(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 January 2015 (15.01.2015)

WIPO | PCT

(10) International Publication Number
WO 2015/006568 A1

(51) International Patent Classification:
H04L 12/28 (2006.01)

(21) International Application Number:
PCT/US2014/046165

(22) International Filing Date:
10 July 2014 (10.07.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/845,040 11 July 2013 (11.07.2013) US

(71) Applicant: PLEXXI INC. [US/US]; 100 Innovative Way, Suite 3320, Nashua, NH 03062 (US).

(72) Inventors: SPOCK, Derek, E.; 4 Cumston Street, Boston, MA 02118 (US). LI, Ruoding; 193 Davis Road, Carlisle, MA 01741 (US).

(74) Agents: KENNEDY, Brendan J. et al.; Preti Flaherty Beliveau & Pachios LLP, Ten Post Office Square, Boston, MA 02109 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

[Continued on next page]

(54) Title: NETWORK NODE CONNECTION CONFIGURATION

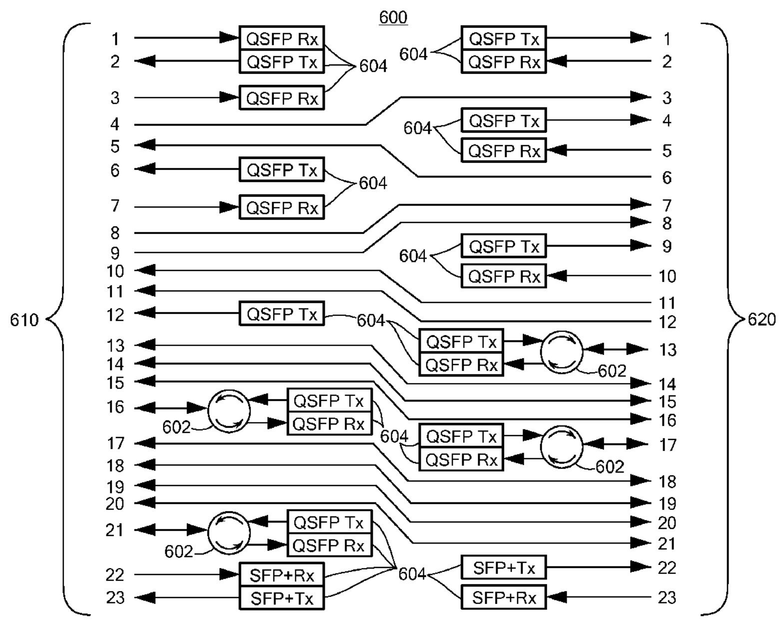

FIG. 6

(57) Abstract: A system and method for connectivity configuration of a network node permits an optical signal to be passed through the node and shifted from a first connector position to a second connector position that is offset from the first connector position. The shifted optical signal permits a number of distant nodes in the network to be reached with a direct optical connection, which can be configured to be bidirectional. The disclosed connectivity configuration reduces the cabling requirements for the network and simplifies the interconnections.

WO 2015/006568 A1

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

TITLE OF THE INVENTION

NETWORK NODE CONNECTION CONFIGURATION

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

(Not Applicable)

BACKGROUND OF THE INVENTION

Communication networks tend to be constructed according to various physical and/or logical topologies, which can often depend on the capabilities of the components of the communication network. For example, Fig. 1 shows a communication network 100 in a hierarchical topology previously used in enterprise and data center communication networks.

Network 100 has a lower layer 110 comprised of servers 112, which are typically rack mounted or otherwise concentrated with regard to physical location. A layer 120 uses layer 2 top-of-the rack (TOR) switches 122 to connect servers 112. A layer 130 is composed of layer 2 and/or layer 3 aggregation switches (AS) 132 to interconnect several TOR switches 122. A layer 140 is the top layer of network 100, and is composed of core routers (CR) 142 that connect aggregation switches 132. Often, core routers 142 also function as a gateway to connect to an Internet 150.

One major drawback of the network architecture of network 100 is that the design is oriented mostly for network traffic from users to the servers, so-called North-South traffic that travels in a generally vertical direction in network 100. Due to the very high oversubscription ratio from layer 120 to layer 140, which is collectively from about 1:80 to about 1:240, the so-called West-East traffic between servers 112 that travels in a generally horizontal direction in network 100 can be subject to performance issues. For example, such high oversubscription ratios can create a bottle neck for traffic between servers 112, since the traffic typically flows through layers 120, 130 and 140, rather than directly between servers 112.

Several network topologies have been proposed to overcome the above-mentioned drawbacks of network 100, where the architecture aim is to flatten the network topology to promote West-East traffic and reduce the oversubscription ratio to a more reasonable range of from about 1:3 to about 1:1. Fig. 2 shows a communication network 200, which is an example of a so-called fat-tree topology for a data center. The topology of network 200 is a special type of Clos topology that is organized in a tree-like structure. Clos topologies help to reduce physical circuit switching needs with respect to the capacity of the switches used to implement the topology. This type of topology is built of k-port switches, and has k pods of switches. Each pod has two layers of switches, each layer has k/2 switches and each pod connects with $(k/2)^2$ servers. There are $(k/2)^2$ core switches, which connect with k pods. The total number of servers supported is $k^3/4$. Network 200 shows an example of the fat-tree topology with k = 4. Accordingly, each switch 202 has four ports, there are four pods 210, 211, 212 and 213, with two layers and two switches in each layer. Each pod 210-213 connects with four servers 220, for a total of sixteen servers supported. There are four core switches 230 that connect with four pods 210-213. Note that although network 200 has twenty switches 202, compared to fourteen for network 100 (Fig. 1), each of switches 202 has four ports. Thus, the topology of network 200 can permit greater West-East traffic through-flow than network 100, and can reduce the oversubscription ratio with switches that have a relatively small number of ports. Also, network 200 avoids the use of expensive core routers 142 (Fig. 1). Network 200 also scales to larger server connections by adding more layers.

Besides fat-tree, other network topologies based on Clos architecture have been proposed, such as the spine and leaf topology of network 300 of Fig. 3. The topology of network 300 can be viewed as a folded Clos topology, and scales to larger server connections by adding more layers. Unlike the architecture of network 100 that has two big core routers 142, in the folded Clos design of network 300, each of layers 330 and 340 uses a relatively large number of switches that are connected to a lower layer.

However, fundamentally, both fat-tree and folded Clos architecture are topologically similar to traditional layered networks, in that they are all assembled in a tree like topology. The difference is the fat-tree and folded Clos arrangements use a series of switches in the top layer, while the traditional network uses one or more big routers at a top layer. These architectures are often called "scale-out" architecture rather than "scale-up" (bigger router) architecture.

One drawback of fat-tree and folded Clos architectures is the increased number of switches used. In addition, large numbers of cable connections are made between all the switches being used to implement the architectures. The complexity of the cabling connectivity and the sheer number of cables used to implement these architectures make them less attractive from a practicality viewpoint. Moreover, in practice, these architectures tend to scale poorly once the network has been built, due at least in part to the further increased complexity of modifying and adding a relatively large number of cable connections. In addition to the complexity, the costs tend to be driven up by relatively expensive cabling used to implement these architectures.

For example, optical cabling is often used to increase speed and throughput in a data center network. Switch ports are directly connected to other switch ports according to the topology configuration, so careful mapping of ports that may be physically separated by relatively large distances is undertaken. In addition, the physical reach of the optical cables is often expected to be greater than 100 meters. If there is a problem with cable or a switch component malfunction, correction of the problem can be costly as well as complicated to implement, since switches and/or cables may need to be installed, and correctly connected in accordance with the complex topology being implemented.

As data centers become more like high performance computing (HPC) platforms, many of the network topologies used in HPC have been proposed for data center networks. However, the topologies employed in an HPC application do not translate well to data center network environments, since the HPC computer processors tend to be densely packed, and the networking connections tend to be restricted to a smaller space, thus limiting complexity and cost for those applications.

Accordingly, the relationship between the number of switches, number of ports on a switch and cabling requirements to implement a desired network topology can present significant challenges in practice. Moreover, problems with scalability and maintenance further increase cost and complexity for scaling up or scaling out and maintaining a desired network topology.

BRIEF SUMMARY OF THE INVENTION

The present disclosure provides a system and method for connectivity of network devices that permits simplified connections for realizing complex networking topologies. The connectivity for the network devices can be achieved using lower cost components. The disclosed system and method permits cabling to be simplified and permits reduced cost cabling to be used to make connections while providing implementations of complex networking topologies. The disclosed system and method assist in simplifying connectivity implementation, so that complex networking topologies can be realized faster and with greater reliability.

Typically, data center network implementation involves connectivity that uses optical technology, which tends to dictate at least a portion of implementation cost. Some of the types of optical technology used for connectivity can include:

Fabry Perot Direct Modulation 1km

DWDM 10G SFP+

CWDM 10G 10km SFP+

850 nm 300 meter SR SFP+

Silicon Photonics 4 km 4x10G

850 nm12x10G miniPod, 100 meter

The above 850 nm 12 channel module tends to be the lowest cost solution but may be limited to a 100 meter reach. The Silicon Photonics 40G QSFP+ (quad small form factor pluggable) (from Molex) can reach 4 km and the cost can be one quarter of the CWDM (coarse wave division multiplexing) SFP+ solution. Although the Silicon Photonic 40G QSFP+ is not CWDM, it can advantageously be used in a low cost solution in accordance with the present disclosure. The present disclosure permits multi-fiber MTP (multi-fiber termination push-on) fiber to be incorporated into various topologies according to user design, and can accommodate topologies such as chordal rings, including mesh rings, such as a mesh ring with 11 or more nodes. A number of other desirable topologies are also possible.

According to an aspect of the present disclosure, a connectivity arrangement is provided at a network node that includes fiber optic transmitters and receivers. The connectivity configuration provides for pass-through fiber connections that are passive and that offer an optical signal path that is offset or shifted by one or more connector positions as the optical signal passes through the node. The connector position offset for pass-through fiber optic connections permits direct optical signal connection between network nodes that are not necessarily physically connected to each other.

For example, using a disclosed connectivity configuration, a fiber optic signal can originate on one node and be transmitted to another node via a direct physical connection. The transmitted fiber optic signal is received at a first connector interface at an incoming connector position and passed through the node via a passive fiber pathway to a second connector interface at an outgoing connector position that is shifted or offset from the incoming connector position. The second connector interface is directly physically connected to a third node that receives the optical signal directly from the first node via the intermediate node. Thus, the third node is not directly physically connected to the first node, but receives the optical signal directly from the first node via the shifted passive optical pathway in the intermediate node.

In the above example, there is a distinction between direct physical connections between nodes, and direct optical connections between nodes. The direct physical connection is in the form of a cable that can be directly connected between two nodes, while direct optical connection can be implemented via an optical connection between two nodes where the path of the direct optical connection includes an intermediate node that passively passes an optical signal that is shifted or offset by at least one connector position. Accordingly, one or more nodes can be "skipped" with the use of the connection offset or shift, which connectivity configuration can be commonly applied to all of the nodes for simplified modularity and construction, while permitting simplified connectivity.

According to another aspect, one or more connector positions can each be coupled to a bidirectional fiber construct. The bidirectional construct can transmit and receive on a single fiber, so that a single connector position is used for transmitting and receiving. This configuration saves connector space and permits relatively complex network topologies to be implemented with fewer connector positions and thus reduce the number of connector positions that are used in the cabling provided to each of the nodes. The connectivity arrangement permits a bidirectional signal transmitted and received between the bidirectional constructs on different nodes to pass through one or more nodes with a passive connection based on a pathway that connects one connector position for one connector (plug) to an offset or shifted connector position for another connector (plug). The connectivity arrangement can be implemented at each node so that a common connectivity configuration can be used at each node to simplify connectivity cabling for the entire network.

The disclosed system and method can reduce the number of cables used to connect switches to implement relatively complex network topologies while providing greater chordal reach. The arrangement for connectivity in accordance with the present disclosure also can eliminate multiplexers/demultiplexers and wavelength division multiplexing lasers in a node to further reduce the component requirements and simplify connectivity solutions.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The present disclosure is described in greater detail below, with reference to the accompanying drawings, in which:

Fig. 1 is an illustration of a network organized according to a hierarchical three tier topology;

Fig. 2 is an illustration of a network organized according to a fat-tree topology;

Fig. 3 is an illustration of a network organized according to a folded Clos topology;

Fig. 4 is an illustration of a network organized according to a meshed ring topology;

Fig. 5 is an illustration of a network organized according to a three dimension flattened butterfly topology;

Fig. 6 is a diagram illustrating connectivity at a network node in accordance with an exemplary embodiment of the present disclosure;

Fig. 7 is a logical network topology diagram with five nodes; and

Fig. 8 is a physical network topology diagram with five nodes.

DETAILED DESCRIPTION OF THE INVENTION

Data center switches and routers can utilize fiber optical interconnections through their network interface ports. In accordance with the present disclosure, standard fiber optical connectors in conjunction with internal fiber optical interconnections and configurations that can be used to implement desired network topologies.

Fig. 4 shows a network 400 that is implemented in a meshed ring architecture, where each switch 402 has a direct connection with all of the other switches 402. In prior implementations of network 400, each connection was accomplished with one or more physical cables. Such a physical topology implementation is limited in terms of scalability, since the size is limited by the total number of switch ports available for interconnection for each switch through a physical cable.

Fig. 5 shows a network 500 organized as a three dimension flattened butterfly topology. This topology of network 500 can scale to large numbers of switch nodes 510 that can support a relatively large number of servers in a relatively large data center. Network 500 can be built using the same organization for switch nodes 510 for the entirety of network 500, and offers a flat network topology, higher bisection bandwidth, and low hop counts. However, previously implemented three dimension flattened butterfly architectures tend to have a high port count per switch, which tends to increase costs, and use long global connections, which tend to be relatively expensive and also add to implementation costs.

While the architectures illustrated in Figs. 4 and 5 are attractive for a data center network from the perspective of performance, the complicated connectivity and cabling make networks 400 and 500 difficult to implement in terms of a physical topology in a data center environment in practice. In addition to the complexity, the costs tend to be driven up by relatively expensive cabling used to implement the topology, which implementation is typically made more challenging with the typical cabling errors that occur during installation.

Fig. 6 illustrates connectivity for a network node 600 in accordance with an exemplary embodiment of the present disclosure. Network node 600 includes two sets 610, 620 of connector positions that are each labeled 1-23. Each of connector positions 1-23 in sets 610, 620 are suitable for being coupled to optical fibers to transfer optical signals in and out of network node 600. Sets 610, 620 represent connections for external connectivity using standard fiber optical pluggable cables, such as MTP cables, which in the embodiment of network node 600 can have 24 fibers. It should be understood that although the disclosed system and method is described using the example of a 24 fiber connector and cable, any type of fiber cable can be employed with the connectivity configuration of the present disclosure. For example, cables with 48 fibers can be employed with the connectivity configuration of the present disclosure.

Some or all of the network nodes in a datacenter network can, for example, be configured with the arrangement of network node 600. In such a configuration, each of the connector positions 1-23 is connected to the same numbered connector position in a connected node. So, for example, connector position 1 in set 610 is connected to connector position 1 in a connector of a node to which network node is directly physically connected. In such an instance, connector position 1 of set 610 receives a signal from a connector position 1 of a network node physically connected to network node 600 via set 610. Likewise, connector position 1 of set 620 transmits a signal to a network node physically connected to network node 600 via set 620. Since all the network nodes in this exemplary embodiment can be configured with the same connectivity arrangement of network node 600, connector positions 1 and 2 of each set 610, 620 are respectively reserved for direct, one way, single fiber connections between physically connected nodes.

Connector positions 3-6 in sets 610 and 620 illustrate a shifted or offset arrangement for communicating between nodes. This arrangement permits an intermediate node to passively forward an optical signal from an originating node to a receiving node using a standard fiber optic cable. An optical signal launched from connector position 4 in set 620 would arrive on connector position 4 of set 610 at an intermediate network node, and the signal would be output at connector position 3 of set 620 of the intermediate node. The optical signal would then arrive at connector position 3 of set 610 of a receiving node, so that the optical signal is effectively sent directly from a first node to a third node, skipping an intermediate node. This scenario is implemented in an opposite direction using connector positions 5 and 6 of sets 610 and 620. Thus, an optical signal launched from connector position 6 in set 610 will pass through an intermediately connected network node from connector position 6 in set 620 to connector position 5 in set 610 to land on connector position 5 in set 620 of a third node.

With the configuration of connector positions 1-6, a five node ring mesh network 700 can be constructed, as is illustrated in Fig. 7. Each node 710 is directly optically connected to an immediately adjacent node 710 on the ring via connector positions 1 and 2 in each set 610, 620 in each node 710. Each node 710 is also directly optically connected to a non-adjacent node 710 via connector positions 3-6 in each set 610, 620 in each node 710. The connections made using connector positions 1 and 2 are also physically direct connections, while the connections made using connector positions 3-6 are not physically direct. Accordingly, a distinction is made between a physical, direct connection and a logical or data path connection. The physical, direct connection has a direct, physical connection to another network node, such as with a connector cable. The logical or data path connection does not necessarily rely on direct, physical connection, and connected nodes need not be directly physically connected to each other. For example, a logical or data path connection may physically cross one or more nodes through several connector cables. Such a connection may be direct as between two nodes, as in the case of a chord connection in a chordal ring, and need not have a direct, physical connection, such as with a single connector cable, for implementation.

The physical cable connections for network 700 can be physically accomplished using five connector cables with six fibers each, in a physical ring topology, as illustrated in Fig. 8. Each node 810 in network 800 is configured with the connector arrangement of connector positions 1-6 in network node 600 (Fig. 6). Accordingly, each node passively passes an optical signal from connector position 4 to 3 and from connector position 6 to 5 to realize a direct optical connection to a non-adjacent, or non-physically connected node 810. Note that if the connections for the topology of network 700 were to be directly realized physically, ten cables would be used to interconnect all the nodes. With the connectivity configuration of the present disclosure, five cables in a ring connection in network 800 can be used to realize network 700 as a logical or data path connection topology.

Referring again to Fig. 6, additional multiple pass-through arrangements can be realized using standard 24 fiber cables with the configuration of connection positions 7-21. Connection positions 7-12 are shown as being single direction optical pathways, while connector positions 13-21 are shown as being bidirectional. Connection positions 7-12 are configured with offsets or position shifts to accommodate a two-node passive pass-through, in two different directions. Thus, using the arrangement of connection positions 1-12 to implement each network node in a network permits a seven node ring mesh network to be constructed using a physical ring connection topology, or an extension of networks 700, 800 by an additional two nodes.

It is noteworthy that such an extension of networks 700, 800 to seven nodes can be achieved with relative ease, since an additional two cables would be connected to the existing network nodes 810 to form a physical ring. Presuming that each node 810 was arranged to have the configuration of network node 600, such additional connections to two additional nodes would readily produce a logical seven node mesh ring topology configuration. If such an extension were contemplated for directly physically connected nodes in a network, an additional eight cables would be used to interconnect all the nodes, and each node would have six physical cable connections. Accordingly, the connectivity configuration of the present disclosure reduces the number of physical cables used, as well as simplifies network extensions.

In the above discussion, the optical pathways are described as being unidirectional. However, it is possible to use bidirectional techniques to further improve the efficiency of the disclosed connectivity configuration. For example, bidirectional pathways are implemented with circulators 602 in network node 600 using connection positions 13-21. Circulators 602 are bidirectional fiber constructs that have an input port and an output port to permit optical signals to be sent and received on a single optical fiber. A transmit QSFP 604 and a receive QSFP 604 are coupled to each circulator 602. Each of transmit QSFP 604 and receive QSFP 604 illustrated in network node 600 are specified as QSFP-LR4. The LR4 variant in transmit and receive QSFPs 604 includes four CWDM transmitters and receivers and an optical multiplexer/demultiplexer. The LR4 variant for QSFP permits four channels to be used with one fiber pair for transmit and receive. It is possible to use nominal QSFP configurations, e.g., without an optical multiplexer/demultiplexer, which would occupy additional fibers. In addition, or alternatively, multi-core fibers can be used with such a nominal QSFP configuration to permit the number of connector positions to be less than an implementation using single core fibers.

In the arrangement shown in network node 600, connector positions 13-16 provide bidirectional pass-through with three offsets or shifts. This arrangement permits circulator 602 on connector position 13 of set 620 to communicate with circulator 602 on connector position 16 of set 610 on a node that is four nodes away, or through three intermediate nodes. The optical signal provided at connector position 13 in set 620 thus transits three pass-through nodes, being offset or shifted one connector position for each node transited, and arrives at connector position 16 at the forth node. Accordingly, a direct optical connection between connector position 13 of a first node and connector position 16 of a fourth node is established, with the direct optical connection physically passing through three intermediate nodes. In addition, because the connections are made between circulators 602, the communication between connector position 13 on a first node and connector position 16 on a fourth node is bidirectional.

Connector positions 17-21 further expand on the connectivity configuration of network node 600 by offering a direct, bidirectional optical connection between a first node and a fifth node that passes through four intermediate nodes. In total, connector positions 1-21 in sets 610, 620 permit a direct optical connection with five adjacent nodes on either side of a given node with bidirectional communication. This configuration permits ring mesh network 400 illustrated in Fig. 4 to be constructed as a physical topology that uses eleven nodes that are each physically connected to two neighboring nodes 402 in a physical ring using eleven cables. Similarly, flattened butterfly network 500 can be constructed with a physical topology that uses greatly simplified cabling, where each TOR switch can have two cables for internal node connections, and four cables for external node connections to realize a three dimensional topology.

It should be understood that a greater than five node reach can be implemented for an extended topology configuration by expanding the number of connection positions in network node 600, for example. In addition, or alternately, a greater than five node reach can be implemented by coupling a packet switch or crosspoint switch to a node. The packet switch or crosspoint switch can receive traffic from the node in the network ring and redirect traffic back into the ring, which restarts a five node reach for that node.

The present disclosure provides an advantage in simplified cabling to realize complex topologies that can be extended and be maintained with relative ease. In addition, the use of circulators and/or reduced number of cables significantly reduces fiber count, leading to significant cost savings, to the point where complex topologies become significantly more practical to realize. Moreover, the nodes are not required to multiplex/demultiplex multiple signals to permit reduced fiber count and cable connections, leading to further reductions in complexity and cost. In addition, numerous desirable topologies can be practically realized without prohibitive costs. For example, chordal ring topologies, mesh topologies, torus topologies, Manhattan grid topologies and other desired topologies, each of two, three or arbitrary dimensions, can be constructed quickly, reliably and inexpensively to permit significant advancements in complex network construction and configuration.

The foregoing description has been directed to particular embodiments of the present disclosure. It will be apparent, however, that other variations and modifications may be made to the described embodiments, with the attainment of some or all of their advantages. The scope of the appended claims is therefore not to be limited to the particular embodiments described herein, and is intended to cover all such variations and modifications as come within the true spirit and scope of the present disclosure.

CLAIMS

What is claimed is:

1. A network node configured to be connected in a network, comprising:

a first set of connectors arranged in an ordered series;

a second set of connectors arranged in the ordered series;

at least two connectors in the first set being connected to at least two connectors in the second set to provide at least two pass-through connection pathways between the at least two connectors in the first set and the at least two connectors in the second set;

the at least two connectors in the first set being located in the ordered series at positions that are offset by at least one position in correspondence with the ordered series of the at least two connectors in the second set; and

a transmitter or receiver being connected to a connector in the first set or a connector in the second set at a position from which at least one of the at least two connectors is offset by the at least one position.

2. The network node according to claim 1, wherein the at least two pass-through connection pathways are each respectively configured to carry data in single and different directions between the at least two connectors in the first set and the at least two connectors in the second set.

3. The network node according to claim 1, wherein the at least two pass-through connection pathways are each respectively configured to carry data in single and same directions between the at least two connectors in the first set and the at least two connectors in the second set.

4. The network node according to claim 1, wherein the at least two connectors in one or both of the first set or the second set are located in consecutive positions in the ordered series.

5. The network node according to claim 1, further comprising:

a bidirectional optical device connected to a connector in the first set or a connector in the second set at a position from which at least one of the at least two connectors is offset by the at least one position.

6. The network node according to claim 1, further comprising:

at least three connectors in the first set being connected to at least three connectors in the second set to provide at least three pass-through connection pathways between the at least three connectors in the first set and the at least three connectors in the second set; and

the at least three connectors in the first set being located in the ordered series at positions that are offset by at least one position in correspondence with the ordered series of the at least three connectors in the second set.

7. The network node according to claim 6, wherein the at least three connectors in one or both of the first set or the second set are located in consecutive positions in the ordered series.

8. The network node according to claim 6, wherein each of the at least three pass-through connection pathways are configured to carry bidirectional data.

9. The network node according to claim 6, further comprising:

a bidirectional optical device connected to a connector in the first set or a connector in the second set at a position from which at least one of the at least three connectors is offset by the at least one position.

10. The network node according to claim 1, further comprising:

a plurality of the network nodes interconnected in a physical topology and a logical topology via at least some of the connectors of respective ones of the first set of connectors and the second set of connectors.

11. The network node according to claim 10, wherein the physical topology is a ring and the logical topology is a chordal ring.

12. The network node according to claim 10, wherein the physical topology is a q-dimensional torus ring, and the logical topology is a q-dimensional chordal ring.

13. The network node according to claim 10, wherein the physical topology is a q-dimensional Manhattan street topology, and the logical topology is a q-dimensional chordal path topology.

14. The network node according to claim 10, further comprising a switch connected to at least one network node for directing a signal from the at least one network node back to the at least one network node or at least another network node to thereby increase the reach of one or more network nodes in the network.

15. A method for interconnecting nodes on a network, comprising:

providing a network node with a first set of connectors arranged in an ordered series;

providing the network node with a second set of connectors arranged in the ordered series;

connecting at least two connectors in the first set to at least two connectors in the second set to provide at least two pass-through connection pathways between the at least two connectors in the first set and the at least two connectors in the second set;

arranging the at least two connectors in the first set to be located in the ordered series at positions that are offset by at least one position in correspondence with the ordered series of the at least two connectors in the second set; and

connecting a transmitter or receiver to a connector in the first set or a connector in the second set at a position from which at least one of the at least two connectors is offset by the at least one position.

16. The method according to claim 15, further comprising configuring respective ones of the at least two pass-through connection pathways to carry data in single and different directions between the at least two connectors in the first set and the at least two connectors in the second set.

17. The method according to claim 15, further comprising connecting a bidirectional optical device to a connector in the first set or a connector in the second set at a position from which at least one of the at least two connectors is offset by the at least one position.

18. The method according to claim 15, further comprising:

connecting at least three connectors in the first set to at least three connectors in the second set to provide at least three pass-through connection pathways between the at least three connectors in the first set and the at least three connectors in the second set; and

arranging the at least three connectors in the first set to be located in the ordered series at positions that are offset by at least one position in correspondence with the ordered series of the at least three connectors in the second set.

19. The method according to claim 18, further comprising arranging the at least three connectors in one or both of the

first set or the second set to be located in consecutive positions in the ordered series.

20. The method according to claim 18, further comprising configuring each of the at least three pass-through connection pathways to carry bidirectional data.

21. The method according to claim 18, further comprising connecting a bidirectional optical device to a connector in the first set or a connector in the second set at a position from which at least one of the at least three connectors is offset by the at least one position.

22. A network node configured to be connected in a network, comprising:

a first set of connectors arranged in an ordered series;

a second set of connectors arranged in the ordered series;

at least two connectors in the first set being connected to at least two connectors in the second set to provide at least two pass-through connection pathways between the at least two connectors in the first set and the at least two connectors in the second set;

the at least two connectors in the first set being located in the ordered series at positions that are offset by at least one position in correspondence with the ordered series of the at least two connectors in the second set; and

a bidirectional optical device connected to a connector in the first set or a connector in the second set at a position from which at least one of the at least two connectors is offset by the at least one position.

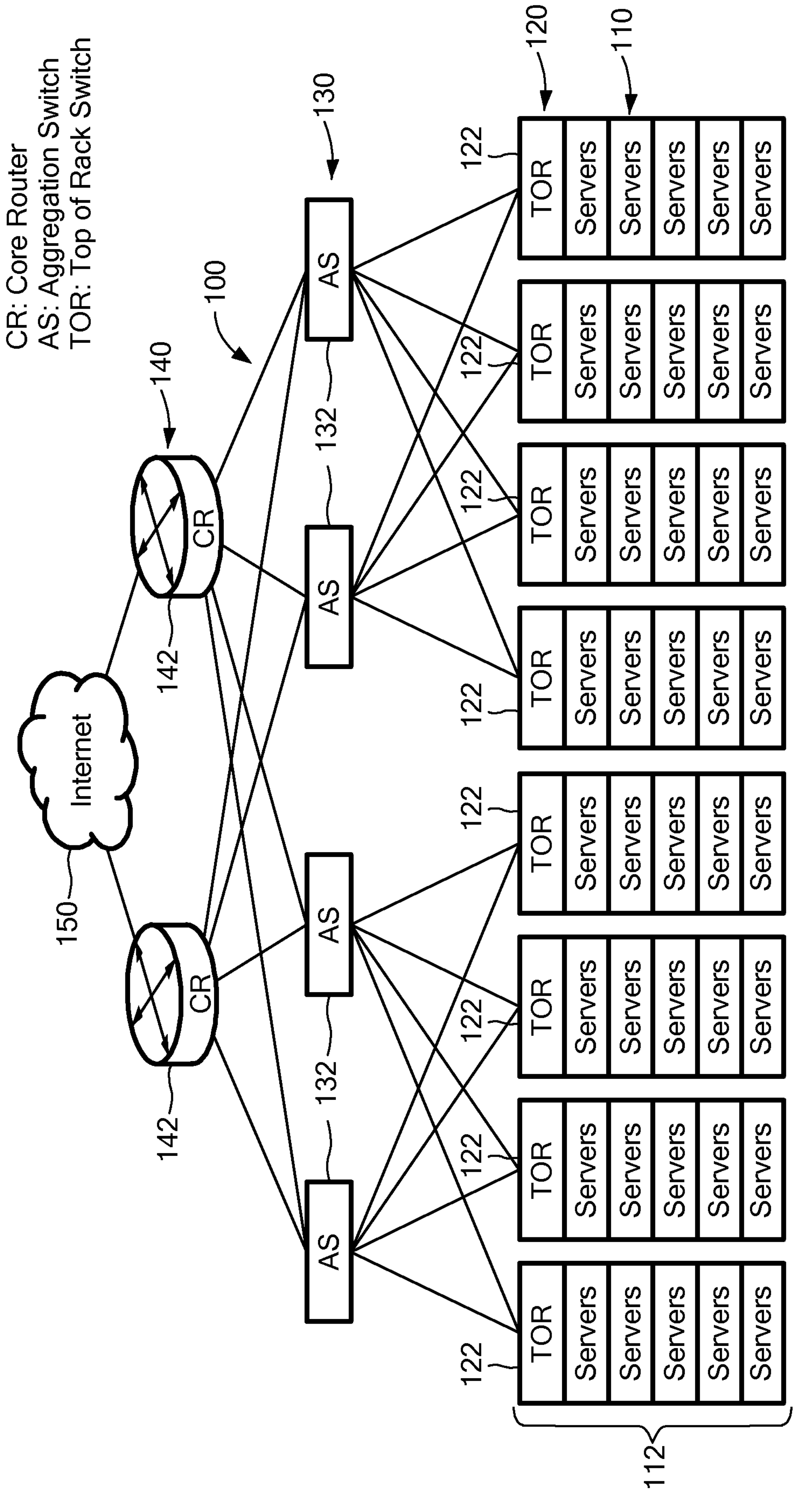

FIG. 1
PRIOR ART

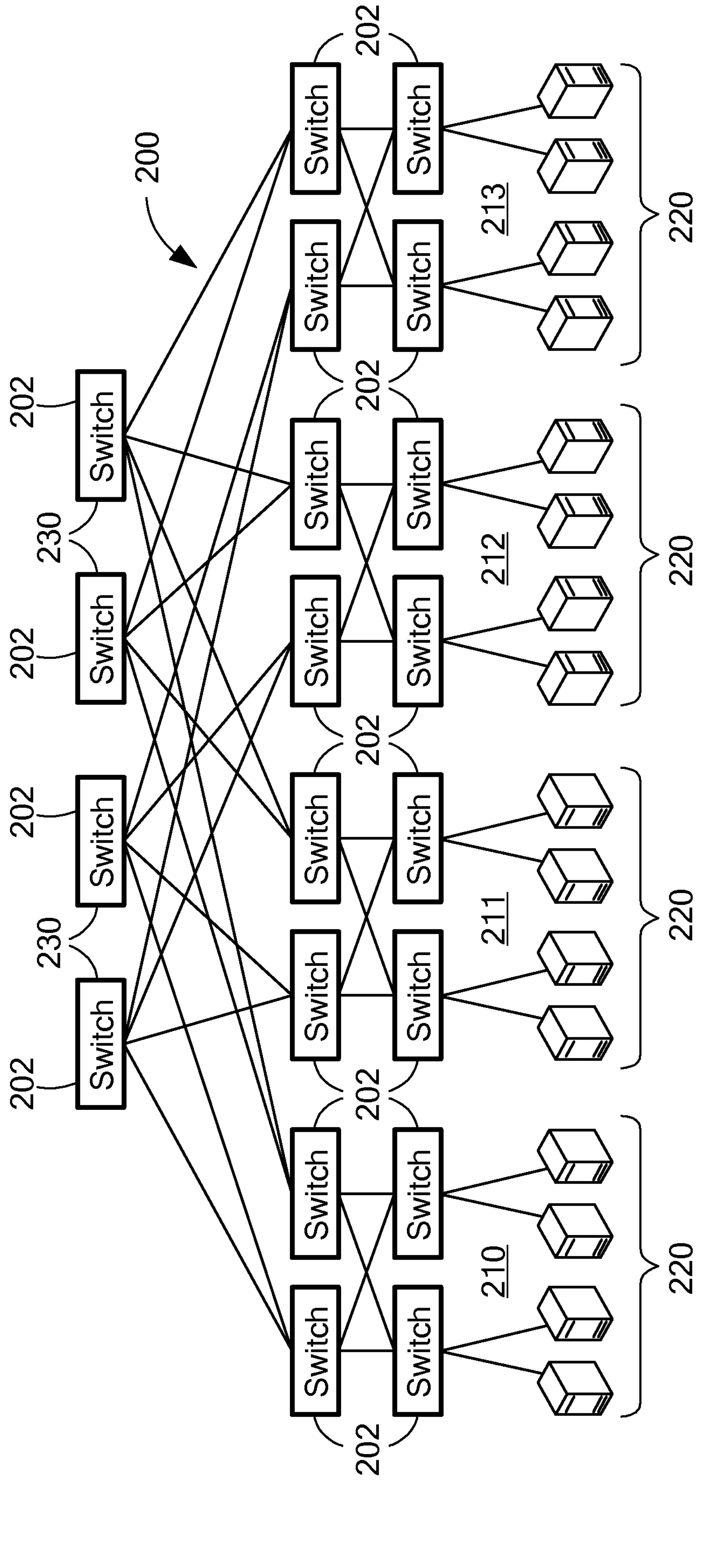

FIG. 2
PRIOR ART

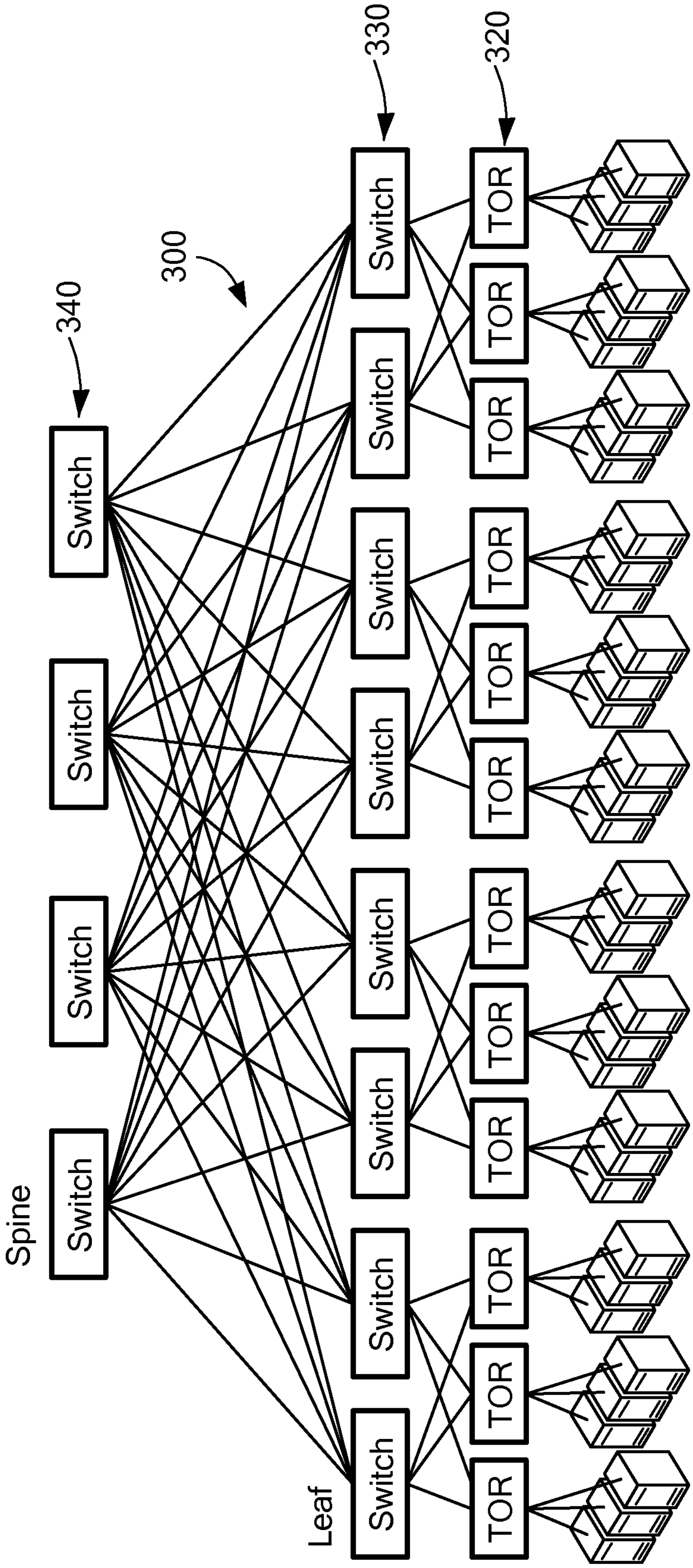

FIG. 3

PRIOR ART

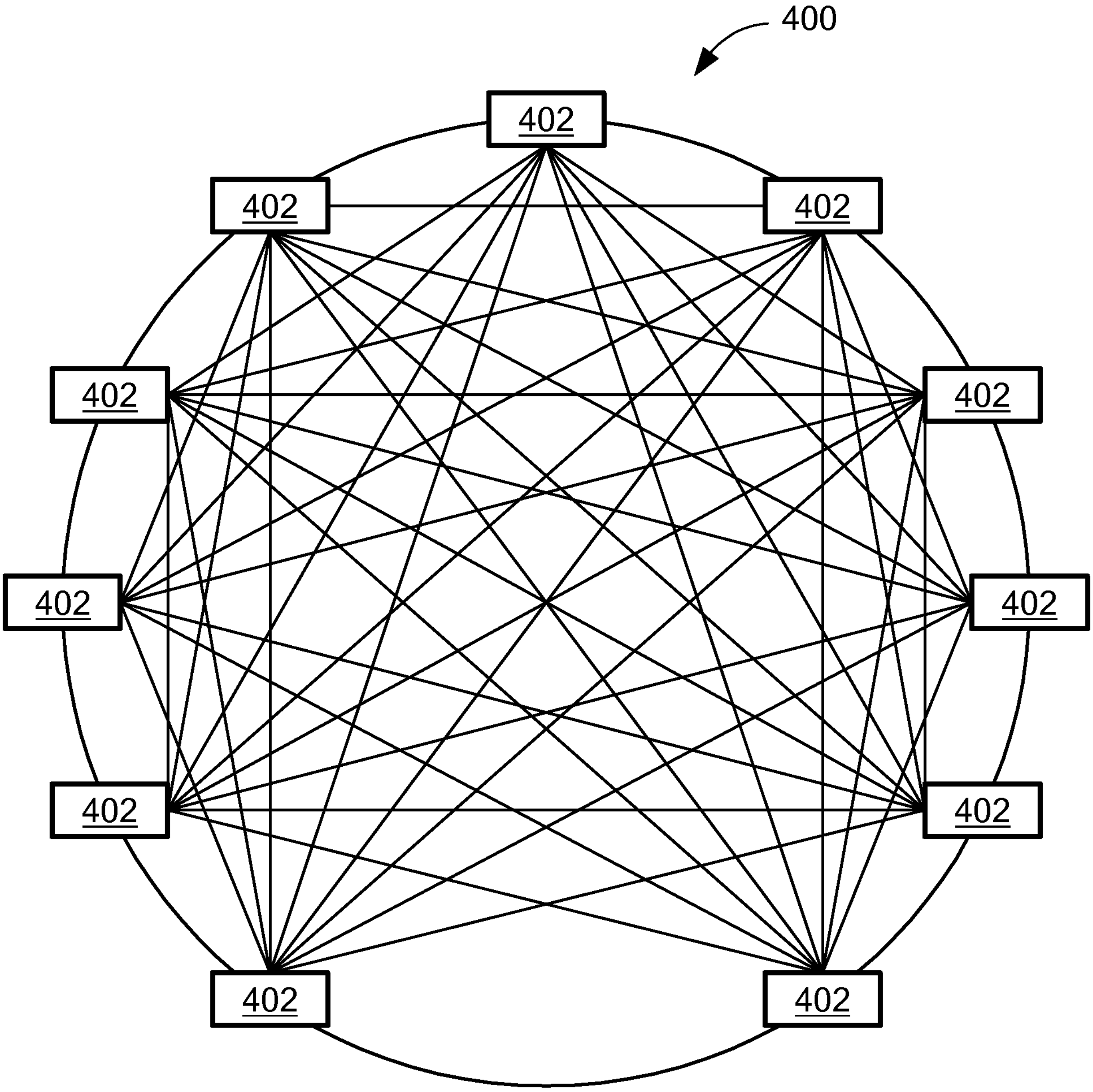

FIG. 4

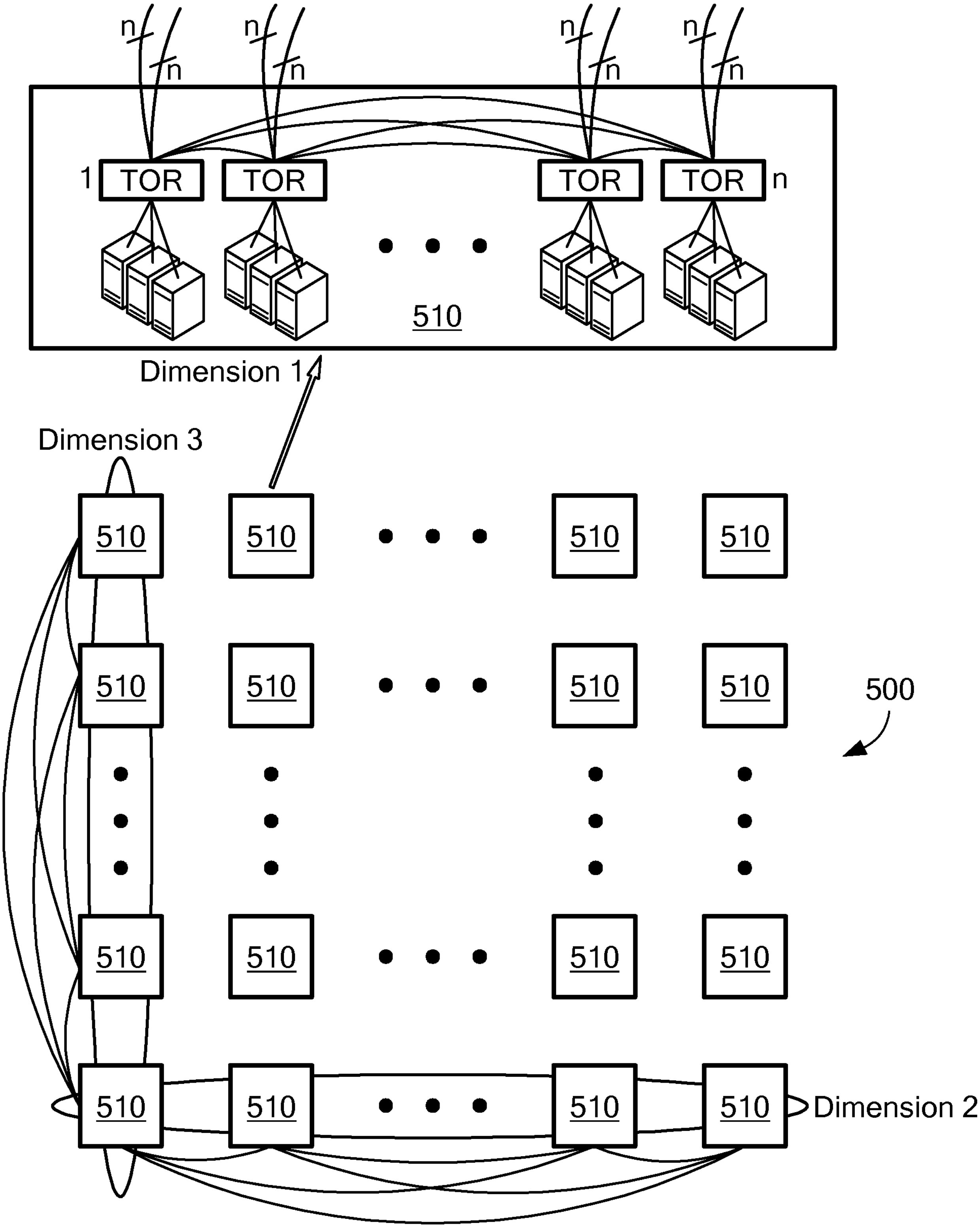
n
n
n
n
n
n
n
n
1
TOR
TOR
TOR
TOR
n
510
Dimension 1
Dimension 3
510
510
510
510
510
510
510
510
510
510
510
510
510
510
510
510
500
Dimension 2

FIG. 5

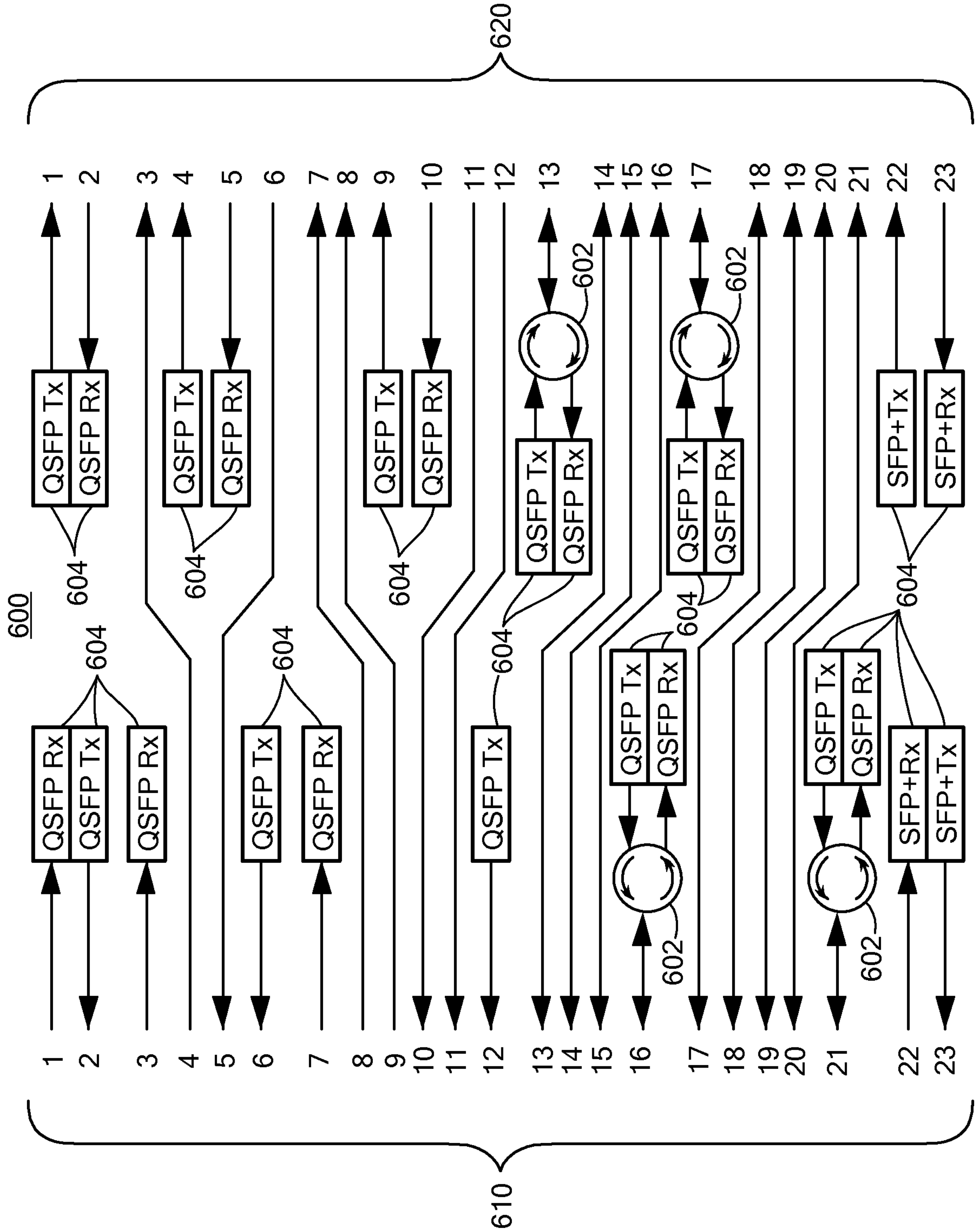
600
620
610
QSFP Tx
QSFP Rx
SFP+Tx
SFP+Rx
602
604
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

FIG. 6

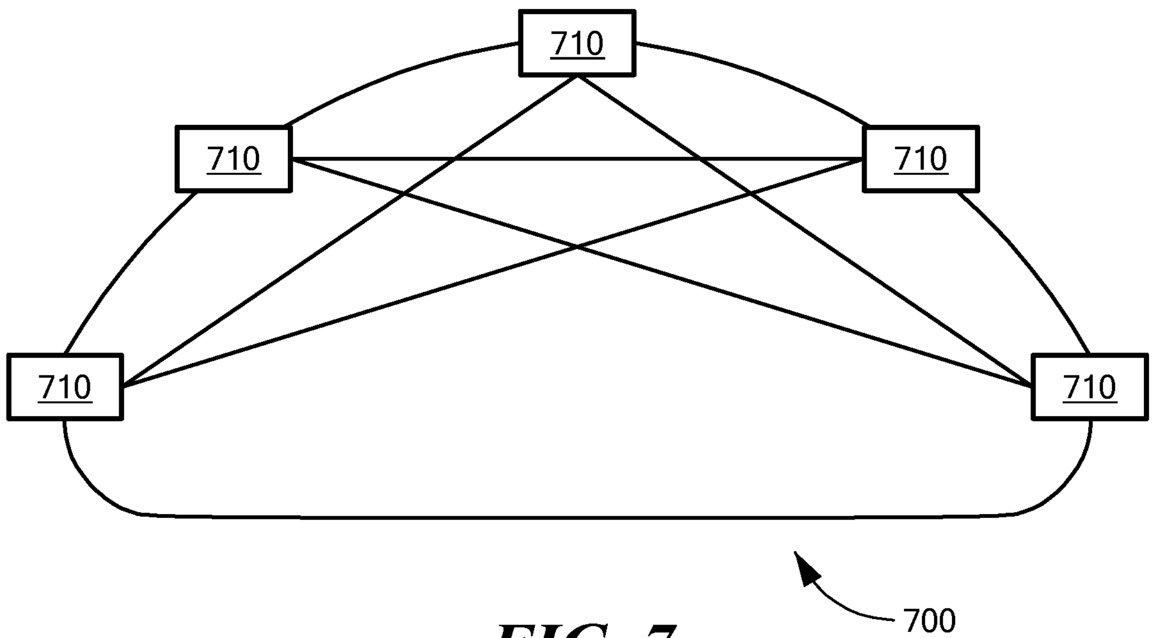

FIG. 7

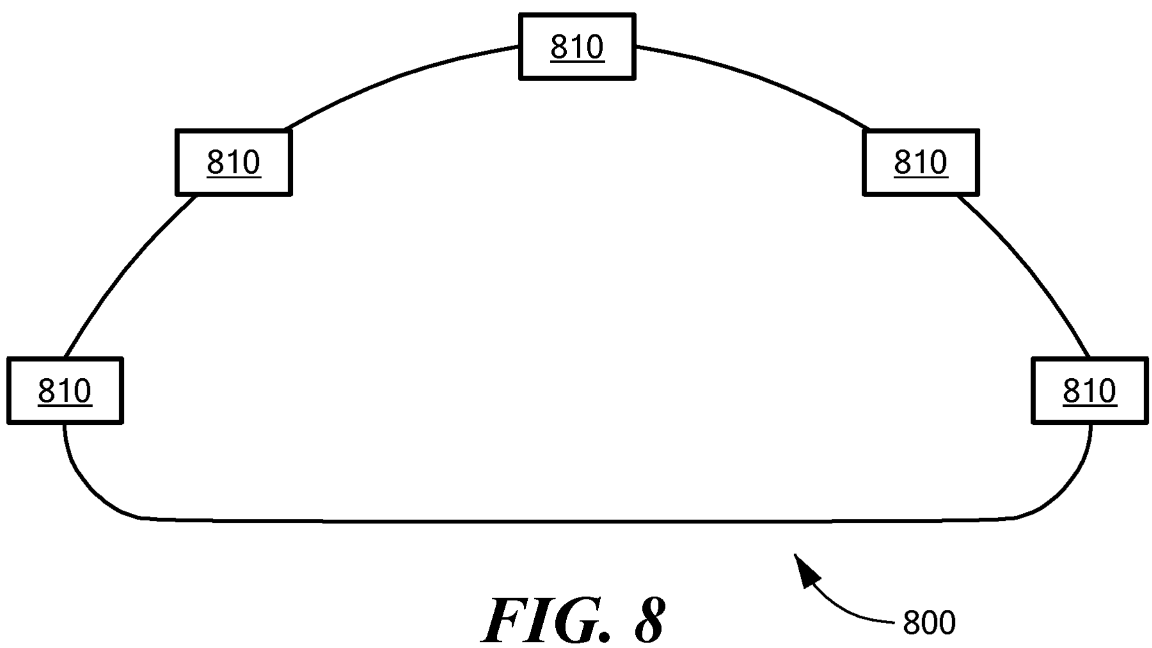

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/046165

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H04L 12/28 (2014.01)
CPC - H04L 12/42 (2014.09)
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(8) - H04L 12/28, H04L 29/14, H04L 12/66, H01R 3/00, H01R 13/60, H04L 12/56 (2014.01)
USPC - 370/223, 370/254, 370/352, 439/488, 439/540.1, 370/392

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - H04L 12/42, H04L 45/02, H04L 45/06, H04L 45/48, H04Q 1/13, H04L 49/1515, H04L 45/24, H04L 49/65 (2014.09)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Orbit, Google Patents, Google Scholar, Google.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2011/0026411 A1 (HAO) 03 February 2011 (03.02.2011), entire document	1-22
Y	US 2007/0154221 A1 (MCNICOL et al) 05 July 2007 (05.07.2007), entire document	1-22
Y	US 6,760,302 B1 (ELLINAS et al) 06 July 2004 (06.07.2004), entire document	3
Y	EP 0486203 A2 (ROCKWELL et al) 20 May 1992 (20.05.1992), entire document	4, 7, 19
Y	US 5,691,885 A (WARD et al) 25 November 1997 (25.11.1997), entire document	6-9, 18-21
Y	US 2012/0321309 A1 (BARRY et al) 20 December 2012 (20.12.2012), entire document	11-13
Y	US 7,433,593 B1 (GULLICKSEN et al) 07 October 2008 (07.10.2008), entire document	8, 20
A	US 2008/0162732 A1 (BALLEW) 03 July 2008 (03.07.2008), entire document	1-22
A	US 2013/0044588 A1 (KOGGE) 21 February 2013 (21.02.2013), entire document	1-22
A	US 2010/0254374 A1 (FORTIER) 07 October 2010 (07.10.2010), entire document	1-22
A	US 2013/0022047 A1 (NAKASHIMA et al) 24 January 2013 (24.01.2013), entire document	1-22

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"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)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"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
"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
"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
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
09 October 2014	03 NOV 2014

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774