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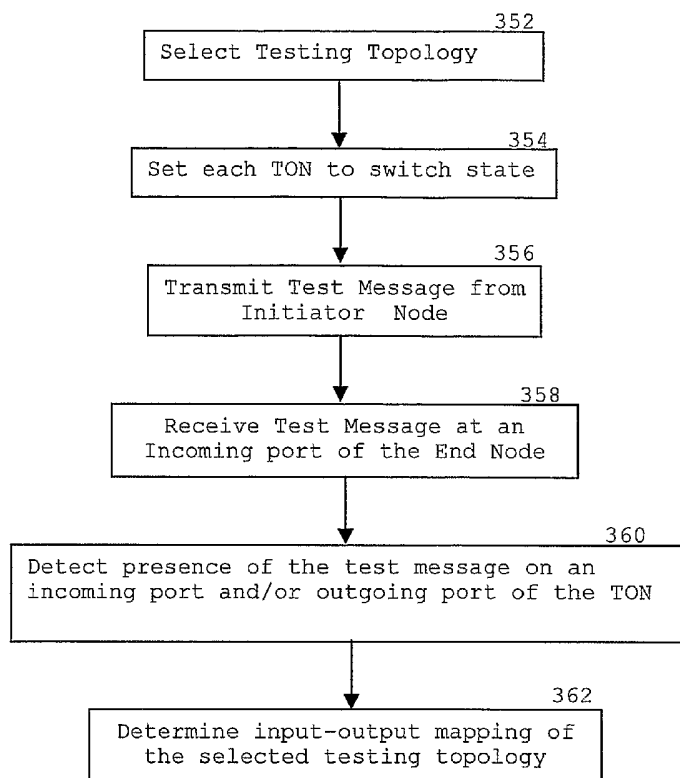
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(54) Title: SYSTEMS AND METHODS FOR TESTING DATA LINK CONNECTIVITY OF AN OPTICAL NETWORK EMPLOYING TRANSPARENT OPTICAL NODES



(57) Abstract: A method for testing data link connectivity of an optical network includes selecting a testing topology of the optical network, the selected testing topology including an initiator node, one or more end nodes, and one or more transparent optical nodes coupled therebetween, each of the one or more transparent optical nodes having a plurality of incoming ports and a plurality of outgoing ports. The method further includes setting each of the transparent optical nodes in a first switch state and transmitting a test message from the initiator node from a first predetermined outgoing port of the initiator node. The method further includes receiving the test message on an incoming port of the end node and detecting, for each transparent optical node, at which input port, which output port, or which input and output ports the test message is present. The input-output port mapping of the selected testing topology for the selected switched state can then be determined.

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SYSTEMS AND METHODS FOR TESTING DATA LINK CONNECTIVITY OF AN OPTICAL NETWORK EMPLOYING TRANSPARENT OPTICAL NODES

Background of the Invention

5 [0001] The present invention relates to link testing protocols in optical networks, and more specifically to systems methods for testing data link connectivity in optical networks which employ Transparent Optical Nodes (TONs).

[0002] The demand for higher network capacity has been high, especially in the recent
10 years when more and more data information is desired to be transmitted to users over computer networks. Optical networks, based on the emergence of the optical layer in transport networks, has provided higher capacity and reduced cost for new applications such as internet, video and multimedia interaction. In optical networks, data are transmitted through optical fibers in the form of optical signals.

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[0003] To further increase the capacity of the optical networks, dense wavelength division multiplexing (DWDM) has been introduced. DWDM is a technique which assigns multiple incoming optical signals to specific frequencies (wavelength, λ) within a designated frequency band, and multiplexes the incoming optical signals into a resultant
20 combined signal to be transmitted in the same fiber. Thus, several optical signals can be transmitted in a single fiber using DWDM, which otherwise would require several optical fibers.

[0004] One important task in the optical network is network management. Network
25 management for an optical network includes path protection and restoration, routing and signaling, link status verification, resource discovery, and signal performance monitoring. In order to perform the various aspects of network management, a priori parameters of the links and nodes of the optical network are needed. Therefore, optical interface ID mapping discovery and physical link connectivity verification are fundamental functions to be
30 performed in the optical network, either manually or automatically to determine the a priori parameters. Usually, optical interface ID mapping discovery and physical link connectivity verification are performed manually. For the evolving optical network with thousand of optical nodes, such functions are more appropriately performed automatically.

[0005] Typically, each node in the optical network includes a control plane with control plane devices and a data plane with data plane devices. The control plane devices perform functions such as resource discovery, link status dissemination, path management and control, link management, path protection, and path restoration. The control plane devices
5 also control the exchange of control messages through control channels. Data plane refers to the physical media for data link connections such as lambdas and optical fibers. Data plane devices are optical components which provide switch matrices to connect fibers from input (incoming) ports to output (outgoing) ports.

10 [0006] A summary of a typical procedure for optical interface ID mapping discovery and physical link connectivity verification is as follows:

[0007] 1. *Testing request parameter and mechanism negotiation.* An initiator node sends a test request message through the control channel to an adjacent peer node. The
15 adjacent peer node responds accordingly to the initiator node whether it is available for testing. The test request message may contain information such as the number of data links to be verified, interval of test messages, encoding scheme and transport mechanisms that are supported, data rate of the test message, and the wavelength identifier over which the test messages will be transmitted.

20

[0008] 2. *Sending and receiving test message.* Initiator node repeatedly sends the test message from a specific outgoing port. The adjacent peer node scans all its free incoming ports continually until either the test message is received at one incoming port of the peer node or when no test message is received after a predetermined time.

25

[0009] 3. *Test result reporting.* Peer node sends test result to the initiator node using the control channel.

[0010] 4. *Test next data link.* Initiator node repeats the test procedure on the next
30 outgoing port until all the outgoing ports of the initiator node are tested.

[0011] By performing the above test procedure, an optical interface ID mapping table as shown in Fig.1 can be obtained. The interface ID mapping table may include hierarchical information about local and remote traffic engineering (TE) link ID mappings which

comprises data link ID mappings and link properties. The above test procedure is performed when establishing a TE link, and subsequently, repeated for all data links of the TE link which are not allocated for data transmission. If the optical interface ID mappings are already known, the above test procedure may also be used to verify physical link
5 connectivity.

[0012] An example of the hardware configuration of the initiator node and the adjacent peer node is shown in Fig. 2. Both the initiator node 101 and the peer node 102 includes an optical add/drop port or optical switch 103 and media converters 104. The media converters
10 104 are used for wavelength conversion, which normally handle conversion between 850 nm multimode signal and ITU standard 1550 nm single mode signal in DWDM ring. The initiator node 101 and the peer node 102 also include Gigabit Ethernet (GE) line cards (not shown) as transceivers. Using the GE cards and media converters 104, data can be injected into the optical ring from the add port 103 in the initiator node 101 and received by the drop
15 port 103 in the peer node 102.

[0013] In order for the optical nodes to perform the function of optical interface ID mapping discovery and physical link connectivity verification, the optical nodes will typically include transceivers, add/drop ports and media converters for generating and
20 receiving test messages. Such optical nodes are referred as “opaque” nodes.

[0014] To ensure proper link management, each optical node in the optical network is preferably “opaque”. Accordingly, equipment such as transceivers, wavelength converters and add/drop ports should be present in each optical node for injecting and retrieving data,
25 and also for data termination.

[0015] Optical nodes are normally implemented using optical switches. There are two kinds of switches: Opaque switches and transparent switches. Opaque switches are switches with built-in electrical-optical converter and are able to add and drop data signal between electrical domain and optical domain. Transparent switches do not have any of the
30 components mentioned above, and hence, could not modify or examine data from the data optical network.

[0016] With the trend in optical networks developments, all-optical devices (i.e. transparent optical switches) are preferred to be implemented as optical nodes in optical

networks as all-optical switches provide faster switching and lower cost than electrical-optical switches (opaque switches). An optical node implemented using all-optical devices is known as a transparent optical node (TON).

- 5 [0017] Fig.3 illustrates a TON architecture 110. The TON 110 includes a control device 111 and an optical device 112 such as optical cross-connect (OXC) or optical switch. The TON 110 is considered to be transparent because the control device 111 can control and configure the optical device 112 electronically, but cannot inject or remove data from the optical network since it does not have any add/drop ports.

10

[0018] Fig.4 shows the combination of a 32x32 transparent optical switch 120 with additional equipment to implement an "opaque" node. The optical switch 120 has 32 incoming ports and 32 outgoing ports. To make the optical switch "opaque", one of the incoming port is chosen as an add port, and an outgoing port is chosen as the drop port.

- 15 Therefore, a 31x31 optical switch with an add/drop port is formed such that any of the 31 Channels can be selectively dropped from the incoming port to the drop port or added from the add port to the outgoing port. In addition, a wavelength converter 121 is also used for changing the wavelength of the modulating light of the added/dropped channel in order to match the wavelength supported by the transceiver.

20

[0019] A significant disadvantage of the above solution is that the cost of assigning of transceivers, wavelength converters and add/drop ports for transmitting and receiving test
25 signal to and from the TON node is very high. Also, the main purpose of transparent optical devices is for dynamic switching, and not for injecting and retrieving data. Accordingly, it is impractical to dedicate equipment to each transparent optical node only for the purpose of link verification.

30 Summary of the Invention

[0020] The present invention provides for systems and methods for testing optical network connectivity employing TONs without the need for the aforementioned transceivers, wavelength converters or add/drop ports. As a result, optical networks employing TONs can be constructed at lower expense, and with less complexity.

[0021] In a particular embodiment, a method for testing data link connectivity of an optical network includes selecting a testing topology of the optical network, the selected testing topology including an initiator node, one or more end nodes, and one or more transparent optical nodes coupled therebetween, each of the one or more transparent optical nodes having a plurality of incoming ports and a plurality of outgoing ports. The method further includes setting each of the transparent optical nodes in a first switch state and transmitting a test message from the initiator node from a first predetermined outgoing port of the initiator node. The method further includes receiving the test message on an incoming port of one of the end nodes and detecting, for each transparent optical node, at which input port, which output port, or which input and output ports the test message is present. The input-output port mapping of the selected testing topology for the selected switched state can then be determined.

[0022] These and other aspects and features of the invention will be better understood in light of the following drawings and detailed description.

Brief Description of the Figures

[0023] Fig. 1 shows optical interface mapping tables, a control channel, and data links connections between two nodes as known in the art.

[0024] Fig. 2 shows a hardware configuration of an initiating node and an adjacent node for optical interface mapping discovery and link physical connectivity verification as known in the art.

25

[0025] Fig. 3 shows architecture for a transparent optical node (TON) as known in the art.

[0026] Fig. 4 shows a 32x32 transparent optical switch used in the implementation of an opaque node as known in the art.

[0027] Fig. 5 shows an exemplary optical network in which the present invention can be employed.

[0028] Fig. 6 shows a first embodiment of an optical monitoring assembly in accordance with the present invention.

[0029] Fig. 7 shows a second embodiment of an optical monitoring assembly in accordance with the present invention.

[0030] Fig. 8 shows a two-node testing topology using the optical monitoring system.

[0031] Fig. 9 shows a three-node testing topology using the optical monitoring system in accordance with the present invention.

[0032] Fig. 10 shows a schematic block diagram of the three-node testing topology shown in Fig. 9.

[0033] Figs. 11-14 show exemplary testing topologies in accordance with the present invention.

[0034] Fig. 15 shows a first exemplary method for testing data link connectivity of an optical network in accordance with the present invention.

[0035] Fig. 16 shows a second exemplary embodiment of a method for testing data link connectivity of an optical network in accordance with the present invention.

[0036] Fig. 17 shows exemplary messages exchange process between the initiator node and the other nodes during the testing process in accordance with the present invention.

[0037] Figs. 18 and 19 show exemplary processes for resolving indeterminate input-output port mappings in accordance with the present invention.

30 Detailed Description of Exemplary Embodiments

[0038] Fig. 5 shows an exemplary optical network including optical nodes 201. The optical nodes 201 are physically connected to one another using optical fibers 202. Usually, the optical nodes 201 in the optical network 200 are a mixture of transparent or opaque

optical devices such as optical lambda routers/switches, optical cross-connects, optical splitter or add/drop multiplexers.

- [0039] Optical lambda switches are typically of two types: all-optical switches or
5 electro-optical switches. All-optical switches are configured to route and direct optical transmissions and are not able to modify data without using additional equipment. Electro-optical switches have built-in electrical optical converters which are able to add and drop signal between the electrical and optical domains.
- 10 [0040] Data which are to be transmitted is injected into the optical network 200 from a source node. The source node normally includes an add/drop multiplexer for adding a new wavelength for data transmission into the optical fiber 202 of the optical network 200. The injected data is transmitted to a destination node in the optical network 200 and is retrieved therefrom. The destination node for retrieving the data normally also includes an add/drop
15 multiplexer for dropping the wavelength at which the data is transmitted.

[0041] The transmission path of the data may be a direct path from the source node to the destination node, or may transverse a plurality of intermediate nodes between the source node and the destination node.

20

[0042] All the optical nodes 201 have a control plane with control channels, in which, control and command messages are transmitted. The optical nodes 201 also have a data plane which includes the physical data links connecting the nodes 201. The control plane is separate from the data plane.

25

[0043] In order to perform optical interface ID mapping discovery and physical link connectivity verification, all the optical nodes 201 should be able to generate and receive (or terminate) test signals for the mentioned discovery and verification process. However, as previously mentioned, TONs do not have any add/drop multiplexers, and therefore, not able
30 to generate or terminate any test signals.

[0044] In a particular embodiment, an optical monitoring assembly for each TON is used to detect optical signal passing through the incoming ports of the TONs. Of course, the same or functionally similar monitoring system may be employed on the outgoing ports, or

both the incoming and outgoing ports of the TONs. Use of the optical monitoring assembly at each TON to determine at which incoming ports data (in the form of the optical signal) are received and to which outgoing ports the received data are switched to, optical interface ID mapping discovery and physical link connectivity verification of the optical network can
5 be achieved. Therefore, the need for transceivers, wavelength converters, add/drop ports, or other equipment used to generate or terminate test signals is obviated.

[0045] Fig. 6 shows an optical monitoring assembly implemented at the incoming ports 211 of a TON (TON not shown). The TON has four incoming ports 211 as shown in Fig. 6.
10 A tap coupler 212 is used to decoupled a portion (e.g. 1% or -20 dB) of the optical signal from one of the incoming ports 211, and a corresponding light monitoring system (LMS) 210 is configured to detect the presence of light above a particular threshold level (e.g., nominal background light level).

15 [0046] Fig. 7 shows a second embodiment of the optical monitoring assembly. Similar to Fig.6, each tap coupler 212 is used to tap or detect optical signal from each incoming port 211 of the TON. However, the tap couplers 212 are connected to a tap coupler switch 213 which connects the tap coupler 212 to the optical monitoring system 210. The switching states of the tap coupler switch 213 (e.g., a micro-electro-mechanical MEM switch in one
20 embodiment) changes in a predefined manner to allow the optical monitoring system 210 to monitor the optical signal in all the incoming ports 211 of the TON.

[0047] The optical monitoring system 210 used in the invention monitors the optical signal power, the optical signal-to-noise ratio or other optical parameters of the optical signal that passes through the incoming ports 211 of the TON. For example, the optical
25 monitoring system 210 may monitors the laser power with a predefined threshold value to detect loss of light. Specifically, about 1% to 5% of the optical signal power of the optical signal is decoupled by the tap coupler 212, and remaining 95% to 99% of the optical power remains unchanged.

30

[0048] Fig. 8 shows a two-node testing topology using the optical monitoring system according to the invention. The two-node testing typology includes an electro-optical node 301 and a TON 302. The electro-optical node 301 and the TON 302 each has a controller

303, 304 in their respective control plane for controlling the exchange of control messages between the control channel and the respective optical nodes 301, 302.

[0049] The electro-optical node 301 is a normal lambda router having equipment for
5 signal termination and transmission. For sake of convenience, an electro-optical node 301 is herein referred to as an EN node. As noted above, the TON 302 does not have the capability of terminating signal, but is operable to switch signals from the incoming ports of the all-optical node 302 to the outgoing ports. As used herein, the terms “incoming” and “outgoing” as used to refer to the direction of signal propagation in order to clearly
10 description the system’s operation. Such terms, unless explicitly indicated, do not denote a unidirectional function, and those skilled in the art will readily appreciate that the ports of the opaque nodes and the TONs are in bi-directional, and a previously described outgoing port can function as an incoming port in another embodiment.

15 [0050] Although the TON 302 does not have any equipment for terminating signal, it includes an optical monitoring assembly as shown in Figs. 6 and 7 to detect optical signal in each incoming port (or alternatively or in addition, at each outgoing port). When the EN 301 sends test message (in the form of optical signal) from one of its outgoing port, the TON 302 detects the test message from one of its incoming port using the optical
20 monitoring system.

[0051] In a particular embodiment, the TON 302 also sends a test message to the EN 301. However, as noted above, TON 302 is not able to send any test message, as it does not have the necessary equipment for generating any optical signal. Therefore, a three-node
25 testing topology, as shown in Fig. 9, is provided which enables the TON 302 to “send” test message.

[0052] The three-node testing topology of Fig. 9 includes a second electro-optical node 306 as EN. The EN 306 has a controller 307 which controls the exchange information
30 between the control channel 305 and the EN 306.

[0053] During the testing process, the EN 301 acts as an initiator node and sends test message from one of its outgoing ports (1, 3, 5). The test message is detected in one of the incoming ports of the TON 302 (2, 4, 6) by the optical monitoring system. The path of the

test message is switched to an outgoing port of the TON 302 (11, 13, 15), and is received by one of the incoming ports of the EN 306 (7, 8, 9) acting as a peer (or “end”) node. When all the outgoing ports of the EN 301 have been tested, the EN 306 acts as the initiator node and sends test message from one of its outgoing ports. The testing process ends when all the
5 outgoing ports of the EN 306 have been tested. For each node (EN or TON), the respective node neighbors are discovered or known in advance.

[0054] In a further embodiment, the above-described process is repeated for each switching state available for the TON or until all optical interface mappings are known. As
10 an example, the switching state of TON 302 can be changed such that incoming port 2 is switchable to outgoing port 11 in a second switching state.

[0055] Fig. 10 illustrates a schematic block diagram of the three-node testing topology shown in Fig. 9 EN 301 has three outgoing ports to be tested (port ID 1, 3, 5). TON 302 has
15 three incoming ports (port ID 2, 4, 6) and three outgoing ports (port ID 11, 13, 15) to be tested. EN 306 has three incoming ports (port ID 7, 8, 9) to be tested.

[0056] The switch state of the TON 302 is set (e.g., set randomly or to a particular input/output state) during the testing process. The EN 301 as initiator node negotiates for
20 the testing process to be performed with the TON 302 and EN 306 through the control plane. Upon successful negotiation, EN 301 sends test message from outgoing port ID 1. TON 302 and EN 306 monitor or scan their incoming ports for optical signal and test message, respectively.

[0057] The optical monitoring system of TON 302 (not shown) is operable to detect the
25 optical signal representing the test message in the incoming port ID 2. According to a pre-configured switching table, it is also determined that the detected optical signal is switched to the outgoing port ID 15. EN 306 would then receive the test message in the incoming port ID 9. The TON 302 and EN 306 would correspondingly report to the initiator node EN
30 301 in which port IDs the test message is received as test results. In this case, the data link path of outgoing port ID 1 is 1-2-15-9, and the local and remote interface ID mappings are 1-2 and 15-9. Alternatively or additionally, the described process can be applied in the reverse direction whereby EN 306 operates as an initiator node and EN 301 operates as an end node, the TON operating in any switching state as desired or randomly selected.

[0058] To ensure that all optical paths relating to a node are tested completely, a testing topology is defined. As used herein, the term "testing topology" for an EN node refers to an optical network segment that includes the EN node as the initiator node, one or more end nodes (the EN nodes reachable via optical data paths from the initiator node), and one or more TONs coupled between the initiator and end nodes. In a specific embodiment, an EN node terminates the incoming optical paths. In a further embodiment, the initiator node and the end node are included within the same EN node. Such an embodiment may be found in a ring configuration in which one or more TONs are coupled in a ring configuration with a single EN node. In another embodiment, the initiator node and the end node(s) are different EN nodes which are on the border and enclose one or more interposed TONs.

[0059] Determining a testing topology is a procedure for network segmentation. Therefore, to determine the testing topology for a node is to find a network segment satisfying the aforementioned definition. The testing topology for a node may be determined either manually or automatically using intelligent algorithms.

[0060] In a particular embodiment, the testing topology of an EN node can be determined with the following procedure:

1. Set the EN node as the initiator node.
2. Put the EN node in a set N.
3. Put all other nodes in the network in a set S.
4. Move all neighbours of the initiator node from S to N.
5. Move any TON node from N to a set T and all its neighbours in S to N.
6. Repeat procedure 5, until there is no TON node in N.
7. Now the nodes in N and T and the interconnecting links between them form the testing topology of the initiator node. The nodes other than the initiator node in N are the end nodes.

[0061] Each node is defined such that it will belong to at least one testing topology, although a node, e.g., an EN node, may belong to several different testing topologies. For example, an EN node may belong to a first testing topology as an initiator node, and to a second testing topology as an end node. "Neighbouring" nodes are nodes which are directly connected together.

[0062] Fig.12 shows a detailed exemplary embodiment of an optical network having several smaller testing topologies, as described above. The network includes ENs 310 and TONs 311. For ease of description, the ENs 310 are indicated as E1, E2, E3 and E4, and the
5 TONs 311 shall be denoted as T1, T2, T3, T4, T5, T6 and T7.

[0063] Fig. 13 shows the testing topology when E1 acts as the initiator node. In the testing topology, E2 and E3 act as the end nodes where any optical data path initiated from E1 will be terminated.

10

[0064] Fig. 14 exhibits the testing topology for E4 including node: E3-T6-T7-E4, where E4 acts as the initiator node and E3 as the end node. Once identified, any of the testing topologies can be identified and the network section they represent tested according to the present invention.

15

[0065] Fig. 15 shows an exemplary method for testing data link connectivity of an optical network. Initially at 352 an EN node and its testing topology is selected. As detailed herein, the topology includes one initiator node, one or more end nodes and one or more transparent optical nodes (TONs) coupled between the initiator and end node(s). Next at
20 354, each of the one or more TONs is set to an input/output switch state. The TON's switch state may be selected randomly or it may be set to connect a particular input to a particular output. Next at 356, a test message is transmitted from a predetermined outgoing port of the initiator node. The test message is received at one of the incoming ports of one of the end nodes (358), and during the transmission the presence of the test message on the input port,
25 the output port, or both the input and output ports of the TON is detected (362). By knowing from which outgoing port the test message was transmitted, on which TON(s) and which of its (their) input port(s) and/or output port(s) the presence of test message was detected, and on which end node and which of its incoming ports the test message was detected, a set of input-output port mapping for the selected testing topology can be determined.

30

[0066] In a further refinement of the exemplary method of Fig. 15, the system is configured to transmit a second test message from a second predetermined outgoing port of the initiator node. In such an embodiment, the processes of 358-362 are repeated to provide a second set of input-output port mapping for the selected testing topology. The process

may be repeated for all outgoing ports of the selected initiator port to provide a complete input-output port mapping for the selected testing topology. It is noted that if the input/output port switching of each of the TONs is known beforehand (which will typically be the case), test message detection may be conducted at either the incoming ports or the
5 outgoing ports.

[0067] Further specific embodiments of the aforementioned method may be employed. For example, the switching state of one or more of the TONs may be changed, and the processes repeated. In addition, a second EN node and its corresponding testing topology
10 may be selected, and any of the aforementioned operations performed.

[0068] Fig. 16 shows a second exemplary embodiment of a method for testing data link connectivity of an optical network. At 400, the testing topology for the initiator node is determined. At 401, the initiator node sends a test request message to all the other nodes in
15 the same testing topology. The test request message is sent using the control channel in a particular embodiment.

[0069] The other nodes will acknowledge whether they are available for the testing process in step 402. The acknowledgement of the other nodes is "positive" when they are
20 available for testing, and "negative" when they are not available for testing. In a particular embodiment, the TON is involved in the negotiation process over the control channel and in the electronic message form. In this embodiment, the initiator node does not monitor the state of the LMS on the TONS. If TON is determined to be presently in use or otherwise unavailable for testing, the particular testing topology is not tested.

25

[0070] The test request message may contain the number of data links that are to be tested, the interval over which the test message will be sent by the initiator node, the encoding scheme and transport mechanisms that are supported, the data rate of the test message, and the wavelength identifier over which the test message will be transmitted. In a
30 particular embodiment, each of the TONs in the testing topology receive, through the control channel, the test request message and process it, but do not forward it, as the initiator node is operable to send the request message to other nodes in the testing topology directly

[0071] When the test request message is received by the other nodes, the other nodes may also acknowledge the test request message negatively with a different parameter choice. The initiator node will then resend a new testing request message with the new parameters to the other nodes until the initiator node and the other nodes reach an
5 agreement. The negotiation stage is then considered to be complete.

[0072] After the agreement is established between the initiator node and the other nodes, the state of the switches in the TONs are set in 403. The switches' states are held constant throughout the whole testing process. At 404, the initiator node sends test message
10 in the form of an optical signal from one of its outgoing ports periodically. The TONs continually monitor all their respective incoming ports under test until an optical signal is detected in one of the incoming ports, or when no optical signal is detected after a predefined time. Similarly, the ENs continually scan all their respective incoming ports under test until the test message is received in one of the incoming ports, or when no test
15 message is received after a predefined time. In addition, the initiator node also continually scans its incoming ports until the test message is received in one of its incoming ports, or when no message is received after a predefined time.

[0073] At 405, the TONs report to the initiator node whether any optical signal is
20 received in one of their respective incoming ports. For those TONs which receive an optical signal in one of their incoming ports, the TONs would also report to the initiator node in which incoming ports (port ID) the optical signal is received, and/or to which outgoing port the optical signal is switched. In an alternative embodiment when the input/output switching of the TON(s) is known, only knowledge of which incoming or outgoing port the test
25 message has been detected is needed. The ENs report to the initiator node whether the test message is received in one of their respective incoming ports. For ENs which received the test message in one of their incoming ports, the ENs also report to the initiator node in which incoming ports the test message is received.

30 [0074] At 406, the initiator node analyzes the testing results reported by the TONs and ENs, and determines the optical path of the optical signal representing the test message as well as the interface ID mappings between two adjacent nodes. The interface ID mappings between two adjacent nodes are then sent to the respective nodes. The initiator node would

also determine the link connectivity according to the testing results if the interface ID mappings between two adjacent nodes are known in advance.

[0075] At 407, the initiator node determines whether another of its outgoing port is
5 available to be tested. When the other outgoing port of the initiator node is available, processes 404 to 406 are repeated to test the data link connectivity of the other outgoing port. The processes 404 to 406 are repeated until all the other outgoing ports of the initiator node are tested.

10 [0076] At 408, a subsequent EN acts as a new initiator node and its corresponding testing topology is selected, and processes 401 to 407 are repeated to test the data link connectivity of all the outgoing ports of the new initiator node. The testing process is complete when all the ENs in the network have acted as the initiator node once.

15 [0077] Fig.17 illustrates exemplary messages exchange process between the initiator node and the other nodes during the testing process. As shown, the initiator node transmits the test request message to the EN and TON nodes along the control channel, each of the EN and TON nodes communicating a Test Request Acknowledgement and/or Test Pass/Fail status messages. The test messages are transmitted one way from the initiator node to the
20 EN & TON nodes along the data channel.

[0078] At process 403, the switch state of the TONs may be set randomly or to a predefined switch state. However, the switch state of the TONs should be held constant after they are set to avoid ambiguity of optical paths passing through the TONs, and also to
25 prevent an incomplete testing process. However, not all the data links may be tested based on the randomly setting the switch states of the TONs. In a particular embodiment based on the discovered interface ID mappings of the adjacent nodes in the testing topology, the switch states of some of the TONs would be set to direct the optical signal to specific incoming/outgoing ports to test specific data links in the testing topology.

30

[0079] The setting of specific switch states in TONs may be used to determine the path of the optical signal. Using, for example, the optical network segment shown in Fig. 14, the optical path of an optical signal from E3 to E4 may be E3-T6-T7-E4 or E3-T7-T6-E4 as shown in Fig.18. However, these two optical paths are not distinguishable from each other.

The optical path of the optical signal from E3 to E4 can be determined by changing the switch state of T6 and holding the switch state of T7 constant. If the optical signal passes through T7 using the same incoming ports, this means that T7 is located before T6, i.e. the optical path is E3-T7-T6-E4. Else, the optical path is E3-T6-T7-E4.

5

[0080] The setting of specific switch states in TON may also be used to eliminate optical path loops that may be introduced into the optical network of the testing topology due to the random switch state of the TONs. For example, an optical path loop may be formed between T6 and T7 as shown in Fig.19. In such a case, the test message from an
10 initiator node (EN) would not be able to transverse the ports of the optical path loop. Therefore, the switch state of T6 and/or T7 may be changed specifically to eliminate such an optical path loop. This can ensure that each port of the nodes in the optical network must be and only be on an optical path, so that a complete testing process can be ensured.

15 [0081] An advantage of the system is that there is no requirement that all the ports in the nodes are free and ready for testing. Only data links which are not occupied are tested, and hence, the data flow in the occupied data links are not affected.

[0082] As readily appreciated by those skilled in the art, the described processes may be
20 implemented in hardware, software, firmware or a combination of these implementations as appropriate. In addition, some or all of the described processes may be implemented as computer readable instruction code resident on a computer readable medium (removable disk, volatile or non-volatile memory, embedded processors, etc.), the instruction code operable to program a computer or other such programmable device to carry out the
25 intended functions.

[0083] The foregoing description has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and obviously many modifications and variations are possible in light of the
30 disclosed teaching. The described embodiments were chosen in order to best explain the principles of the invention and its practical application to thereby enable others skilled in the art to best utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto.

CLAIMS

What is claimed:

1. A method for testing data link connectivity of an optical network, the method
5 comprising:
 - (i) selecting a testing topology of the optical network, the selected testing topology including an initiator node, one or more end nodes, and one or more transparent optical nodes coupled therebetween, each of the one or more transparent optical nodes having a plurality of incoming ports and a plurality of outgoing ports;
 - 10 (ii) setting each of the transparent optical nodes in a first switch state;
 - (iii) transmitting a test message from the initiator node from a first predetermined outgoing port of the initiator node;
 - (iv) receiving the test message on an incoming port of one of the end nodes;
 - (v) detecting, for each transparent optical node, at which input port, which output
15 port, or which input and output ports the test message is present; and
 - (vi) determining an input-output port mapping of the selected testing topology for the selected switched state.
2. The method of claim 1, wherein the initiator node and the end node comprise one
20 electro-optic node.
3. The method of claim 1, wherein the initiator node and the end node comprise separate electro-optic nodes.
- 25 4. The method of one of claims 1-3, wherein each of the transparent optical nodes comprises an all optical switch that omits an add/drop port.
5. The method of one of claims 1-4, wherein (v) comprises:
 - decoupling a portion of the test message present from any of said ports; and
 - 30 detecting the presence of the test message in the decoupled portion of the test message.
6. The method of one of claims 1-5, further comprising:

transmitting a test message from a second predetermined outgoing port of the initiator node; and

repeating (iv)-(vi).

5 7. The method of one of claims 1-6, further comprising:

setting each of the transparent optical nodes in a second switch state; and

repeating (iii)-(vi) for the second switch state.

8. The method of one of claims 1-7, further comprising:

10 (vii) selecting a second testing topology of the optical network, the second testing topology including a second topology initiator node, one or more second topology end nodes, and one or more transparent optical nodes coupled therebetween, each of the one or more transparent optical nodes having a plurality of incoming ports and a plurality of outgoing ports, wherein at least one of the second topology initiator or end nodes is

15 different from one or both of the previously selected initiator or end nodes; and

(viii) repeating (ii)-(vi) for the second topology initiator and end nodes, and the one or more transparent optical nodes coupled therebetween.

9. The method of claim 8, wherein the initiator node of the second testing topology

20 comprises an end node used in a previously selected testing topology.

10. The method of claim 8, further comprising repeating (vii)-(viii) for n testing topologies, where n represents the number of possible initiator nodes within the optical network.

25

11. A system configured to test data link connectivity of an optical network, the system comprising:

(i) means for selecting a testing topology of the optical network, the selected testing topology including an initiator node, one or more end nodes, and one or more transparent
30 optical nodes coupled therebetween, each of the one or more transparent optical nodes having a plurality of incoming ports and a plurality of outgoing ports;

(ii) means for setting each of the transparent optical nodes in a first switch state;

(iii) means for transmitting a test message from the initiator node from a first predetermined outgoing port of the initiator node;

(iv) means for receiving the test message on an incoming port of the end node;

(v) means for detecting, for each transparent optical node, at which input port, which output port, or which input and output ports the test message is present; and

(vi) means for determining the input-output port mapping of the selected testing
5 topology for the selected switched state.

12. The system of claim 11, wherein the initiator node and the end node comprise one electro-optic node.

10 13. The system of claim 11, wherein the initiator node and the end node comprise separate electro-optic nodes.

14. The system of one of claims 11-13, wherein each of the transparent optical nodes comprises an all optical switch that omits an add/drop port.

15

15. The system of one of claims 11-14, wherein (v) comprises:

a coupler operable to decouple a portion of the test message present from any of said ports; and

a detector operable to detect the presence of the test message in the decoupled
20 portion of the test message.

16. The system of one of claims 11-15, further comprising means for transmitting a test message from a second predetermined outgoing port of the initiator node.

25 17. The system of claims 11-16, further comprising means for setting each of the transparent optical nodes in a second switch state.

18. The system of one of claims 11-17, further comprising means for selecting a second testing topology of the optical network, the second testing topology including an second
30 topology initiator node, one or more second topology end nodes, and one or more transparent optical nodes coupled therebetween, each of the one or more transparent optical nodes having a plurality of incoming ports and a plurality of outgoing ports, wherein at least one of the second topology initiator or end nodes is different from one or both of the previously selected initiator or end nodes.

19. The system of claim 18, wherein the initiator node of the second testing topology comprises a node not used in a previously selected testing topology as the initiator node.

5 20. A computer program product, resident on a computer readable medium, operable to execute instructions for testing the data link connectivity of an optical network, the computer program produce comprising:

(i) instruction code to select a testing topology of the optical network, the selected testing topology including an initiator node, one or more end nodes, and one or more
10 transparent optical nodes coupled therebetween, each of the one or more transparent optical nodes having a plurality of incoming ports and a plurality of outgoing ports;

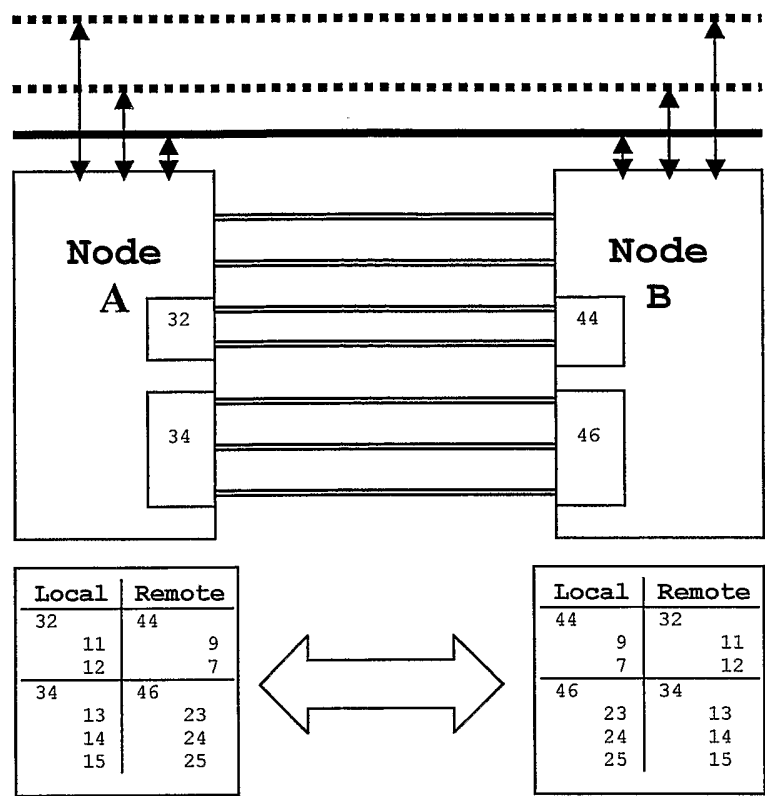
(ii) instruction code to set each of the transparent optical nodes in a first switch state;

(iii) instruction code to transmit a test message from the initiator node from a first
15 predetermined outgoing port of the initiator node;

(iv) instruction code to receive the test message on an incoming port of the end node;

(v) instruction code to detect, for each transparent optical node, at which input port, which output port, or which input and output ports the test message is present; and

20 (vi) instruction code to determine the input-output port mapping of the selected testing topology for the selected switched state.



Prior Art

FIG 1

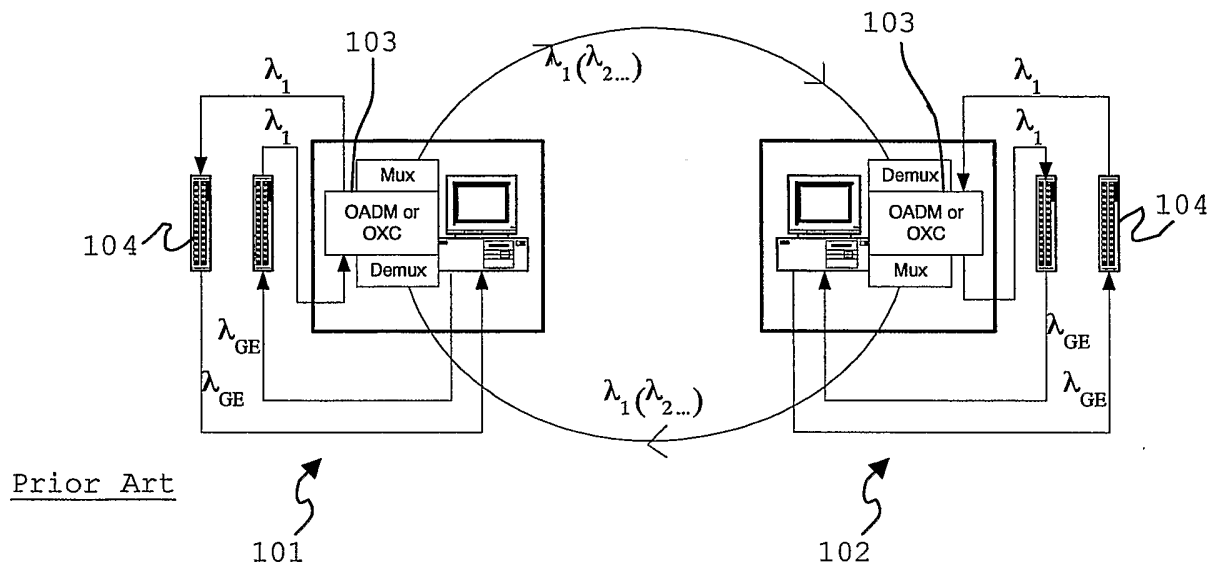


FIG 2

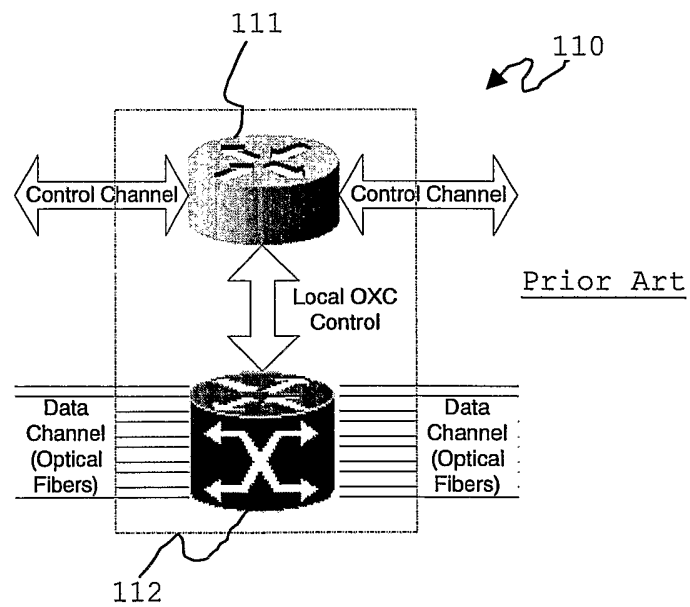


FIG 3

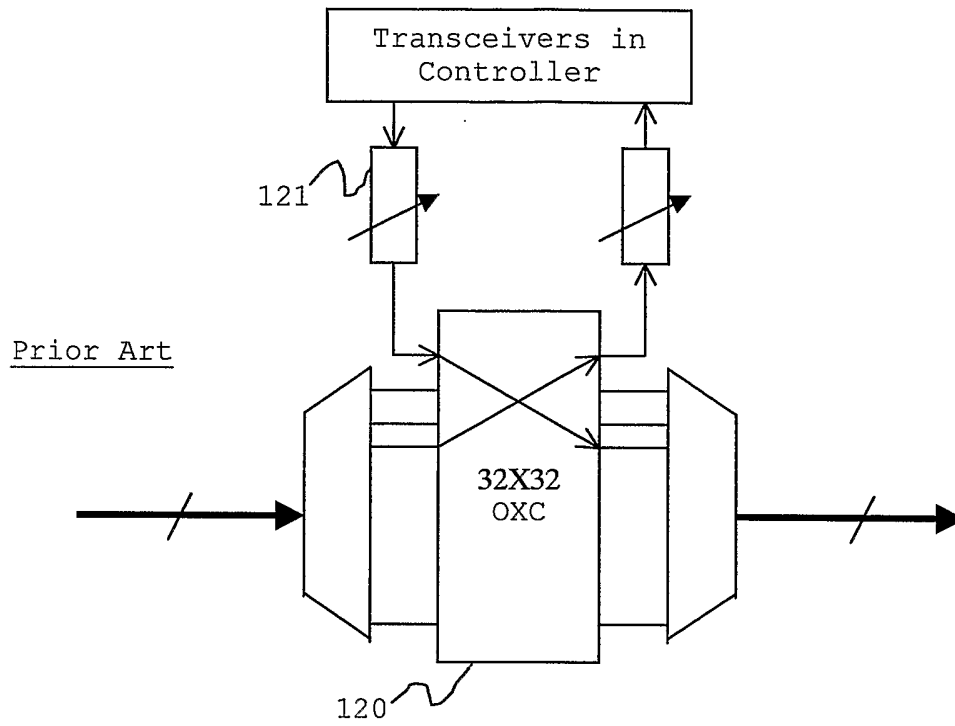


FIG 4

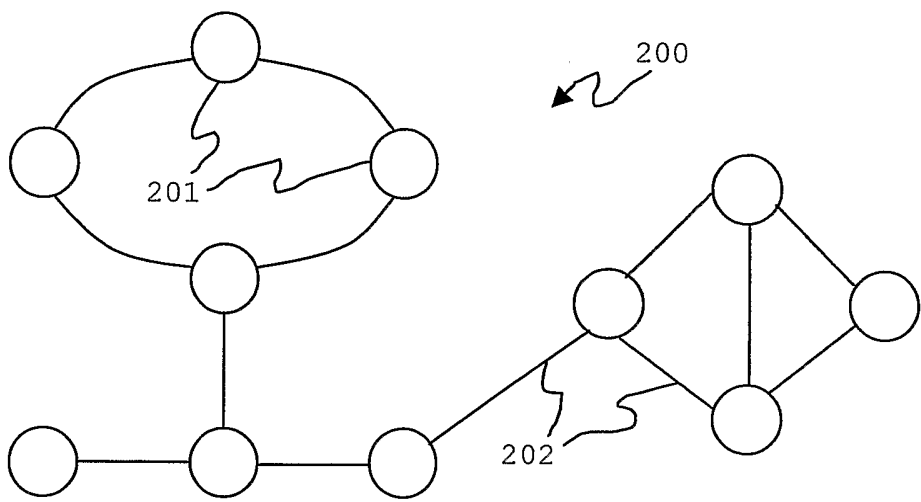


FIG 5

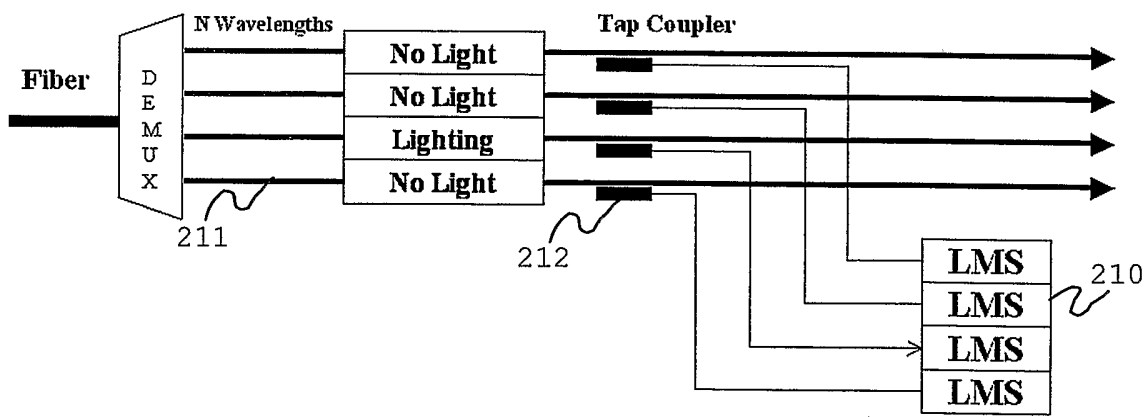
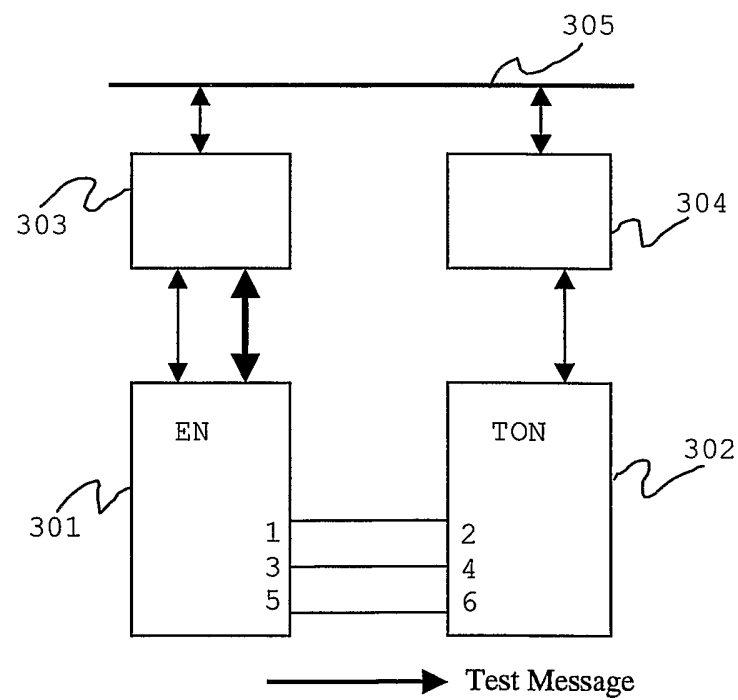
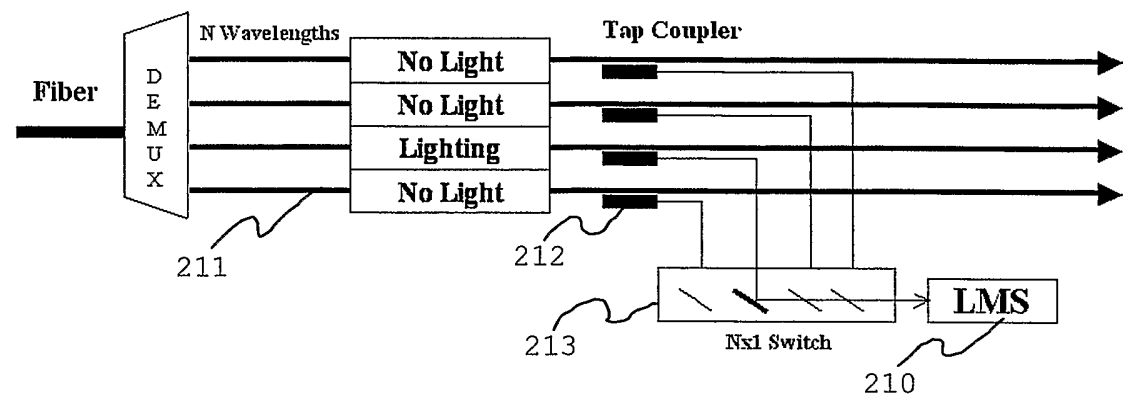


FIG 6



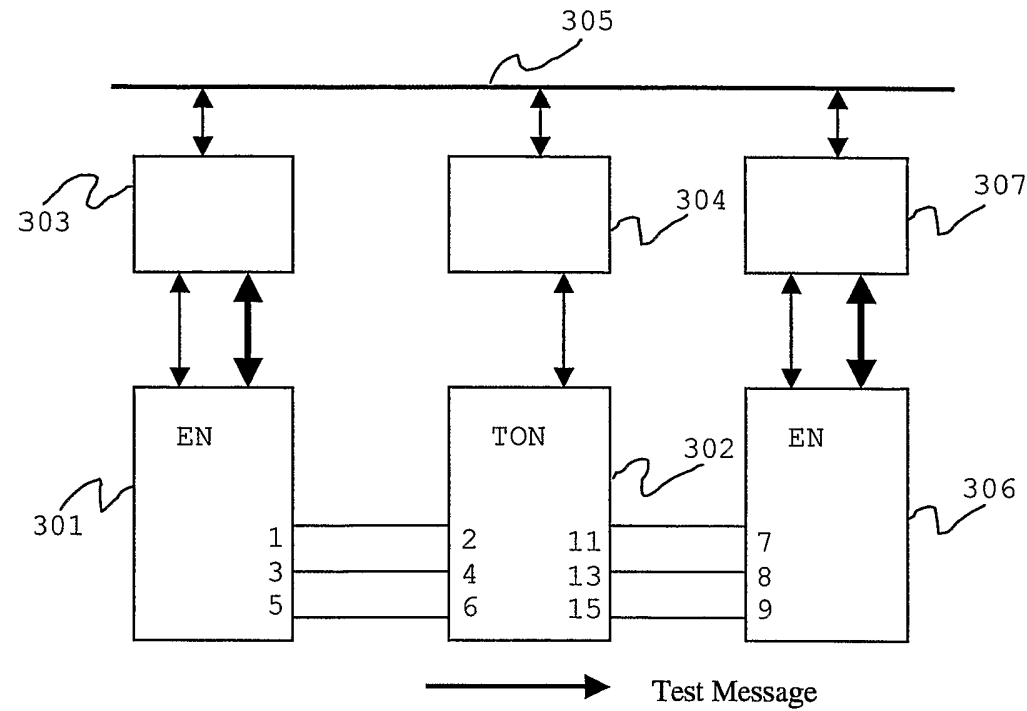


FIG 9

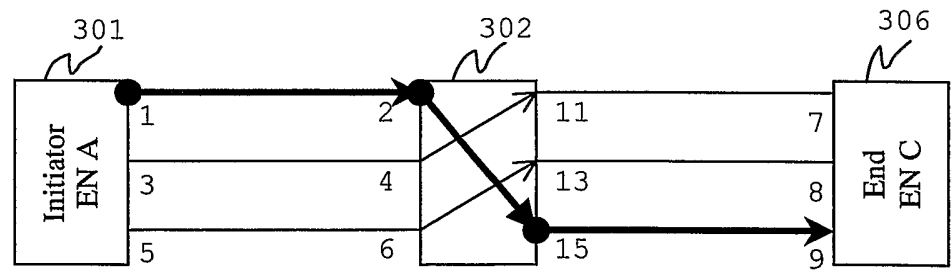


FIG 10

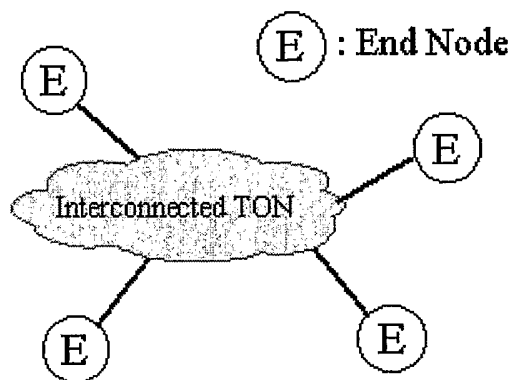


FIG 11

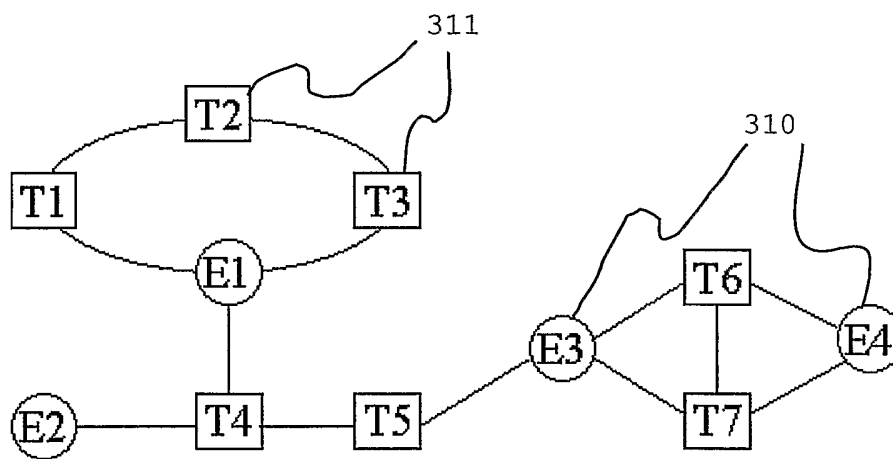


FIG 12

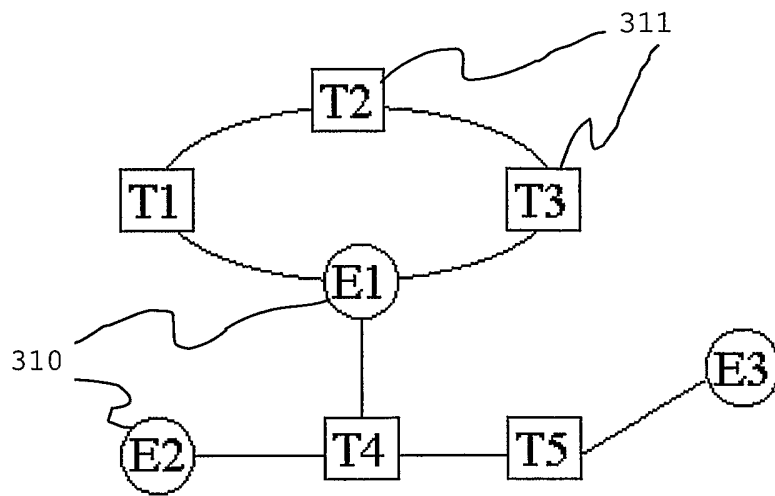


FIG 13

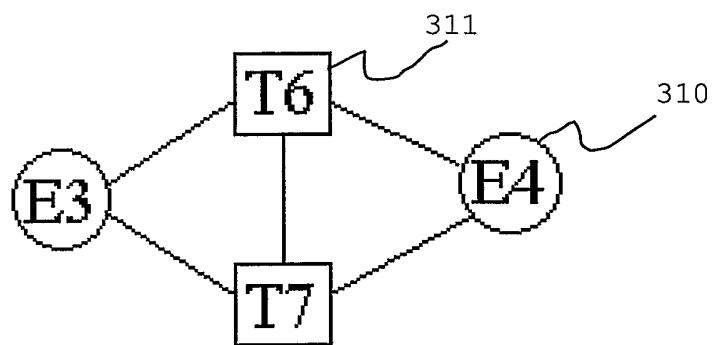


FIG 14

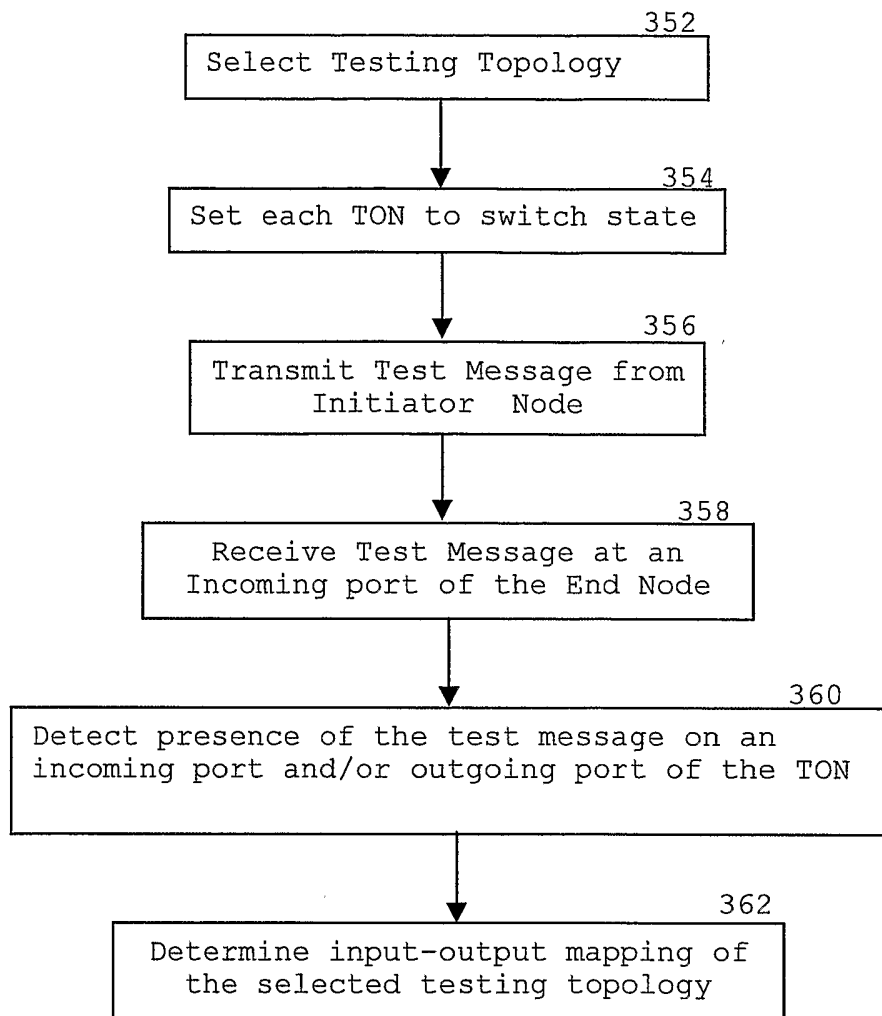


Fig. 15

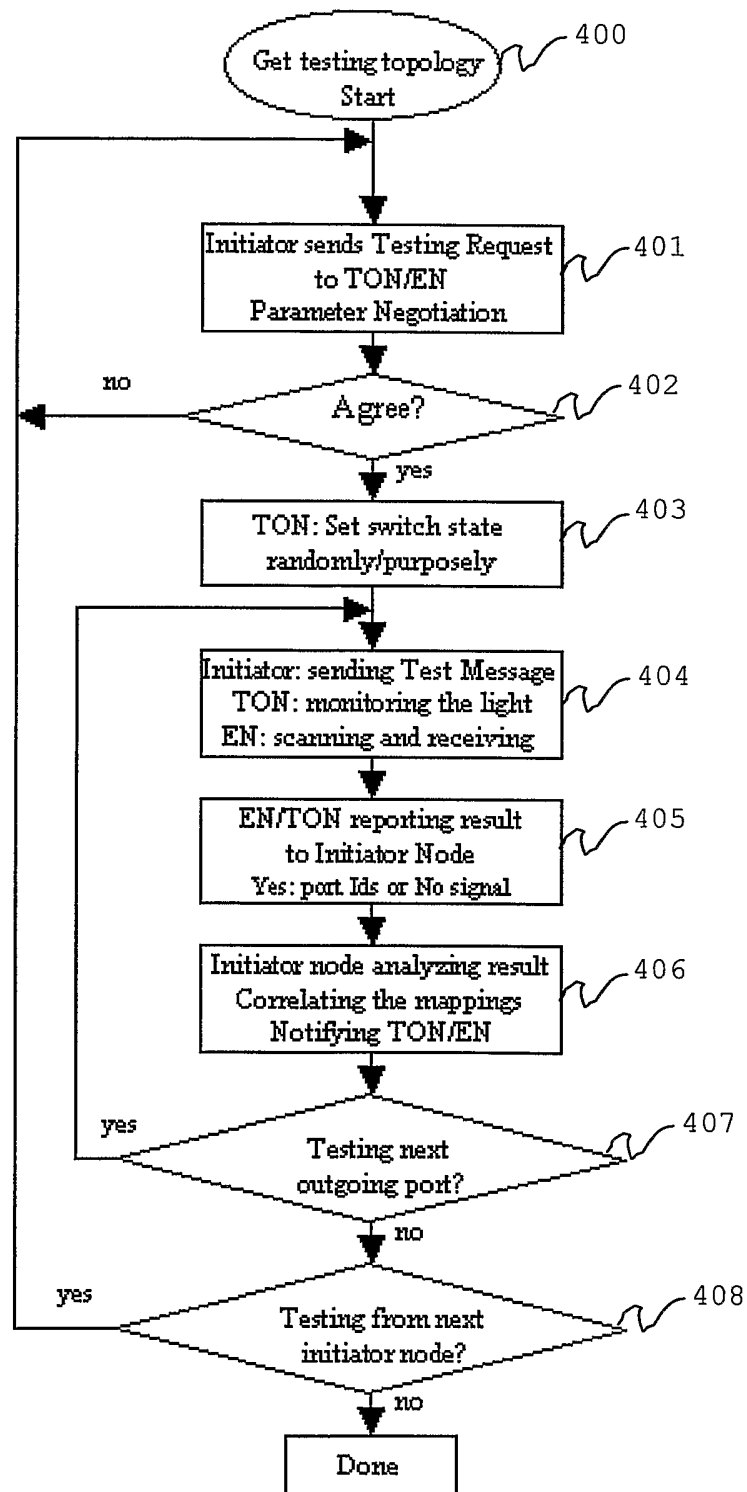


FIG 16

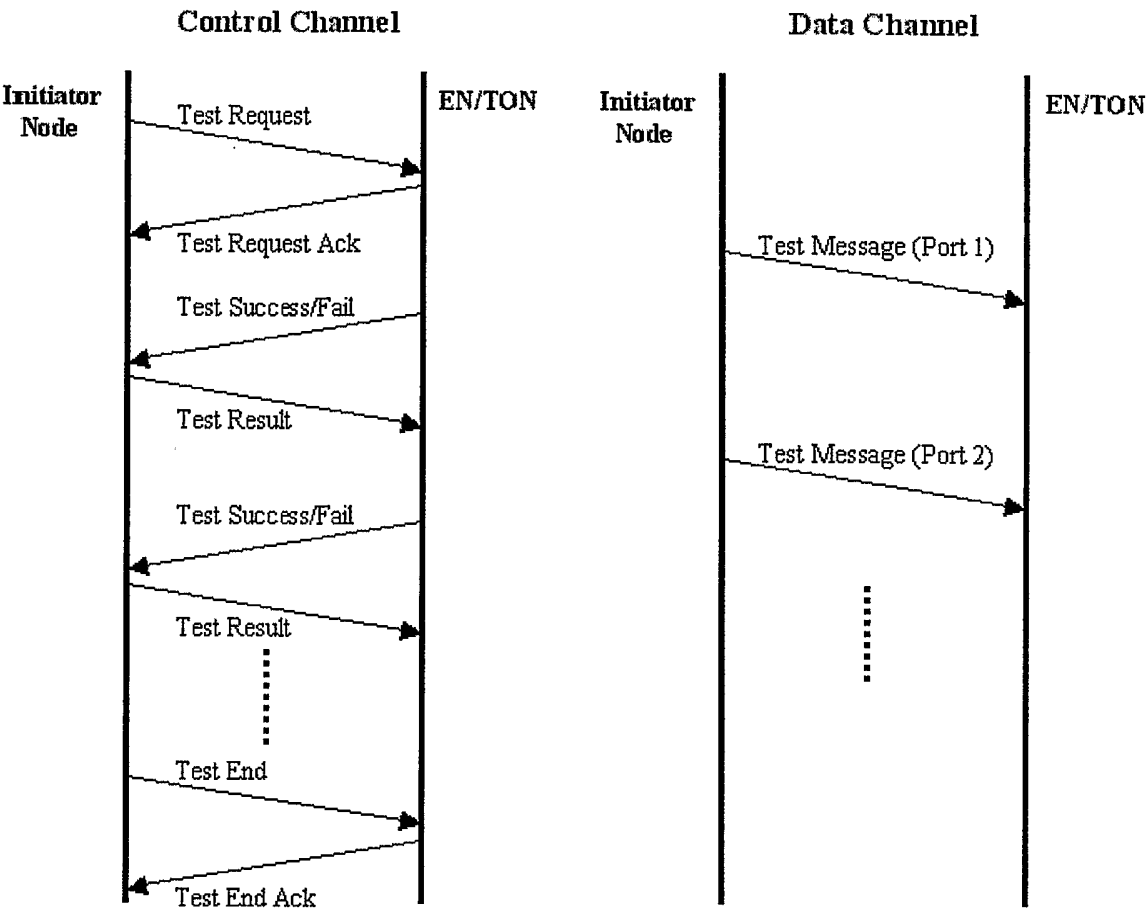


FIG 17

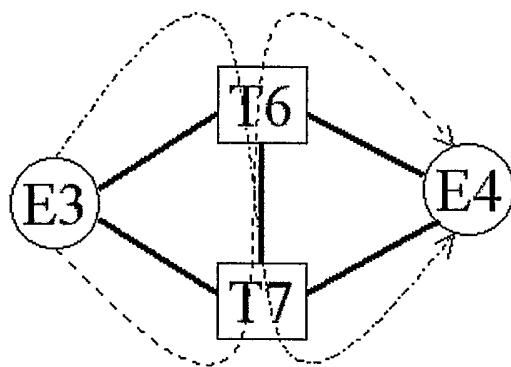


FIG 18

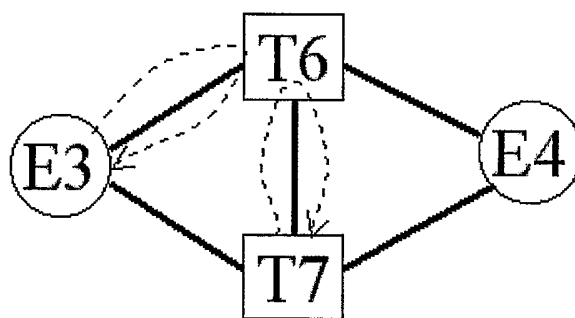


FIG 19

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2005/000023

A. CLASSIFICATION OF SUBJECT MATTER												
Int. Cl. ⁷ : H04B 10/08, H04B 10/20, H04J 14/00												
According to International Patent Classification (IPC) or to both national classification and IPC												
B. FIELDS SEARCHED												
Minimum documentation searched (classification system followed by classification symbols) IPC 7												
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched												
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) WPAT, INTERNET: optical, WDM, network, test, connection, transparent, node, switch												
C. DOCUMENTS CONSIDERED TO BE RELEVANT												
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.										
X	US 2004/0202468 A1 (HARNEY) 14 October 2004 See page 4, paragraphs 32-34, 36.	1-20										
X	US 2004/0151497 A1 (LEE et al.) 5 August 2004 See pages 1 and 2, paragraph 16.	1, 11, 20										
A	US 2002/0126342 A1 (WETZEL et al.) 12 September 2002											
A	WRIGHT "Intelligent Tests for Optical Designs" CommsDesign.com, 1 July 2001. URL: http://www.commsdesign.com/csdmag/sections/feature_article/showArticle.jhtml?articleID=16503086 , retrieved on 11 March 2005.											
☐ Further documents are listed in the continuation of Box C ☒ See patent family annex												
* Special categories of cited documents: <table border="0"> <tr> <td>"A" document defining the general state of the art which is not considered to be of particular relevance</td> <td>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</td> </tr> <tr> <td>"E" earlier application or patent but published on or after the international filing date</td> <td>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</td> </tr> <tr> <td>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</td> <td>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</td> </tr> <tr> <td>"O" document referring to an oral disclosure, use, exhibition or other means</td> <td>"&" document member of the same patent family</td> </tr> <tr> <td>"P" document published prior to the international filing date but later than the priority date claimed</td> <td></td> </tr> </table>			"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family	"P" document published prior to the international filing date but later than the priority date claimed	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention											
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone											
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art											
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family											
"P" document published prior to the international filing date but later than the priority date claimed												
Date of the actual completion of the international search 17 March 2005		Date of mailing of the international search report 30 MAR 2005										
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustalia.gov.au Facsimile No. (02) 6285 3929		Authorized officer Andrea Hadley Telephone No : (02) 6283 2222										

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG2005/000023

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report				Patent Family Member	
US	2004151497	EP	1445976	JP	2004242329
US	2004202468				
US	2002126342	EP	1248490	JP	2002300109
Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.					
END OF ANNEX					