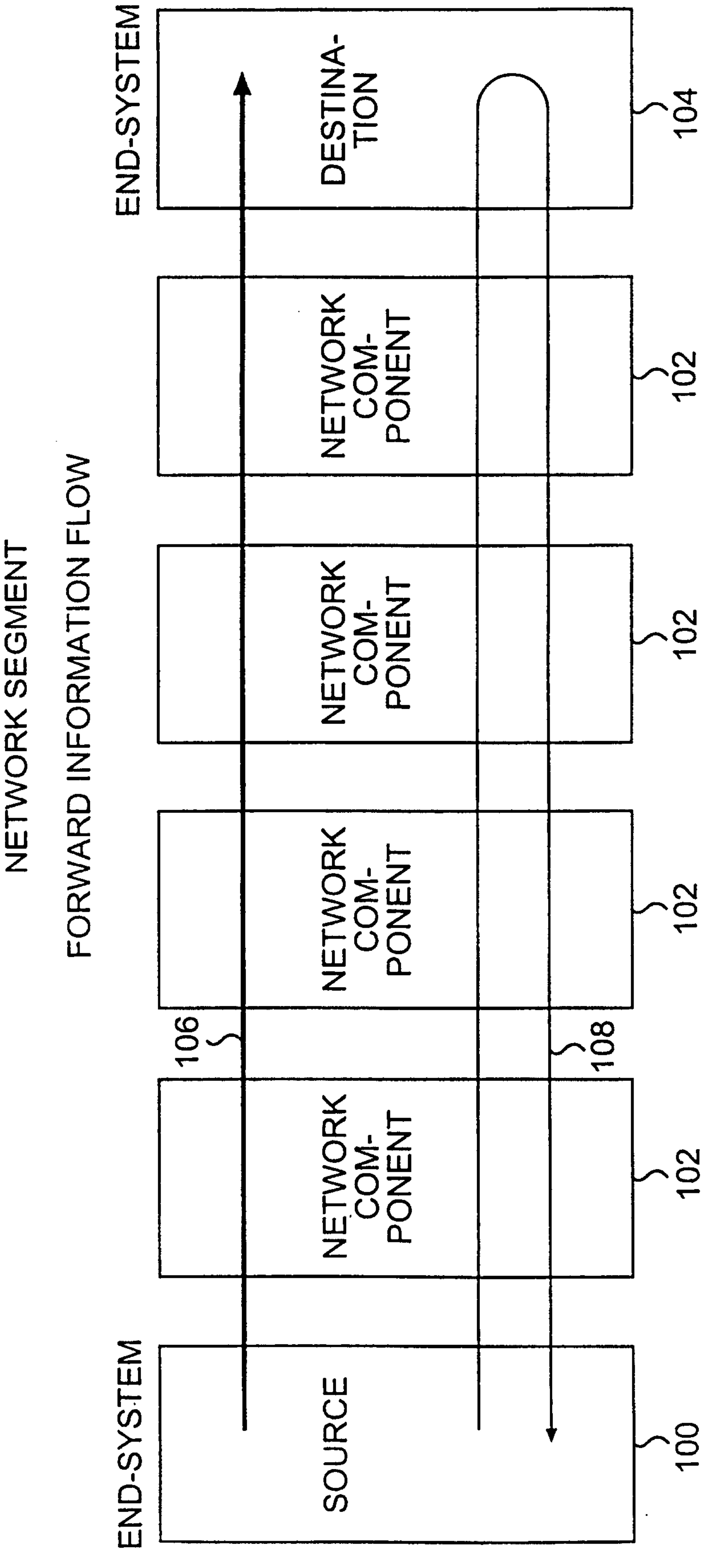
24. The method of claim 16 wherein the step of generating includes the substep of generating one of either an approximated explicit rate or a binary congestion indication.

25. The method of claim 24 wherein the step of mapping includes the substep of mapping the approximated explicit rate into a first field of the backward congestion indicator associated with the first network.

26. The method of claim 24 wherein the step of mapping includes the substep of mapping the binary congestion indication into a second field of the backward congestion indicator associated with the first network.

27. The method of claim 24 wherein the substep of generating includes the substep of

determining the approximated explicit rate using a rate adaptation algorithm.



CONTROL LOOP ASSOCIATED WITH FORWARD INFORMATION FLOW

FIG. 1

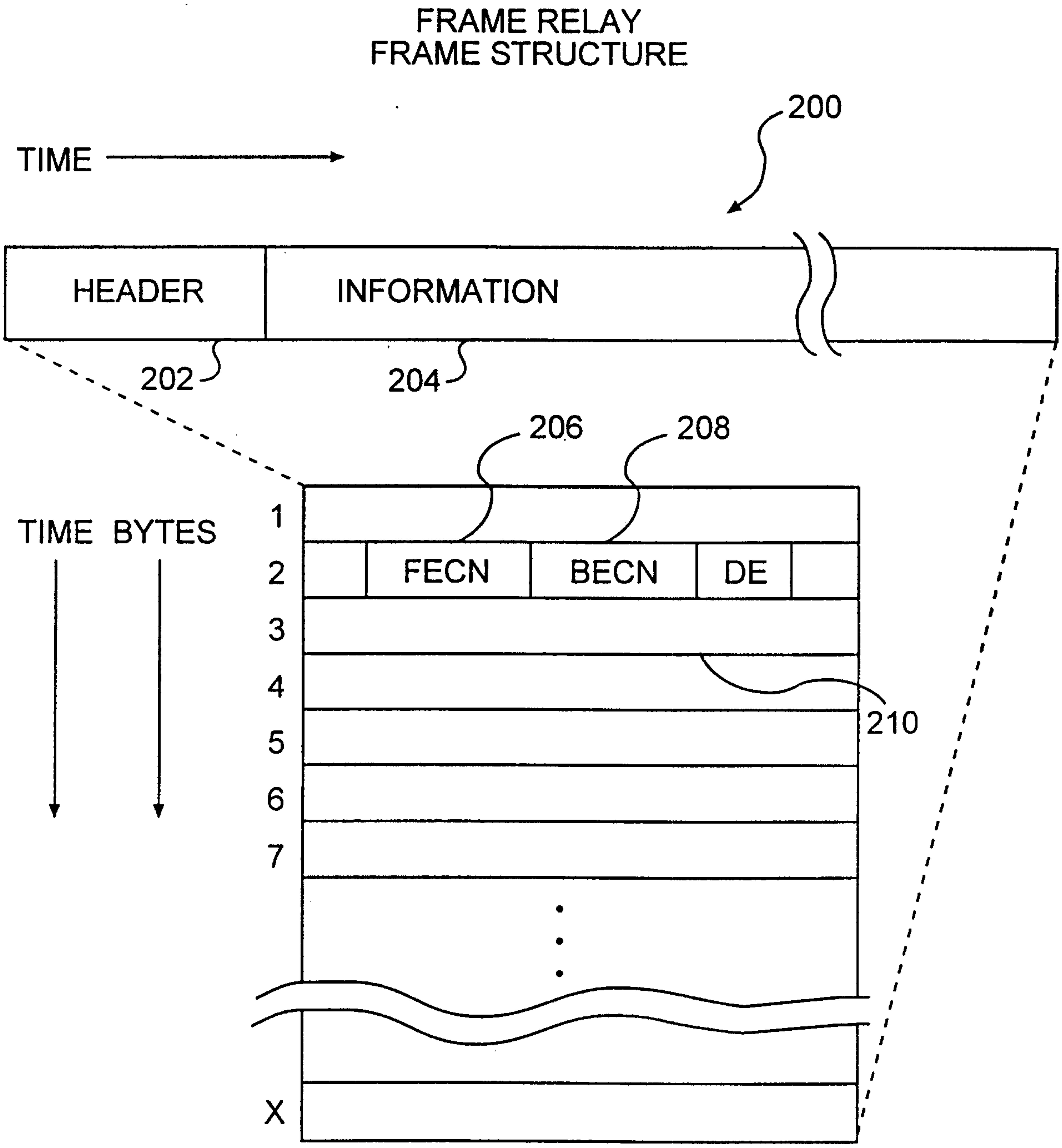

FRAME RELAY
FRAME STRUCTURE
200
TIME
HEADER
INFORMATION
202
204
206
208
TIME
BYTES
1
2
3
4
5
6
7
X
FECN
BECN
DE
210

FIG. 2

ASYNCHRONOUS TRANSFER MODE (ATM)
CELL STRUCTURE

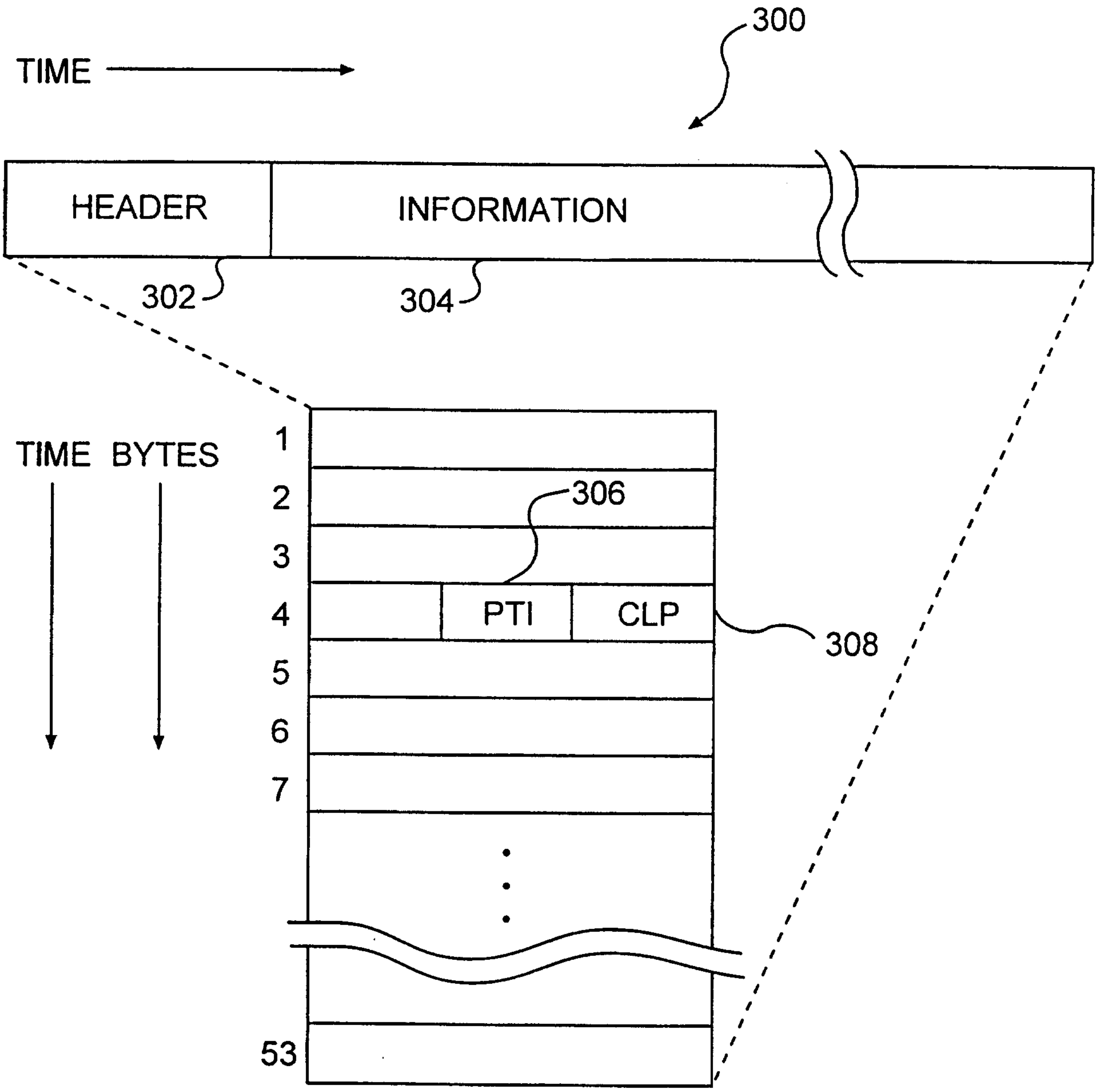


FIG. 3

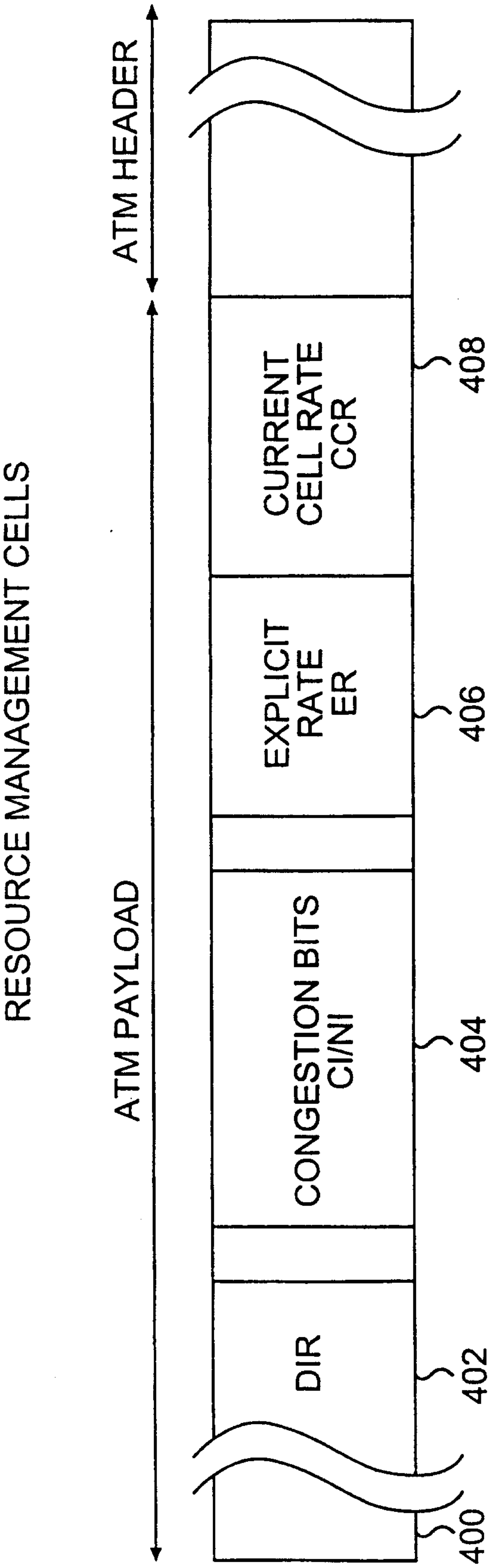

RESOURCE MANAGEMENT CELLS
ATM HEADER
ATM PAYLOAD
DIR
CONGESTION BITS
CI/NI
EXPLICIT
RATE
ER
CURRENT
CELL RATE
CCR
400
402
404
406
408

FIG. 4

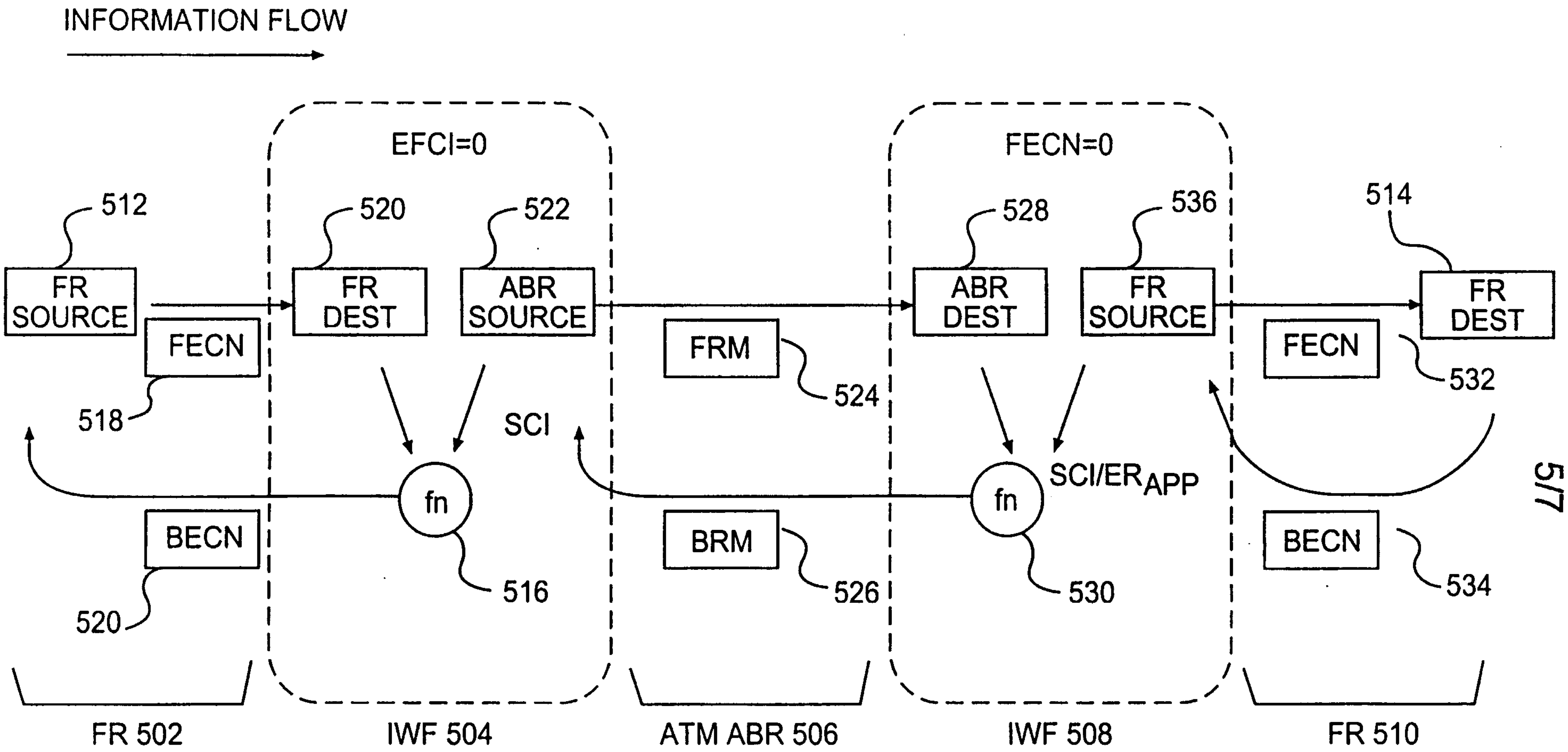

INFORMATION FLOW
EFCI=0
FECN=0
512
FR SOURCE
FECN
518
BECN
520
520
FR DEST
522
ABR SOURCE
fn
516
SCI
FRM
524
BRM
526
528
ABR DEST
536
FR SOURCE
fn
530
SCI/ER_{APP}
514
FR DEST
FECN
532
BECN
534
FR 502
IWF 504
ATM ABR 506
IWF 508
FR 510

FIG. 5

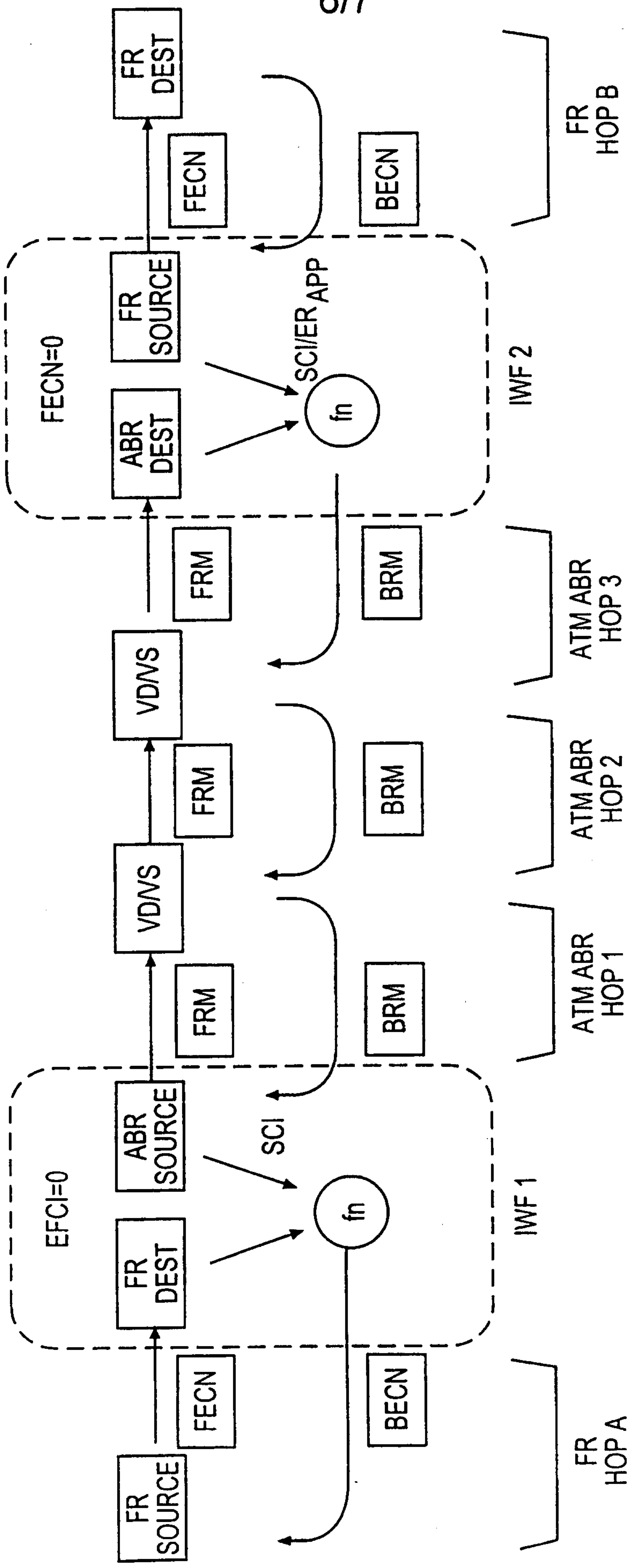

FR SOURCE
FECN
BECN
FR HOP A
EFCI=0
FR DEST
ABR SOURCE
SCI
fn
IWF 1
FRM
BRM
ATM ABR HOP 1
VD/VS
FRM
BRM
ATM ABR HOP 2
VD/VS
FRM
BRM
ATM ABR HOP 3
FECN=0
ABR DEST
FR SOURCE
SCI/ER APP
fn
IWF 2
FECN
BECN
FR DEST
FR HOP B

FIG. 6a

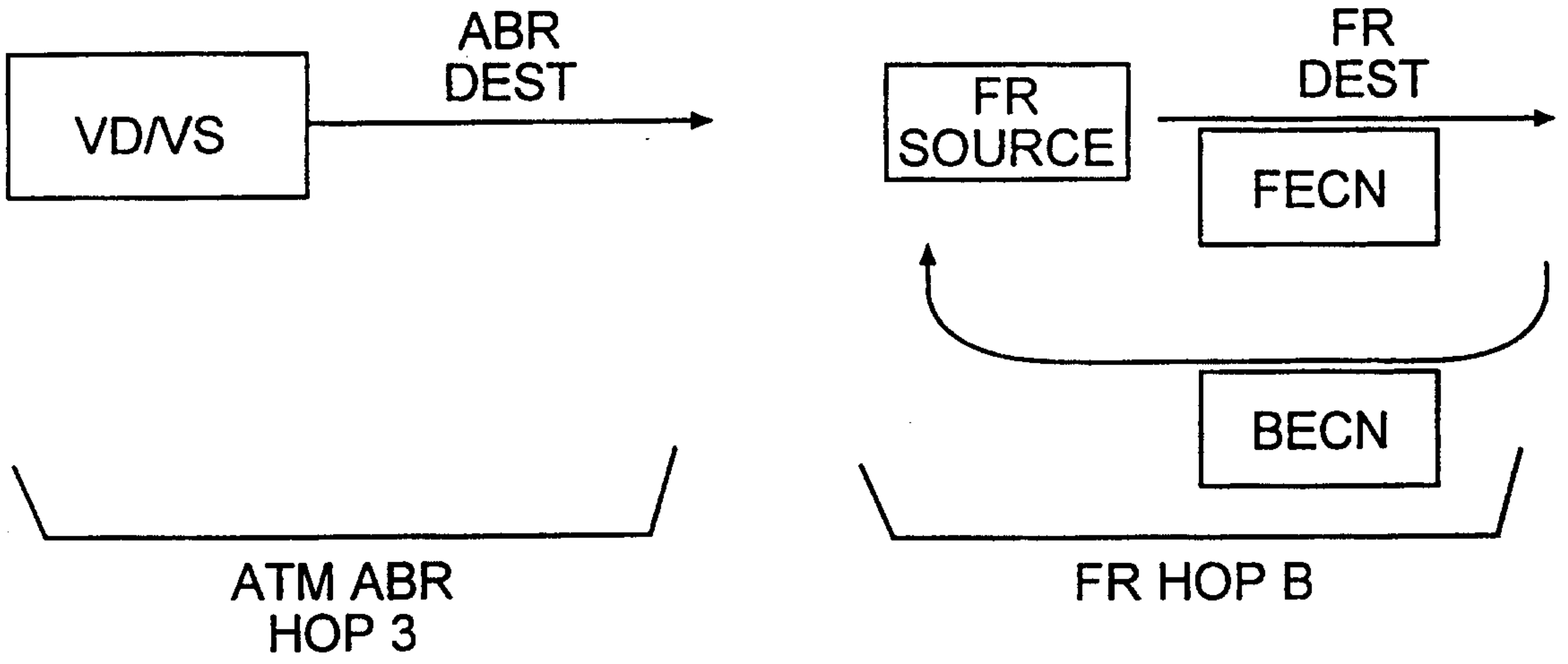


FIG. 6b

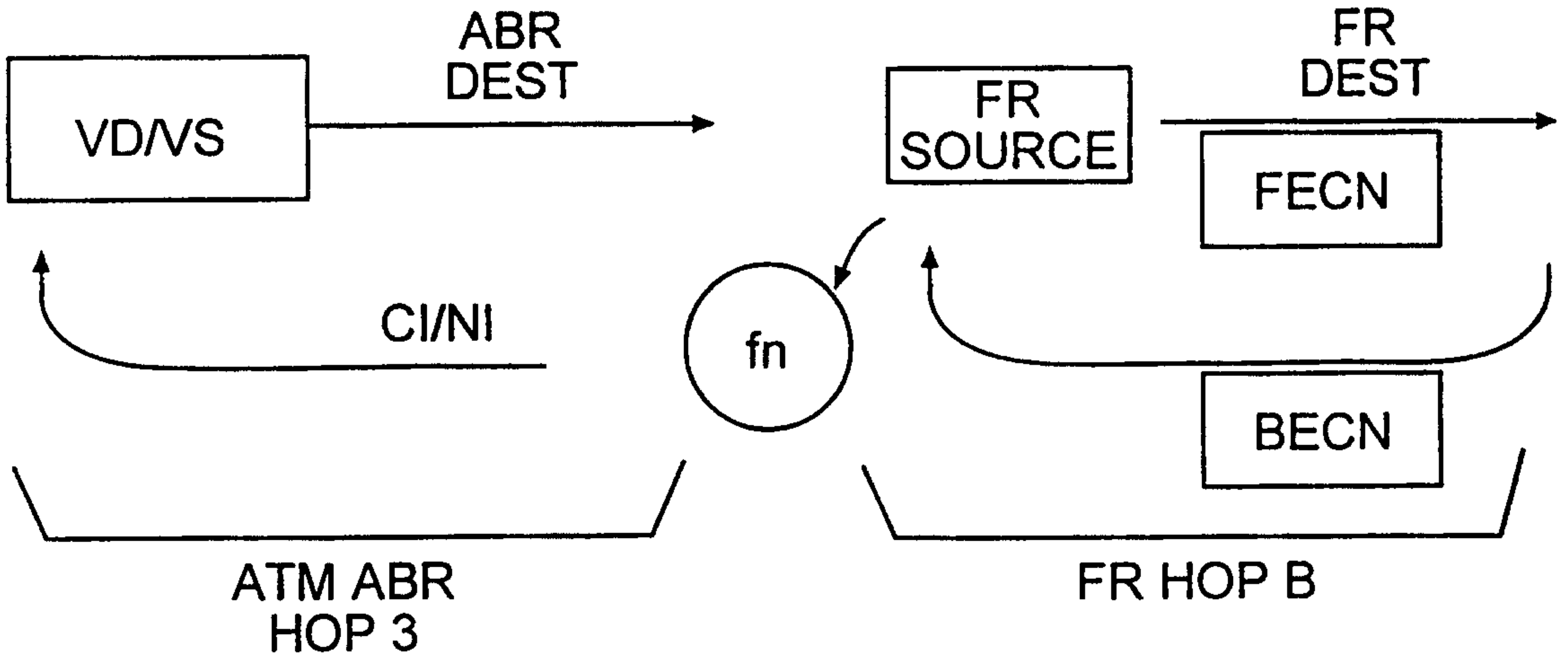


FIG. 6c

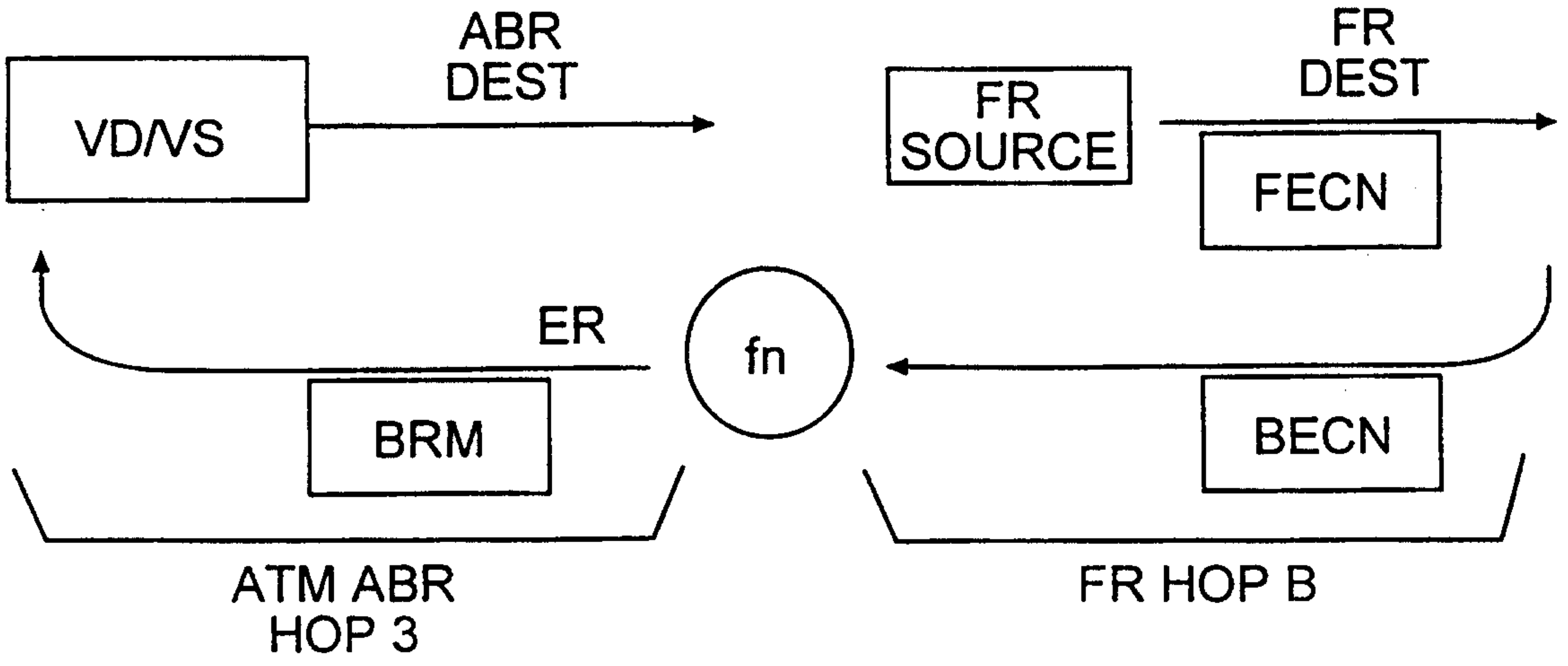
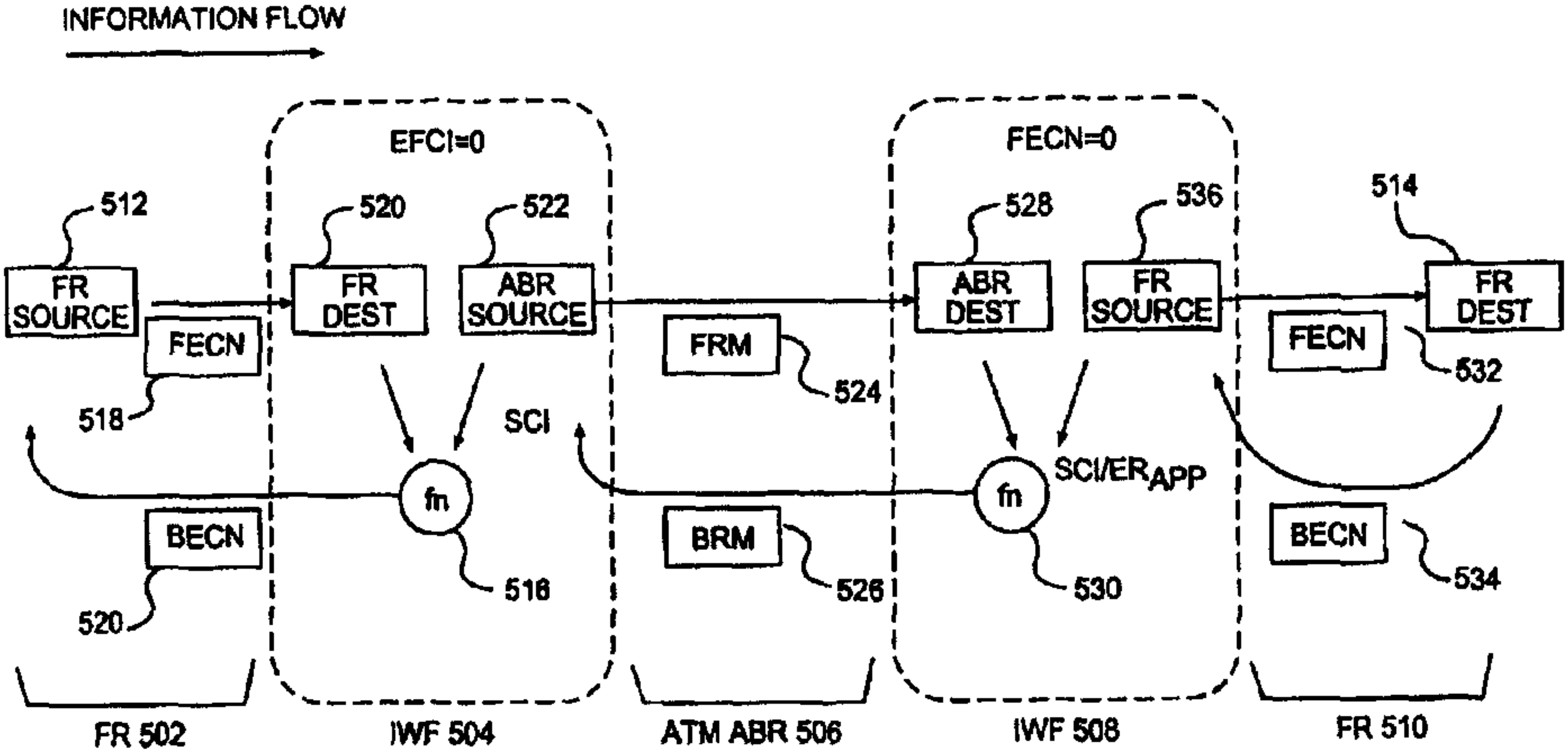


FIG. 6d


INFORMATION FLOW
EFCI=0
FECN=0
512
520
522
528
536
514
FR SOURCE
FR DEST
ABR SOURCE
ABR DEST
FR SOURCE
FR DEST
FECN
FRM
FECN
518
524
532
SCI
SCI/ER$_{APP}$
fn
fn
BECN
BRM
BECN
520
516
526
530
534
FR 502
IWF 504
ATM ABR 506
IWF 508
FR 510