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(54) **HITLESS RE-ROUTING IN COMPOSITE SWITCHES**

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H04J 14/08 (2006.01)

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

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,825,821 A * 10/1998 Okuyama 375/260

| | | | |
|-------------------|---------|----------------------|---------|
| 6,067,304 A * | 5/2000 | Nishioka | 370/516 |
| 6,246,668 B1 * | 6/2001 | Kusyk | 370/228 |
| 6,535,479 B1 * | 3/2003 | Ikematsu | 370/220 |
| 6,970,480 B2 * | 11/2005 | van Heyningen et al. | 370/508 |
| 2002/0118668 A1 * | 8/2002 | Sawey et al. | 370/350 |

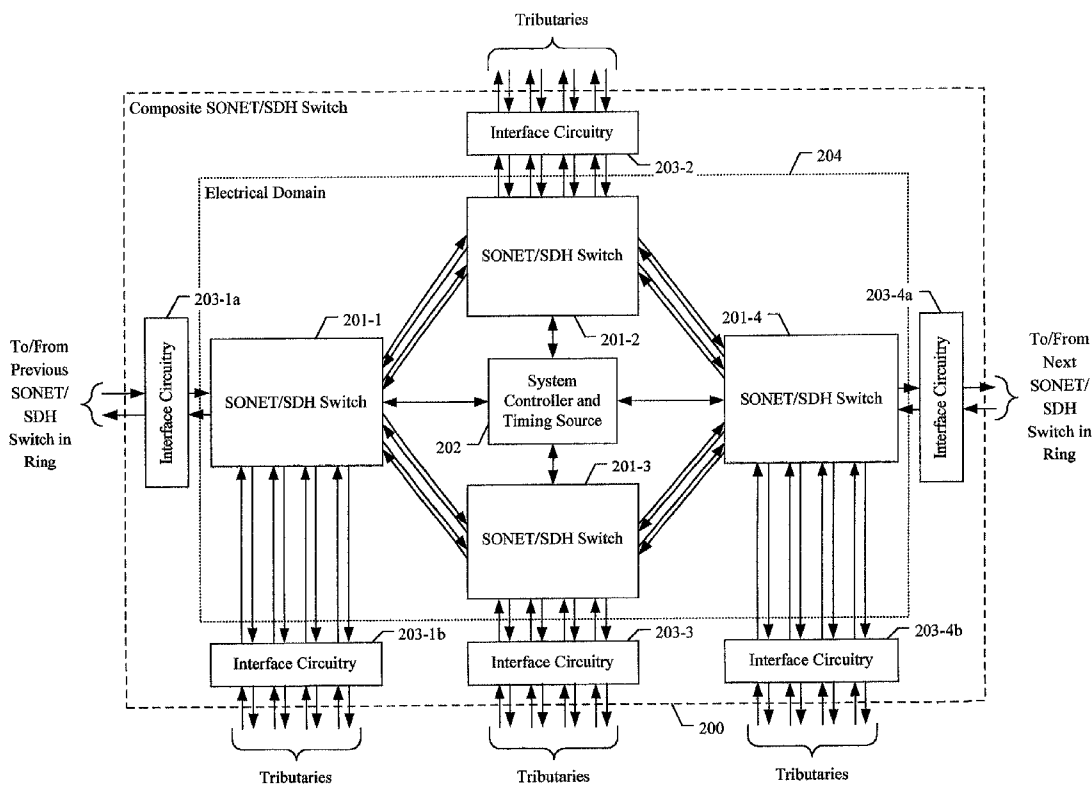
* cited by examiner

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(57) **ABSTRACT**

A method of the grooming traffic signals through a composite switch is disclosed that enables a traffic signal that is being transmitted between any two constituent switches to be re-routed through the composite switch without a hit (i.e., the dropping, replacing, inserting, or repeating of at least one bit in the traffic signal). This applies whether the constituent switches are adjacent in the composite switch or not. The composite switch in accordance with the illustrative embodiment comprises multiple routes between adjacent constituent switches and incorporates a mechanism that compensates for differential propagation delays along the routes. And still furthermore, the composite switch in accordance with the illustrative embodiment comprises alternative routes through different constituent switches and incorporates a mechanism that compensates for differential propagation delays through the constituent switches.

3 Claims, 6 Drawing Sheets



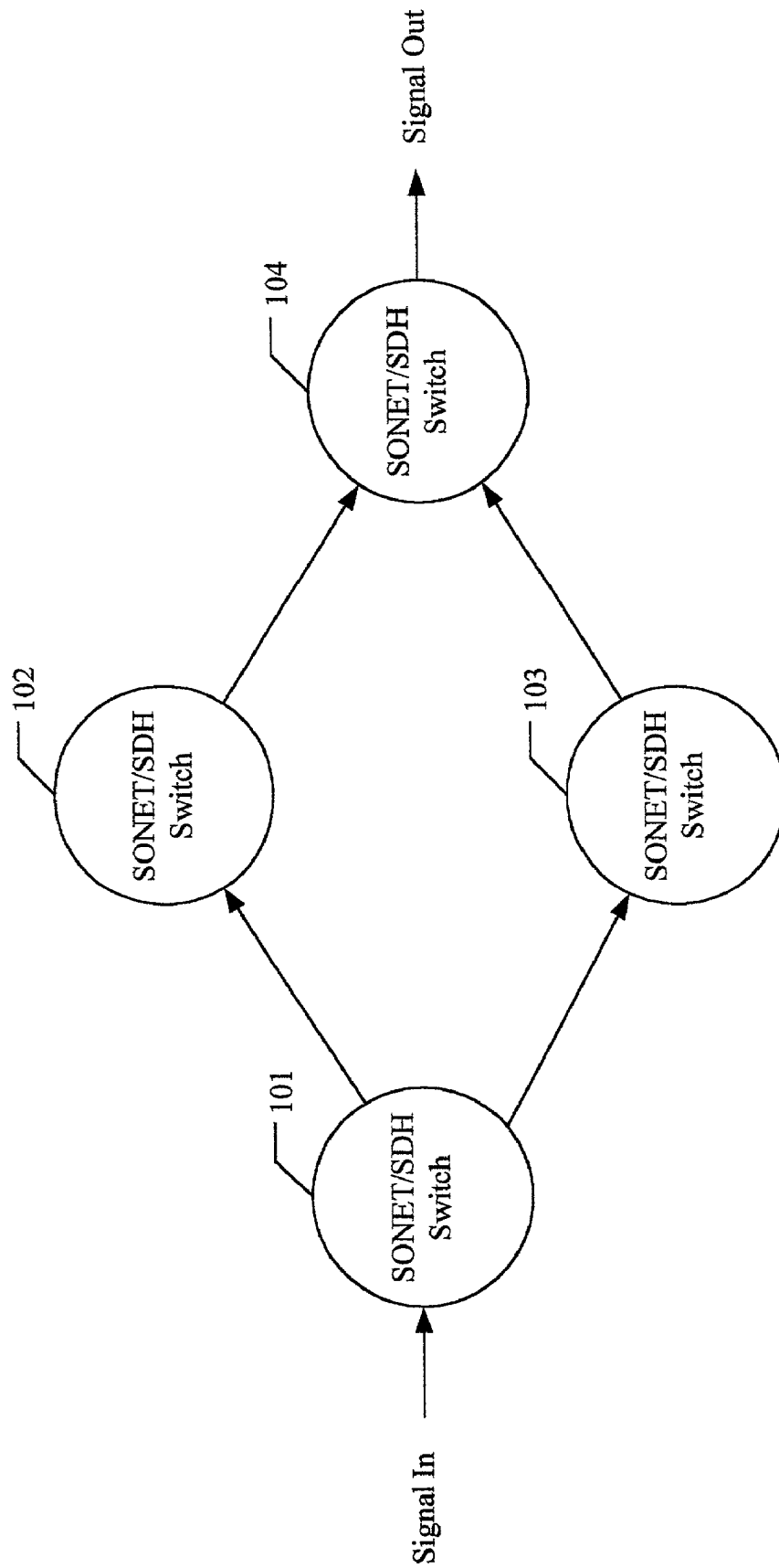


FIG. 1 (Prior Art)

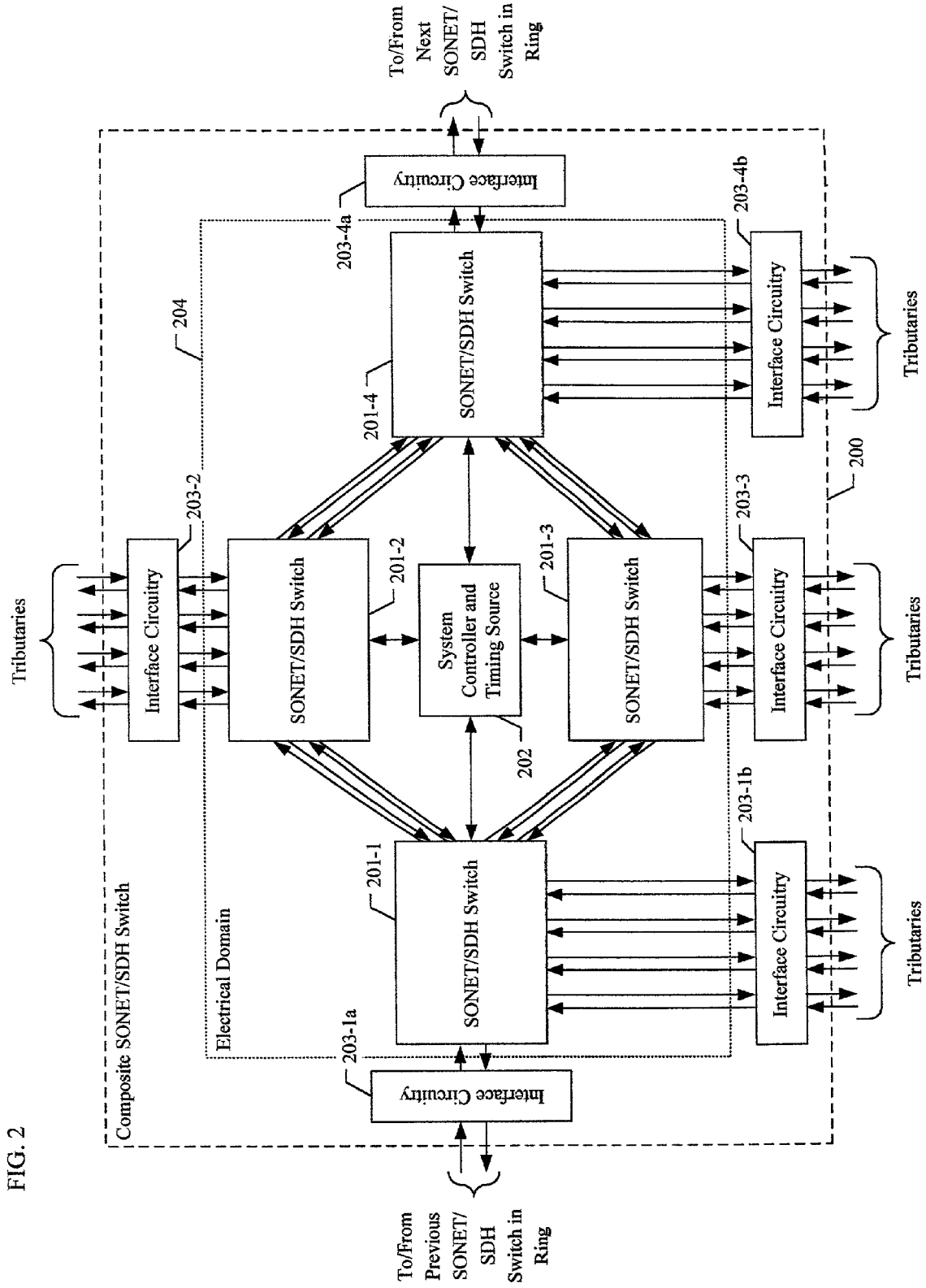


FIG. 2

FIG. 3

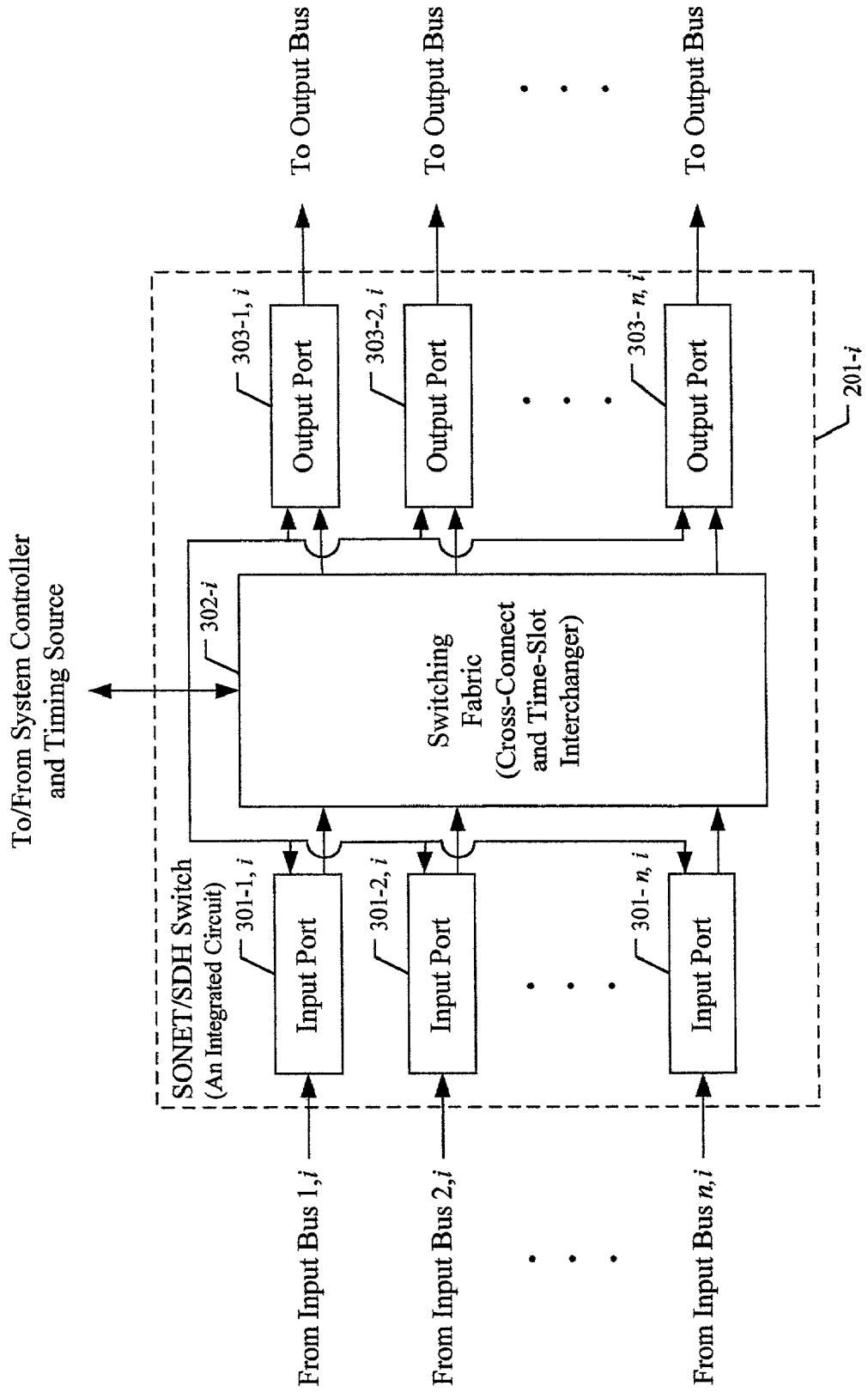


FIG. 4

Value of Read Pointer, Frame Synchronization Signal, and System Clock from System Controller 202; Contents of Frame Position Register 54- j,i to System Controller 202

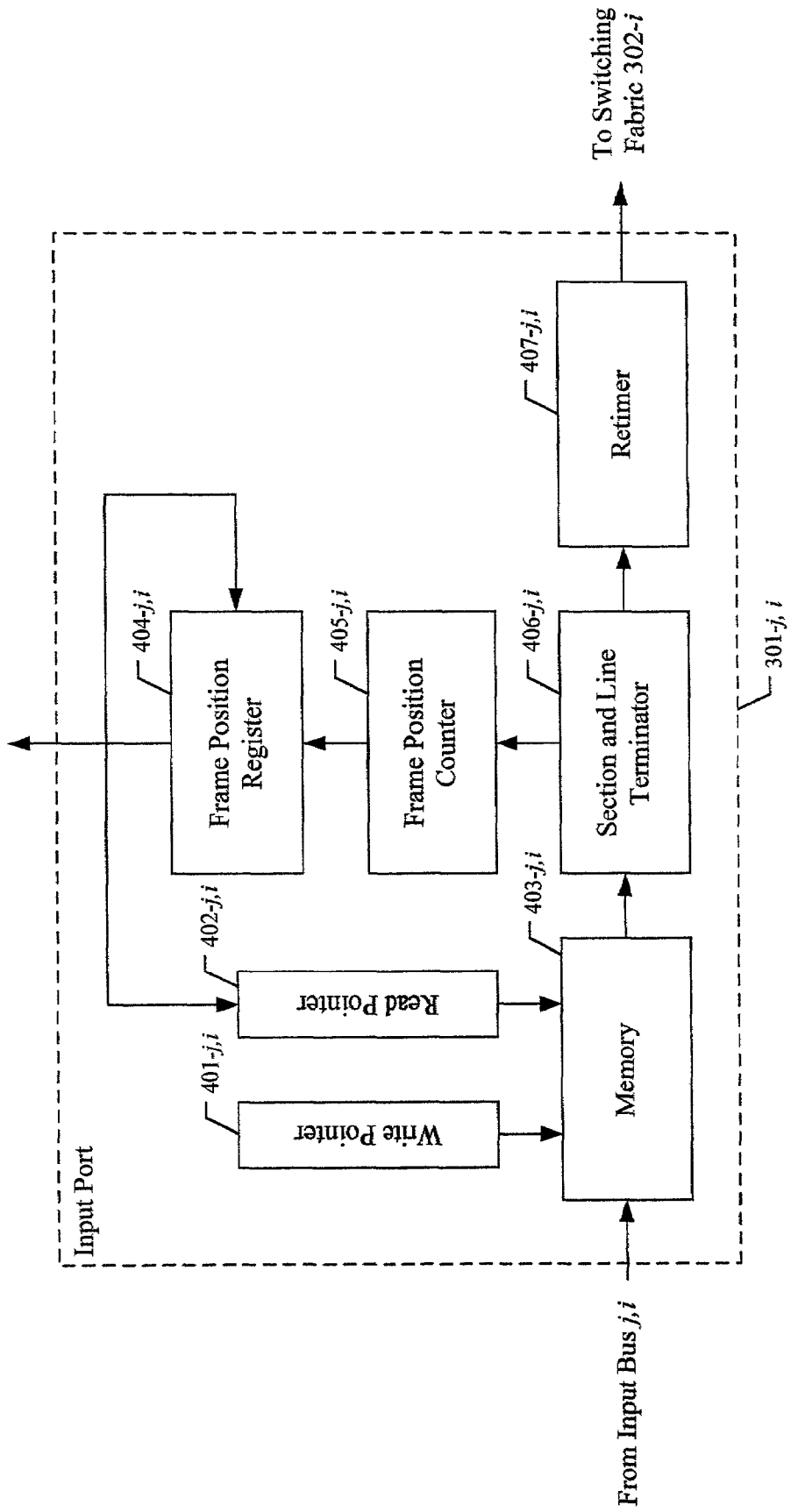


FIG. 5

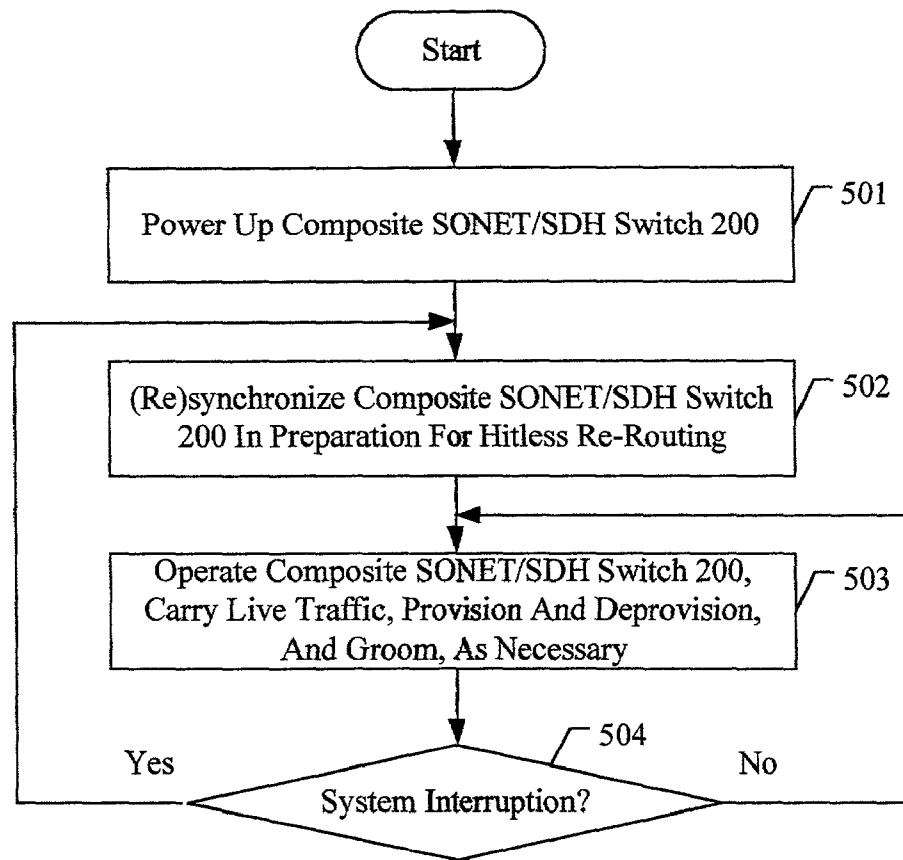
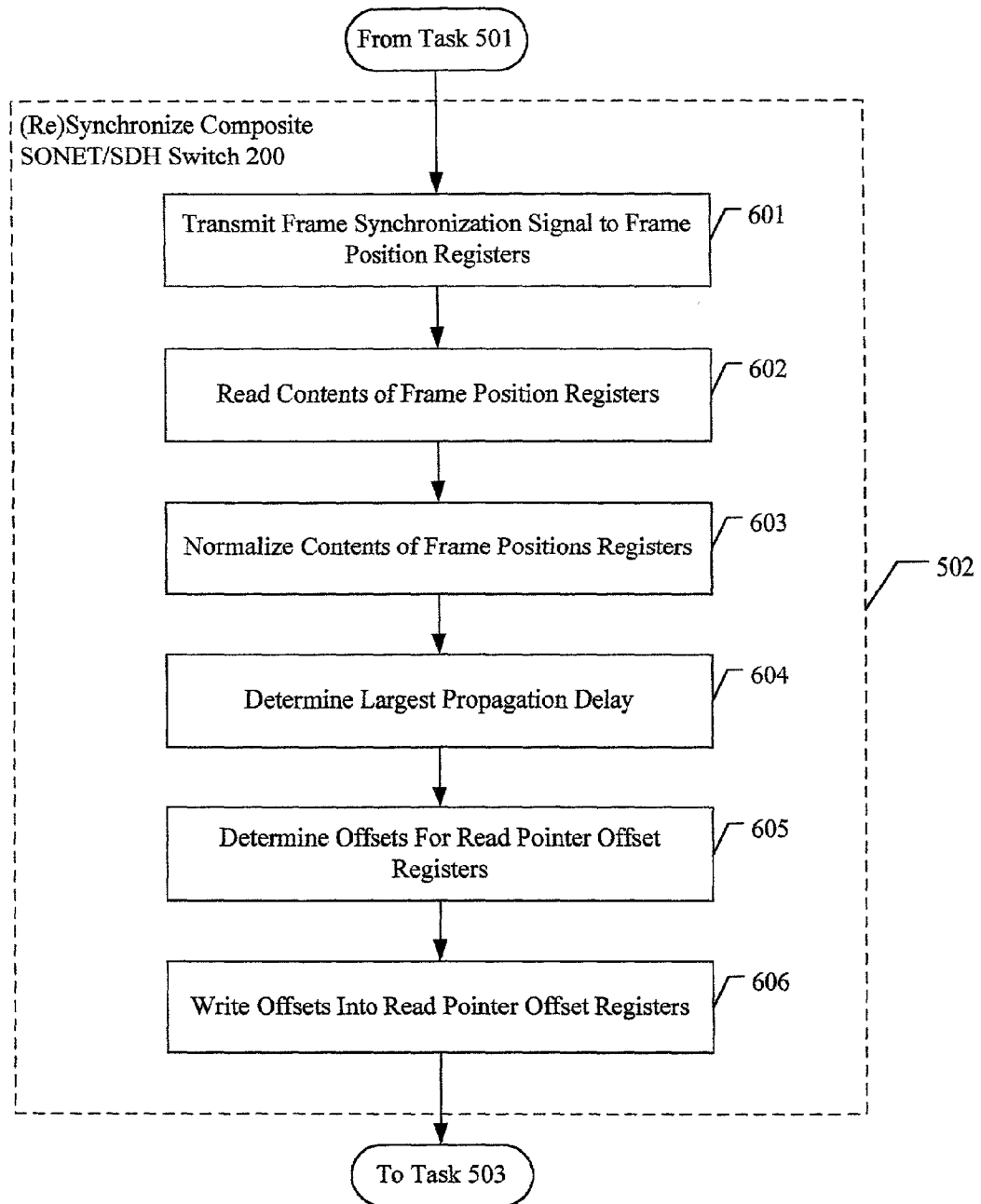


FIG. 6



HITLESS RE-ROUTING IN COMPOSITE SWITCHES

FIELD OF THE INVENTION

The present invention relates to telecommunications in general, and, more particularly, to a novel architecture for composite switches.

BACKGROUND OF THE INVENTION

The first generation of optical fiber systems in the public telephone network used proprietary architectures, equipment line codes, multiplexing formats, and maintenance procedures. This diversity complicated the task of the Regional Bell Operating Companies and the interexchange carriers who needed to interface their equipment with these diverse systems.

To ease this task, Bellcore initiated an effort to establish a standard for connecting one optical fiber system to another. That standard is officially named the Synchronous Optical Network but it is more commonly called "SONET." The international version of the standard is officially named the Synchronous Digital Hierarchy but it is more commonly called "SDH."

Although differences exist between SONET and SDH, those differences are mostly in terminology. In virtually all practical aspects, the two standards are the same, and, therefore, virtually all equipment that complies with either the SONET standard or the SDH standard also complies with the other. For the purposes of this specification, the combined acronym/initialism "SONET/SDH" is defined as the Synchronous Optical Network or the Synchronous Digital Hierarchy or both.

FIG. 1 depicts a block diagram of a portion of a SONET/SDH network that receives a traffic signal at SONET/SDH switch **101** and transmits the signal from SONET/SDH switch **104**. For example, the network might originally transmit the traffic signal from SONET/SDH switch **101** to SONET/SDH switch **104** through SONET/SDH switch **102**. In the course of provisioning and deprovisioning the available resources, the need can arise whereby a traffic signal is carried from SONET/SDH switch **101** to SONET/SDH switch **104** through SONET/SDH switch **103**, rather than through SONET/SDH switch **102**. Analogously, the need can arise whereby a traffic signal is carried from SONET/SDH switch **101** to SONET/SDH switch **104** through SONET/SDH switch **102**, rather than through SONET/SDH switch **103**. These needs often occur when grooming is performed.

If there is a difference in the propagation delay through SONET/SDH switch **101** to SONET/SDH switch **104** through SONET/SDH switch **102**, in contrast to the propagation delay through SONET/SDH switch **103**, then the re-routing of the traffic signal through SONET/SDH switch **103** will cause the dropping, replacing, inserting, or repeating of at least one bit in the traffic signal. This is colloquially, although almost universally, called a "hit." Hits are not advantageous and therefore hitless re-routing is preferred.

If the user of a SONET/SDH network experiences infrequent hits, the hits are most likely to be tolerated. In contrast, if the user of the SONET/SDH network experiences frequent hits, the hits are unlikely to be tolerated. This places a practical limit on the number of hits that the operator of a SONET/SDH network can inflict on its users. Furthermore, the inability to inflict an arbitrarily large number of hits on a user hinders the ability of the operator to groom the

network, and the operator of the network must be capable of freely grooming the network so as to maintain the resource utilization of the network.

Therefore, the need exists for a technique for the re-routing of synchronous signals without causing a large number of hits.

SUMMARY OF THE INVENTION

The present invention enables the grooming of traffic signals through a composite switch without some of the costs and disadvantages associated with techniques for doing so in the prior art. In particular, the illustrative embodiment enables a traffic signal that is being transmitted between any two constituent switches in a composite switch to be re-routed through the composite switch without a hit (i.e., the dropping, replacing, inserting, or repeating of at least one bit in the traffic signal). This applies whether the constituent switches are adjacent in the composite switch or not.

Furthermore, the composite switch in accordance with the illustrative embodiment comprises multiple routes between adjacent constituent switches and incorporates a mechanism that compensates for differential propagation delays along the routes. And still furthermore, the composite switch in accordance with the illustrative embodiment comprises alternative routes through different constituent switches and incorporates a mechanism that compensates for differential propagation delays through the constituent switches.

A further advantage of the illustrative embodiment is that it is largely fabricated from a plurality of identical and modular constituent switches that can be assembled in different numbers and topologies to form a variety of composite switches. In accordance with the illustrative embodiment, each constituent switch is fabricated on a single integrated circuit.

And still a further advantage of the illustrative embodiment is that it can be accomplished upon powering up the composite switch and without the presence of live traffic. This enables the composite switch to be fully synchronized before it carries live traffic.

The illustrative embodiment comprises: a first input port for receiving a first time division multiplexed signal that comprises a first series of frame boundaries; a second input port for receiving a second time-division multiplexed signal that comprises a second series of frame boundaries; a first frame position register whose contents are related to how far the first time-division multiplexed signal is from a frame boundary in the first time-division multiplexed signal at a point in time; and a second frame position register whose contents are related to how far the second time-division multiplexed signal is from a frame boundary in the second time-division multiplexed signal at the point in time.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts a block diagram of portion of a SONET/SDH network in the prior art.

FIG. 2 depicts a block diagram of the illustrative embodiment of the present invention.

FIG. 3 depicts a block diagram of a SONET/SDH switch in accordance with the first and second illustrative embodiments of the present invention.

FIG. 4 depicts a block diagram of an input port in accordance with the SONET/SDH switch depicted in FIG. 3.;

FIG. 5 depicts a flowchart of the operation of composite SONET/SDH switch **200** in accordance with the illustrative embodiment.

FIG. 6 depicts a flowchart of the subtasks associated with task **502**, as depicted in FIG. 5.

DETAILED DESCRIPTION

FIG. 2 depicts a block diagram of the salient components of composite SONET/SDH switch **200** in accordance with the illustrative embodiment of the present invention. For the purposes of this specification, a “switch” is defined as an apparatus that functions as:

- i. a cross-connect, or
- ii. an add-drop multiplexor, or
- iii. a time-slot interchanger, or
- iv. any combination of i, ii, and iii.

Furthermore, for the purposes of this specification, a “composite switch” is defined as an apparatus that comprises a plurality of interrelated constituent switches that share a common timing source.

For the purposes of this specification, a “SONET/SDH switch” is defined as a switch that is compliant with:

- i. the Synchronous Optical Network (i.e., SONET) standard, or
- ii. the Synchronous Digital Hierarchy (i.e., SDH) standard, or
- iii. both i and ii.

For the purposes of this specification, a “composite SONET/SDH switch” is defined as an apparatus that comprises a plurality of interrelated constituent SONET/SDH switches that share a common timing source. Although differences exist between the SONET and SDH standards, it will be clear to those skilled in the art that the present invention is equally applicable for use with both standards.

In accordance with the illustrative embodiment, composite SONET/SDH switch **200** is a node in a SONET/SDH ring network (not shown). It will be clear to those skilled in the art, however, that in some alternative embodiments of the present invention composite SONET/SDH switch **200** can be a node in the address space of:

- i. one or more SONET/SDH ring networks, or
- ii. one or more SONET/SDH mesh networks, or
- iii. any combination of i and ii.

For an example of how composite SONET/SDH switch **200** can be a node in the address space of multiple SONET/SDH networks, see U.S. patent application Ser. No. 09/909,550, filed Jul. 19, 2001, which application is incorporated by reference. Furthermore, it will be clear to those skilled in the art that the present invention is also useful with synchronous ring and mesh networks that are not SONET or SDH compliant.

Composite SONET/SDH switch **200** comprises SONET/SDH switches **201-1** through **201-4**, system controller and timing source **202**, and interface circuitry **203-1a** through **203-4b**, interconnected as shown (in a double bidirectional ring topology). In some alternative embodiments of the present invention, however, composite SONET/SDH switch **200** comprises a different number of constituent SONET/SDH switches. Furthermore, in some alternative embodiments of the present invention, the constituent SONET/SDH switches are interconnected in a different topology (e.g., in a single ring topology, in a mesh topology, etc.).

Any constituent SONET/SDH switch in composite SONET/SDH switch **200** can transmit traffic to its adjacent constituent SONET/SDH switches via z independent buses,

wherein z is a positive integer greater than zero. In the illustrative embodiment, $z=2$. In some alternative embodiments of the present invention, some pairs of adjacent constituent SONET/SDH switches communicate via a different number of pairs of directional buses than do other pairs of adjacent constituent SONET/SDH switches.

In accordance with the illustrative embodiment, the propagation delay along any bus in electrical domain **204** can be different than the propagation delay along any other bus in electrical domain **204**, and the illustrative embodiment will compensate for this difference. The fact that the illustrative embodiment compensates for these different propagation delays enables the hitless re-routing of uni-directional and bi-directional signals between any two constituent SONET/SDH switches in composite SONET/SDH switch **200**, whether the constituent SONET/SDH switches are adjacent or not. For example, a bidirectional traffic signal between SONET/SDH switch **201-1** and SONET/SDH switch **201-2** on bus **1** can be re-routed to bus **2** without a hit. As another example, a bi-directional traffic signal between SONET/SDH switch **201-1** and SONET/SDH switch **201-4** through SONET/SDH switch **201-2** can be re-routed through SONET/SDH switch **201-3** without a hit.

Each constituent SONET/SDH switch in composite SONET/SDH switch **200** transmits time-division multiplexed signals to the other constituent SONET/SDH switches. As is well known to those skilled in the art, a time-division multiplexed signal comprises a series of SONET/SDH frames that are defined by a series of frame boundaries. For example, the SONET/SDH A1 and A2 framing bytes (i.e., the bytes at row **1**, columns **1** and **2**) demarcate the boundary between adjacent SONET/SDH frames.

In the illustrative embodiment, all processing and transport within electrical domain **204** is electrical, in contrast to optical. Interface circuitry **203-1a** and **203-4a** convert between optical and electrical signals for receiving signals from and transmitting signals onto the SONET/SDH ring. In some alternative embodiments of the present invention, however, the transmissions between some or all of constituent SONET/SDH switches **201-1** through **201-4** are optical and interface circuitry is present on both ends of each connection between constituent SONET/SDH switches **201-1** through **201-4** to convert into and out of the optical domain. It will be clear to those skilled in the art how to make and use such interface circuitry.

Furthermore, all of the constituent SONET/SDH switches in composite SONET/SDH switch **200** receive and spawn tributaries, in well known fashion, and in accordance with the SONET/SDH protocol standard or a variety of other protocols (e.g., Gigabit Ethernet, Fiber Channel, ATM, etc.). Interface circuitry **203-1b**, **203-2**, **203-3**, and **203-4b** convert between electrical signal in electrical domain **204** and whatever kinds of signals are presented or needed on the respective tributaries. It will be clear to those skilled in the art how to make and use interface circuitry **203-1a** through **203-4b**. In some alternative embodiments of the present invention, however, some of the buses carry optical signals.

Each bus entirely within electrical domain **204** is p bits wide, wherein p is a positive integer greater than zero. In accordance with the illustrative embodiments, $p=32$. In some alternative embodiments of the present invention, however, some buses have a different width than some other buses.

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System controller and timing source **202** performs three independent, but interrelated, functions:

- i. it provides a system clock signal to all of the constituent SONET/SDH switches in composite SONET/SDH switch **200** so that they all run off of a common clock,
- ii. it directs how each SONET/SDH switch in composite SONET/SDH switch **200** should process each signal it receives, and
- iii. it adjusts each of the constituent SONET/SDH switches to enable hitless switching between them.

The first function is performed by a timing source, in well-known fashion. The second and third functions are performed by a microprocessor capable of providing the functionality described below and with respect to FIGS. **5** and **6**. In some alternative embodiments of the present invention, the second function is performed by one or more processors and the third function is performed by one or more other processors.

FIG. **3** depicts a block diagram of the salient components of SONET/SDH switch **201-i**, for $i=1$ to **4**, in accordance with the illustrative embodiment of the present invention. Each constituent SONET/SDH switch in composite SONET/SDH switch **200** is identically fabricated on a single integrated circuit. For the purposes of this specification, the term "integrated circuit" is defined as a slice or chip of material on which is etched or imprinted a complex of electronic components and their interconnections. One advantage of the illustrative embodiment is that it comprises a plurality of identical and modular components (i.e., SONET/SDH switch **201-i**) that can be assembled in different numbers and topologies to form a variety of composite SONET/SDH switches.

As shown in FIG. **3**, SONET/SDH switch **201-i** receives a signal from each of input buses 1_i through n_i and outputs a signal on each of output buses **1** through n . In accordance with the illustrative embodiment, SONET/SDH switch **201-i** receives the same number of signals as it outputs (i.e., SONET/SDH switch **201-i** is an n by n switch). It will be clear to those skilled in the art, however, that a switch in accordance with some alternative embodiments of the present invention can receive a different number of signals than it outputs (i.e., the switch is an n by m switch).

SONET/SDH switch **201-i** comprises: input ports **301-1** through **301-n**, switching fabric **302**, and output ports **303-1** through **303-n**. The output of input ports **301-1** through **301-n**, switching fabric **302-i** and output ports **303-1** to **303-n** all receive the system clock signal directly from system controller and timing source **202** and, therefore, run synchronously. The input of input ports **301-1** through **301-n** is clocked synchronously with the incoming signals generated at the output of the constituent SONET/SDH switch or the interface circuitry that generated the incoming signals. In other words, the input of input ports **301-1** through **301-n** and the output of input ports **301-1** through **301-n** operate at the same clock frequency, but can have a disparate phase relationship. Furthermore, the disparate phase relationship can change over time.

As will be described in detail below and with respect to FIGS. **4** through **6**, each input port that receives a time-division multiplexed signal from another SONET/SDH switch in composite SONET/SDH switch **200**:

- i. temporally buffers the signal,
- ii. performs SONET/SDH section and line termination for the signal,
- iii. retimes the signal,
- iv. passes the retimed signal to switching fabric **302**, and
- v. maintains a count that is related to how far the signal is from a frame boundary at each point in time.

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How the input port achieves this is described below and with respect to FIGS. **4** through **6**.

Switching fabric **302-i** comprises:

- i. a cross-connect for routing any SONET STS-1 or SDH STM-1 signal from any of input ports **301-1** through **301-n** to any of output ports **303-1** through **303-n**; and
- ii. a time-slot interchanger for changing the STS slot of any STS-1 or STM-1 signal in any time-division multiplexed signal,

under the direction of system controller and timing source **202**. In other words, system controller and timing source **202** controls all of the routing of signals through composite SONET/SDH switch **200**. It will be clear to those skilled in the art how to make and use switching fabric **302**.

Each of output ports **303-1** through **303-n** outputs a time-division multiplexed signal and performs SONET/SDH section and line generation for the signal. It will be clear to those skilled in the art how to make and use each of output ports **303-1** through **303-n**.

FIG. **4** depicts a block diagram of input port **301-j**, for $j=1$ to n , in accordance with the SONET/SDH switch depicted in FIG. **3**. Input port **301-j** comprises: write pointer **401-j**, read pointer **402-j**, memory **403-j**, frame position register **404-j**, frame position counter **405-j**, section and line terminator **406-j**, and retimer **407-j**.

Write pointer **401-j**, read pointer **402-j**, and memory **403-j** together function as a p -bit wide by k word deep first-in, first-out memory ("FIFO"). In accordance with the illustrative embodiments of the present invention, $p=32$ to match the width of the buses between SONET/SDH switches **201-1** through **201-4**. In accordance with the illustrative embodiment of the present invention, the minimum depth of memory **403-j** equals:

$$[D \times B] + 2 \quad (\text{Eq. 1})$$

where D is the maximum differential propagation delay, as measured in seconds, between any two routes through composite SONET/SDH switch **200** with the same starting and ending points, and B is the bus bandwidth as measured in words per second. For example, if D is 60 nanoseconds, and B is 311 Megawords per second, then the minimum depth of memory **403-j** is 20 words.

Write pointer **401-j** is a $\log_2 k$ -bit (i.e., modulo k) up counter that is incremented once for each word written into memory **403-j**. Upon initialization and restart, the initial value of write pointer **401-j** is zero. As stated above, write pointer **401-j** is clocked in phase and frequency with the arrival of incoming words.

Read pointer **402-j** is a $\log_2 k$ -bit (i.e., modulo k) up counter that is incremented once for each word read from memory **403-j**. Upon initialization and restart, the initial value of the offset value, $o_{j,i}$, is two (2). The value in read pointer **402-j** can be affected by system controller and timing source **202** by writing an offset, $o_{j,i}$, into read pointer **402-j** such that the new value in read pointer **402-j** equals the old value in read pointer **402-j** plus the offset, $o_{j,i}$. How the offset, $o_{j,i}$, is determined and when it is written into read pointer **402-j** is described in detail below.

As stated above, read pointer **402-j** is clocked in phase and frequency with the system clock as it arrives at SONET/SDH switch **201-i**.

In accordance with the illustrative embodiment, there is a frame boundary once every G words that section and line terminator **406-j** receives in the temporally buffered signal from memory **403-j**, wherein G is a positive integer greater than one. In accordance with the illustrative embodiment, each input receives an OC-192, which has 192 STS's per frame and 810 bytes per STS and 4 bytes per word, and,

therefore the value of $G=38,880$. In some alternative embodiments of the present invention, some inputs receive a different rate signal and some other alternative embodiments of the present invention (e.g., an OC-768, etc.), some inputs receive a different rate signal (e.g., an OC-768, etc.) than other inputs receive (e.g., an OC-192, etc.).

Frame position register **404-j**, frame position counter **405-j**, and section and line terminator **406-j** together function to provide system controller and timing source **202** with a number that is related to how far the signal arriving at input port **301-j** is from a frame boundary at a point in time dictated by system controller and timing source **202**.

As described in detail below and with respect to FIGS. **5** and **6**, system controller and timing source **202** uses this information, along with same kind of information from other input ports on the same and other SONET/SDH switches in composite SONET/SDH switch **200**, to determine the values stored in read pointer **402-j**.

The contents of frame position register **404-j** need not exactly specify the current position in the signal as measured from a frame boundary, but instead can be measured from a fixed position within a frame such that the number is related to how far the signal is from a frame boundary. In other words, the number, plus or minus a constant, should equal the current position in the signal as measured from a frame boundary.

Frame position register **404-j** is a parallel load in, parallel read out $\log_2 G$ -bit register that loads and holds the contents of frame position counter **405-j** at a point in time indicated by system controller and timing source **202**. In other words, frame position register **404-j** enables system controller and timing source **202** to take a snapshot of frame position counter **405-j** at a point in time indicated by system controller and timing source **202**. Advantageously, system controller and timing source **202** takes a snapshot of all of the frame position counters in composite SONET/SDH switch **200** simultaneously so that it can compare their values and intelligently populate all of the read pointers **402-j**'s in composite SONET/SDH switch **200**. It will be clear to those skilled in the art how to make and use frame position register **404-j**.

Frame position counter **405-j** is advantageously a $\log_2 G$ -bit (i.e., modulo G) up counter that is:

- i. reset upon the detection of a frame boundary by section and line terminator **406-j**, and
- ii. incremented once for each word that section and line terminator **406-j** receives since the last frame boundary.

It will be clear to those skilled in the art how to make and use frame position counter **405-j**. Furthermore, it will be clear to those skilled in the art that in some alternative embodiments of the present invention, position counter **405-j** can be a down-counter. And yet furthermore, it will be clear to those skilled in the art that in some alternative embodiments of the present invention, frame position register **404-j** and frame position counter **405-j** can be combined (e.g., as a counter with two clock enables—one from section and line terminator **406-j** and one from system controller and timing source **202**, etc.).

Section and line terminator **406-j** receives the temporally buffered signal from memory **403-j** and removes the section and line overhead from the signal, in well-known fashion, and passes the payload to retimer **407-j**. Section and line terminator **406-j** also detects frame boundaries in the arriving signal, in well-known fashion, and outputs to frame position counter **405-j** an indication of each word that it has received since the last frame boundary. When section and line terminator **406-j** detects another frame boundary, section and line terminator **406-j** resets frame position counter **405-j**.

Retimer **407-j** receives the payload and performs positive or negative frequency justification, if necessary, in well-known fashion. When the signal arriving at input port **301-j** has been transmitted from a SONET/SDH switch in composite SONET/SDH switch **200**, and, therefore, both switches have a common timing source, no frequency justification is necessary. From retimer **407-j**, the signal is output to switching fabric **302**.

FIG. **5** depicts a flowchart of the operation of composite SONET/SDH switch **200**.

At task **501**, composite SONET/SDH switch **200** is powered up in well-known fashion.

At task **502**, system controller and timing source **202** synchronizes all of the individual SONET/SDH switches in composite SONET/SDH switch **200** so that hitless re-routing in composite SONET/SDH switch **200** can be accomplished. Task **502** is described in detail below and with respect to FIG. **6**. Task **502** can be accomplished before live traffic is carried by composite SONET/SDH switch **200**.

At task **503**, composite SONET/SDH switch **200** carries live traffic and grooming can be performed by re-routing live signals from one SONET/SDH switch in composite SONET/SDH switch **200** to another SONET/SDH switch in composite SONET/SDH switch **200** without a hit. Advantageously, grooming is performed after each deprovisioning operation involving SONET/SDH switch **200**. It will be clear to those skilled in the art how to perform task **503**.

At task **504**, system controller and timing source **202** determines if there has been a full or partial system interruption caused by, for example, the resetting of one or more of the SONET/SDH switches in composite SONET/SDH switch **200**. If there has, then control passes to step **502**; otherwise control passes to step **503**. When there has been a full system interruption, then all of the SONET/SDH switches in composite SONET/SDH switch **200** are resynchronized. In contrast, when there has been only a partial system interruption, the newly restored SONET/SDH switches are synchronized to conform with the timing of the SONET/SDH switches whose operation was not interrupted.

FIG. **6** depicts a flowchart of the subtasks associated with task **502**.

At subtask **601**, system controller and timing source **202** transmits a frame synchronization signal to frame position register **404-j,i**, for $j=1$ to 4 and $i=1$ to 4 . This enables system controller and timing source **202** to sample the contents of frame position counter **405-j,i**.

At subtask **602**, system controller and timing source **202** reads the contents of frame position register **404-j,i**, which is denoted by $fpr_{j,i}$. Table 1 depicts sixteen illustrative values from the sixteen frame position registers in the four SONET/SDH switches.

TABLE 1

| Illustrative Contents of Sixteen Frame Position Pointers | | |
|--|------------|-------------|
| SONET/SDH Switch | Input Port | $fpr_{j,i}$ |
| 201-j | 301-j,i | |
| 201-1 | 301-1,1 | 5 |
| | 301-1,2 | 38,877 |
| | 301-1,3 | 2 |
| | 301-1,4 | 1 |
| 201-2 | 301-2,1 | 38,874 |
| | 301-2,2 | 38,879 |
| | 301-2,3 | 5 |
| | 301-2,4 | 38,879 |
| 201-3 | 301-3,1 | 4 |
| | 301-3,2 | 9 |
| | 301-3,3 | 38,878 |
| | 301-3,4 | 38,875 |

TABLE 1-continued

| Illustrative Contents of Sixteen Frame Position Pointers | | |
|--|-----------------------|--------------------|
| SONET/SDH Switch 201-j | Input Port 301-j,i | fpr _{j,i} |
| 201-4 | 301-4,1 | 7 |
| | 301-4,2 | 4 |
| | 301-4,3 | 38,877 |
| | 301-4,4 | 38,877 |

At subtask 603, normalizes the values of fpr_{j,i} in preparation for determining which frame position register's contents represents the longest propagation delay. This normalization is necessary because frame position register 404-j,i captures the contents of a modulo G counter, and, therefore, smaller numbers do not necessarily represent longer propagation delays than larger numbers. The normalized value of frame position register 404-j,i, nv_{j,i}, equals:

$$nv_{j,i} = (fpr_{j,i} + G/2) \text{ modulo } G \quad (\text{Eq. 3})$$

The normalized values of the contents of the frame position registers are depicted in Table 2.

TABLE 2

| Normalized Contents of Sixteen Frame Position Pointers | | | |
|--|-----------------------|--------------------|-------------------|
| SONET/SDH Switch 201-j | Input Port 301-j,i | fpr _{j,i} | nv _{j,i} |
| 201-1 | 301-1,1 | 5 | 19,445 |
| | 301-1,2 | 38,877 | 19,437 |
| | 301-1,3 | 2 | 19,442 |
| | 301-1,4 | 1 | 19,441 |
| 201-2 | 301-2,1 | 38,874 | 19,434 |
| | 301-2,2 | 38,879 | 19,439 |
| | 301-2,3 | 5 | 19,445 |
| | 301-2,4 | 38,879 | 19,439 |
| 201-3 | 301-3,1 | 4 | 19,444 |
| | 301-3,2 | 9 | 19,449 |
| | 301-3,3 | 38,878 | 19,438 |
| | 301-3,4 | 38,875 | 19,435 |
| 201-4 | 301-4,1 | 7 | 19,447 |
| | 301-4,2 | 4 | 19,444 |
| | 301-4,3 | 38,877 | 19,437 |
| | 301-4,4 | 38,877 | 19,437 |

At subtask 604, system controller and timing source 202 determines the largest propagation delay by locating the smallest normalized value computed in subtask 603. When frame position register 405-j,i is an up counter, the smallest normalized value computed in subtask 603 represents the input port that is the most behind. From Table 2, the smallest normalized value is 19,434, which is associated with nv_{1,2}. Because this represents the longest propagation delay, each of the other input ports will have to be delayed to coincide with this value.

At subtask 605, system controller and timing source 202 determines the offset, o_{j,i}, to be written into read pointer 402-j,i.

The value of the offset to be written into a read pointer is equal to:

$$o_{j,i} = nv_{j,i} - \text{minimum}(\text{of all } nv) \quad (\text{Eq. 4})$$

From Table 2, it can be seen that the minimum(of all nv) equals 19,434. The normalized values of the contents of the frame position registers are depicted in Table 2.

TABLE 3

| Calculated Offsets for All Sixteen Frame Position Pointers | | | |
|--|-----------------------|--|------------------|
| SONET/SDH Switch 201-j | Input Port 301-j,i | | o _{j,i} |
| 201-1 | 301-1,1 | | 13 |
| | 301-1,2 | | 5 |
| | 301-1,3 | | 10 |
| | 301-1,4 | | 9 |
| 201-2 | 301-2,1 | | 2 |
| | 301-2,2 | | 7 |
| | 301-2,3 | | 13 |
| | 301-2,4 | | 7 |
| 201-3 | 301-3,1 | | 12 |
| | 301-3,2 | | 17 |
| | 301-3,3 | | 6 |
| | 301-3,4 | | 3 |
| 201-4 | 301-4,1 | | 15 |
| | 301-4,2 | | 12 |
| | 301-4,3 | | 5 |
| | 301-4,4 | | 5 |

At subtask 606, system controller and timing source 202 writes into read pointer 402-j,i the value of the offset, o_{j,i}, which read pointer 402-j,i adds to the current value of the read pointer to create its new value. After subtask 606 has been completed, system controller and timing source 202 can re-reroute any signals through composite SONET/SDH switch 200 without incurring a hit.

In some alternative embodiments of the present invention, only some paths through composite SONET/SDH switch 200 are synchronized for hitless re-routing. In these cases, the latency through composite SONET/SDH switch 200 can typically be reduced in comparison to when system controller and timing source 202 can re-reroute any signals through composite SONET/SDH switch 200 without incurring a hit.

It is to be understood that the above-described embodiments are merely illustrative of the present invention and that many variations of the above-described embodiments can be devised by those skilled in the art without departing from the scope of the invention. It is therefore intended that such variations be included within the scope of the following claims and their equivalents.

What is claimed is:

1. A composite switch comprising:

a first integrated circuit for outputting a first time-division multiplexed signal that comprises a first series of frame boundaries to a second integrated circuit and for outputting a second time-division multiplexed signal that comprises a second series of frame boundaries to a third integrated circuit;

wherein said second integrated circuit comprises:

- (i) a first input port for receiving said first time-division multiplexed signal,
- (ii) a first memory that stores said first time-division multiplexed signal at a location that is indicated by a first write pointer and that reads said first time-division multiplexed signal at a location that is indicated by a first read pointer,
- (iii) a first frame position register whose contents are related to how far said first time-division multiplexed signal is from a frame boundary in said first time-division multiplexed signal at a first point in time, and
- (iv) a first output port for outputting a third time-division multiplexed signal that is based on said first time-division multiplexed signal and that comprises a third series of frame boundaries;

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wherein said third integrated circuit comprises:

- (i) a second input port for receiving said second time-division multiplexed signal,
- (ii) a second memory that stores said second time-division multiplexed signal at a location that is indicated by a second write pointer and that reads said second time-division multiplexed signal at a location that is indicated by a second read pointer,
- (iii) a second frame position register whose contents are related to how far said second time-division multiplexed signal is from a frame boundary in said second time-division multiplexed signal at said first point in time, and
- (iv) a second output port for outputting a fourth time-division multiplexed signal that is based on said second time-division multiplexed signal and that comprises a fourth series of frame boundaries;

a fourth integrated circuit comprising:

- (i) a third input port for receiving said third time-division multiplexed signal,
- (ii) a third memory that stores said third time-division multiplexed signal at a location that is indicated by a third write pointer and that reads said second time-division multiplexed signal at a location that is indicated by a third read pointer,
- (iii) a third frame position register whose contents are related to how far said third time-division multiplexed signal is from a frame boundary in said third time-division multiplexed signal at a second point in time,
- (iv) a fourth input port for receiving said fourth time-division multiplexed signal,
- (v) a fourth memory that stores said fourth time-division multiplexed signal at a location that is indicated by a fourth write pointer and that reads said fourth time-division multiplexed signal at a location that is indicated by a fourth read pointer,

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- (vi) a fourth frame position register whose contents are related to how far said fourth time-division multiplexed signal is from a frame boundary in said fourth time-division multiplexed signal at said second point in time; and

a controller for reading the contents of said first frame position register and said second frame position register, for storing a value in said first read pointer based on the contents of said first frame position register and said second frame position register, for reading the contents of said third frame position register and said fourth frame position register, and for storing a value in said third read pointer based on the contents of said third frame position register and said fourth frame position register.

2. The composite switch of claim 1 wherein said first point in time and said second point in time are the same.

3. A method comprising:

- transmitting a frame synchronization signal to frame position registers of multiple SONET/SDH switches;
- reading contents of the frame position registers in response to the frame synchronization signal;
- normalizing the contents of the frame position registers;
- determining propagation delays from the normalized contents of the frame position registers;
- determining the largest propagation delay from the non-normalized contents of the frame position registers;
- determining port-specific offsets for read pointer offset registers of the multiple SONET/SDH switches as a function of the largest propagation delay; and
- writing the port-specific offsets into the read pointer offset registers.

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