

(51) International Patent Classification:
H04Q 11/00 (2006.01) *H04L 12/56* (2006.01)(21) International Application Number:
PCT/EP2008/068148(22) International Filing Date:
22 December 2008 (22.12.2008)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant (for all designated States except US): **TELEFONAKTIEBOLAGET LM ERICSSON** (publ) [SE/SE]; Torshamnsgaten 23, S-164 83 Stockholm (SE).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **ANDRIOLLI, Nicola** [IT/IT]; Via G. Moruzzi 1, I-56100 Pisa (IT). **CASTOLDI, Piero** [IT/IT]; Via G. Moruzzi 1, I-56100 Pisa (IT). **BIANCHI, Alberto** [IT/IT]; Via Milazzo 79, I-56128 Marina di Pisa (IT). **RAPONI, Pier Giorgio** [IT/IT]; Via Moruzzi 1, I-56100 Pisa (IT).(74) Agent: **PARKINSON, Neil Scott**; Ericsson Limited, Patent Unit Optical Networks, Unit 4 Middleton Gate, Guildford Business Park, Guildford, Surrey GU2 8SG (GB).

(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, BR, BW, BY, BZ, CA, CH, 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, IS, JP, KE, KG, KM, 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, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, 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, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

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

(54) Title: CONFIGURING SYNCHRONOUS OPTICAL SWITCHES

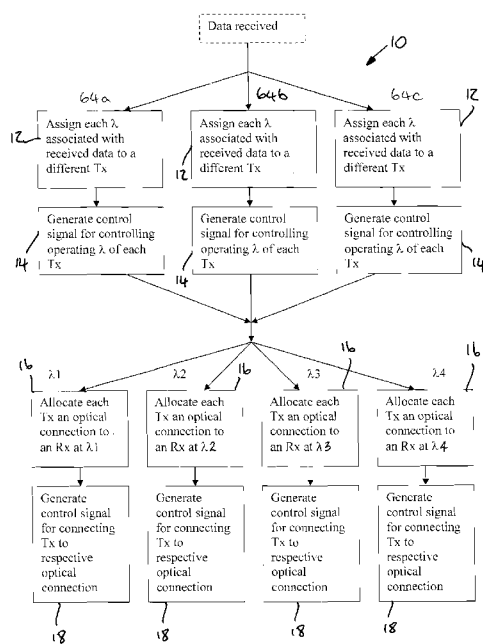


Fig. 1

(57) Abstract: A method (10) of configuring a synchronous optical switch to route received data cells. The synchronous optical switch comprises optical switch transmitter modules, each comprising tunable optical transmitters, optical switch receiver modules, each comprising optical receivers, and optical connections between the transmitter modules and receiver modules. For each optical switch transmitter module, the method: assigns (12) wavelengths associated with the received data cells to the transmitters such that each wavelength is assigned to a different transmitter; and generates (14) a control signal for controlling the operating wavelength of each transmitter. For each wavelength, the method: allocates (16) to each transmitter an optical connection such that each optical switch transmitter module has no more than one connection exiting it at said wavelength and each optical receiver module has no more than one connection entering it at said wavelength; and generates (18) a control signal for connecting each transmitter to the respective optical connection.

CONFIGURING SYNCHRONOUS OPTICAL SWITCHES**Field of the Invention**

The invention relates to a method of configuring a synchronous optical switch and
5 to a router comprising a synchronous optical switch.

Background of the Invention

The amount and data rate of traffic transmitted across optical communications
networks continues to increase and network routers will therefore be required to route data
10 at faster and faster rates, likely at data throughput rates in the range of tens or hundreds of
Terabits per second (Tb/s). Electronic interconnection networks currently used within
routers are approaching their fundamental operational limitations, particularly in terms of
their power density.

15 Optical packet switches have been proposed as a solution for geographic area
networks, where optical packets are transparently switched across several nodes of the
network before reaching the destination. However, the limited capabilities of optical
buffering and synchronization and issues related to the quality of transmission have
significantly hampered this solution. Nevertheless optical packet switching is emerging as
20 a feasible candidate to handle communications on smaller network scales where high
transmission and switching capacity is required [O. Liboiron-Ladouceur et al., "The Data
Vortex Optical Packet Switched Interconnection Network", JLT, Jul. 2008].

Summary of the Invention

25 It is an object to provide an improved method of configuring a synchronous optical
packet switch and to provide an improved router.

A first aspect of the present invention provides a method of configuring a
synchronous optical switch to route received data cells. The synchronous optical switch
30 comprises a first plurality of optical switch transmitter modules each comprising a second
plurality of tunable optical transmitters. The synchronous optical switch further comprises

a said first plurality of optical switch receiver modules each comprising a said second plurality of optical receivers. The synchronous optical switch further comprises a third plurality of optical connections between the said transmitter modules and the said receiver modules. The method comprises the steps:

- 5 a. for each optical switch transmitter module, assigning wavelengths associated with the received data cells to said transmitters such that each said wavelength is assigned to a different one of said transmitters;
- b. for each said optical switch transmitter module, generating a first control signal for controlling the operating wavelength of each said transmitter;
- 10 c. for each said wavelength, allocating to each transmitter assigned said wavelength one of said optical connections coupled to an optical receiver configured to receive said wavelength. The optical connections are allocated such that each optical switch transmitter module has no more than one connection exiting it at said wavelength and each optical receiver module has no more than one connection entering it at
15 said wavelength; and
- d. generating a second control signal for connecting each said transmitter to the respective said optical connection.

The method provides for efficient data routing across a synchronous optical switch.

- 20 The method allows for switch scalability in terms of the number of optical switch transmitter modules and optical switch receiver modules comprising the synchronous optical switch. The method may be used to configure a synchronous optical switch comprising a plurality of transmitter/receiver cards. The method may be used to configure multi-card modular wavelength division multiplexed (WDM) optical packet switches. In
25 the method, steps a. and c. can be specified to meet desired complexity and performance requirements.

- By assigning the wavelengths within the optical switch transmitter modules in one step and allocating the optical connections to the transmitters for each wavelength in a
30 separate step, the method has a much lower computational complexity than known single-steps scheduling algorithms. The method can therefore be used in connection with large switches which many known, high-performance scheduling algorithms cannot be used

with, since the known algorithms cannot perform the scheduling within the tight time constraints required by such switches.

In an embodiment, the method further comprises, prior to step a., storing received
5 data cells received for each said tunable optical transmitter according to wavelength and destination optical switch receiver module data associated with each data cell. In an embodiment, the received data cells are respectively stored in an input buffer associated with each said tunable optical transmitter. The input buffer may be partitioned into a number of virtual output queues equal to the said plurality of wavelengths multiplied by
10 the said plurality of optical switch receiver modules. The method comprises, for each said tunable optical transmitter, storing said received data cells in respective virtual output queues according to said wavelength and destination optical switch receiver module data.

In an embodiment, step a. comprises assigning said wavelengths to said
15 transmitters by:

- i. identifying the greatest number of cells stored at any of said wavelengths for any of said transmitters;
- ii. allocating the wavelength for which said greatest numbers of cells are stored to the said transmitter for which said cells were received;
- 20 iii. identifying the transmitter having the next greatest number of cells stored at any of said wavelengths for any of said transmitters;
- iv. determining whether the wavelength for which said next greatest number of cells are stored has previously been allocated to a said transmitter;
- v. if the said wavelength has not previously been allocated, allocating the wavelength
25 for which said next greatest numbers of cells are stored to the said transmitter for which said cells were received. If the said wavelength has previously been allocated, repeating steps iii. to v.; and
- vi. repeating steps iii. and v. until a different one of said wavelengths has been allocated to each of said transmitters.

In an embodiment, the method further comprises, for each tunable optical transmitter, counting the number of cells stored in each said virtual output queue for each of said plurality of wavelengths and storing the counted number of cells in a counter for each said wavelength. Step i. comprises identifying the greatest number of cells stored at
5 any of said wavelengths for any of said transmitters by identifying the counter having the largest number of counted cells.

In an alternative embodiment, step a. comprises assigning said wavelengths to said transmitters by:

- 10 i. identifying the oldest cell stored at any of said wavelengths for any of said transmitters;
- ii. allocating the wavelength for which said oldest cell is stored to the said transmitter for which said cells were received;
- iii. identifying the next oldest cell stored at any of said wavelengths for any of said
15 transmitters;
- iv. determining whether the wavelength for which said next oldest cell is stored has previously been allocated to a said transmitter;
- v. if the said wavelength has not previously been allocated, allocating the wavelength for which said next oldest cell is stored to the transmitter for which said cells were
20 received. If the said wavelength has previously been allocated, repeating steps iii. to v.; and
- vi. repeating steps iii. to v. until a different one of said wavelengths has been allocated to each of said transmitters.

25 In an embodiment, step a. is carried out simultaneously for each of said plurality of optical switch transmitter modules.

Step b. may further comprise generating a second control signal for transmitting information identifying the wavelength setting for each said transmitter for use in step c.

In an embodiment, in step c. said allocation to each transmitter of one of said optical connections comprises, for each said wavelength, considering the transmitters allocated said wavelength as a set of source nodes and considering the receivers configured to receive said wavelength as a set of destination nodes of a bipartite graph. A maximal matching scheduling algorithm is applied to find the best matching in the bipartite graph. The maximal matching scheduling algorithm may be an iterative maximal matching scheduling algorithm. The iterative maximal matching scheduling algorithm may comprise one of an iterative serial-line IP (iSLIP) matching algorithm, an iterative dual round-robin matching (DRRM) algorithm, and a parallel iterative matching (PIM) algorithm.

Step c. may be carried out simultaneously for each of said plurality of wavelengths.

When a further transmitter/receiver card, and thus an additional optical transmitter module and optical receiver module, is added to the switch the impact on the total complexity of the method is limited, mainly due to this parallel implementation of each of steps a. and c.

The steps of the method may be completed within a single cell time. The steps of the method may alternatively be completed over a plurality of subsequent cell times. By assigning the wavelengths within the optical switch transmitter modules in one step and allocating the optical connections to the transmitters for each wavelength in a separate step, the method may thus be completed over a plurality of subsequent cell times ("pipelined"). As a result, more complex algorithms can be adopted within each step of the method.

25

A second aspect of the invention comprises a router comprising a synchronous optical switch. The synchronous optical switch comprises: a switch control unit; a first plurality of optical switch transmitter modules each comprising a second plurality of tunable optical transmitters and a module control unit; a said first plurality of optical switch receiver modules each comprising a said second plurality of optical receivers; and a third plurality of optical connections between the said transmitter modules and the said

30

receiver modules. Each said module control unit is arranged to assign wavelengths associated with received data cells to the said transmitters of its respective said module. The wavelengths are assigned such that each said wavelength is assigned to a different one of said transmitters. Each said module control unit is further arranged to generate a first
5 control signal for controlling the wavelength setting of each said transmitter. The switch control unit is arranged to, for each said wavelength, allocate to each transmitter assigned said wavelength one of said optical connections coupled to an optical receiver configured to receive said wavelength. The optical connections are allocated such that each optical switch transmitter module has no more than one connection exiting it at said wavelength
10 and each optical receiver module has no more than one connection entering it at said wavelength. The switch control unit is further arranged to generate a second control signal for connecting each said transmitter to the respective said optical connection.

A computer program product comprising program code for performing any of
15 the above method steps.

A data carrier having computer readable instructions embodied therein for providing access to resources available on a router. The computer readable instructions comprise instructions to cause the router to perform any of the above method steps.

20

Brief description of the drawings

Figure 1 is a flow diagram of a method of configuring a synchronous optical switch according to a first embodiment of the invention;

Figure 2 (a) is a flow diagram of a first set of method steps of assigning each
25 wavelength associated with received data to a different transmitter of the method of Figure 1, and (b) is a flow diagram of a second set of method steps of assigning each wavelength associated with received data to a different transmitter of the method of Figure 1;

Figure 3 is a schematic representation of part of a synchronous optical switch suitable for being configured using the method of Figure 1;

30 Figure 4 is a schematic representation of the step of storing received data cells in input buffer virtual output queues (VOQs) of the method of Figure 1;

Figure 5 is a schematic representation of the step of counting the number of cells stored in the virtual output queues (VOQs) for each wavelength of the method of Figure 1;

Figure 6 is a schematic representation of the step of allocating each wavelength associated with the received data cells to a different transmitter (Tx) of the method of

5 Figure 1;

Figure 7 is (a) a schematic representation of the step of allocating each transmitter at one wavelength (λ_1) optical connections to the respective receivers (Rx) configured to receive that wavelength, and (b) a bi-partite graph representing the transmitters and receivers at that wavelength; and

10 Figure 8 is a schematic representation of a router according to a second embodiment of the invention.

Description of embodiments of the invention

Referring to Figures 1 to 7, a first embodiment of the invention provides a method
15 10 of configuring a synchronous optical switch 60.

A synchronous optical switch 60 suitable for being configured according to the method 10 is shown in part in Figures 3 and 7 and comprises a first plurality (three in this example) of optical switch transmitter modules 64a, 64b, 64c and a corresponding plurality
20 (three) of optical switch receiver modules 70. Each transmitter module 64a, 64b, 64c comprises a second plurality (four in this example) of tunable optical transmitters 66. Each receiver module 70 comprises a corresponding plurality (four) of fixed optical receivers 72. The tunable optical transmitters 66 and optical receivers 72 are connected via an optical backplane 76 comprising a third plurality of optical connections 74. The number of
25 optical connections 74 is equal to the number of transmitter modules 64a, 64b, 64c (C) multiplied by the number of tunable optical transmitters 66 (L), and in this example equals twelve optical connections 74 (only five are shown in the drawings for reasons of clarity).

The synchronous optical switch 60 is configured to receive data cells to be routed.
30 Each data cell is provided with a header identifying the tunable optical transmitter 66 that it is to be routed through, the wavelength that it is to be routed on and the receiver module

70 to which it is to be routed. The synchronous optical switch 60 is an optical packet switch which routes data in packets, a set number of packets, equal to the number of tunable optical transmitters 66, being routed during a specified time slot.

5 Referring to Figures 1 and 2(a), in the method 10 of configuring a synchronous optical switch 60 data cells received by each tunable optical transmitter 66 in each transmitter module 64a, 64b, 64c are stored 20 in input buffer virtual output queues (VOQs) 62 associated with each tunable optical transmitter 66. Each tunable optical transmitter has CxL VOQs 62, i.e. twelve VOQs, associated with it in which the received
10 data cells are stored according to the wavelength (λ_{1-4}) on which they are to be routed and according to the receiver module (c_{1-3}) 70 to which they are to be routed, as illustrated in Figure 4.

In the method 10, the number of received data cells stored in each VOQ 62 is
15 counted and the number of received data cells at each wavelength (λ_{1-4}) is stored in a counter 63 for each wavelength for each tunable optical transmitter 66a-d, as illustrated in Figure 5.

Referring to Figure 6, for each transmitter module 64a, 64b, 64c, the method 10
20 assigns 12 the wavelengths associated with the received data cells to the tunable optical transmitters 66a-d such that each wavelength (λ_{1-4}) is assigned to a different tunable optical transmitter 66a-d. The method 10 performs the wavelength assignment to the tunable optical transmitters 66a-d simultaneously for each of the transmitter modules 64a, 64b, 64c in the switch 60.

25

The wavelength assignment 12 is performed as follows, as illustrated in Figures 2(a) and 6. The method 10 identifies 24 the counter 63 with the highest count, in this example 20. The counter with the highest count is associated with wavelength λ_1 . λ_1 is then allocated 26 to the tunable optical transmitter 66c with which the counter is associated
30 and for which the highest counted number of cells were received, as indicated by the solid

line 65c in Figure 6. This tunable optical transmitter 66c will therefore transmit a packet of data cells at λ_1 and the received data cells at $\lambda_{2,4}$ will not be transmitted by this tunable optical transmitter 66c during the time slot for which the switch 10 is currently being configured (as indicated by the dashed lines).

5

The method 10 then identifies 28 the counter 63 with the next highest count, in this example 19. The counter with the next highest count is associated with wavelength λ_3 . A check 30 is made to determine whether λ_3 has been previously allocated to a tunable optical transmitter 66. λ_3 has not previously been allocated so it is allocated to the tunable optical transmitter 66d with which the counter is associated and for which the cells were received, as indicated by the solid line 65d in Figure 6. This tunable optical transmitter 66d will therefore transmit a packet of data cells at λ_3 and the received data cells at $\lambda_{1,2,4}$ will not be transmitted by this tunable optical transmitter 66d during the time slot for which the switch 10 is currently being configured.

15

The method 10 then checks 34 whether all of the wavelengths have been allocated to a tunable optical transmitter 66. Two wavelengths remain to be allocated and the method therefore returns to identifying 28 the counter 63 with the next highest count, which in this example is 16. The counter with the next highest count is associated with wavelength λ_4 . A check 30 is made to determine whether λ_4 has been previously allocated to a tunable optical transmitter 66. λ_4 has not previously been allocated so it is allocated to the tunable optical transmitter 66a with which the counter is associated and for which the cells were received, as indicated by the solid line 65a in Figure 6. This tunable optical transmitter 66d will therefore transmit a packet of data cells at λ_4 and the received data cells at λ_{1-3} will not be transmitted by this tunable optical transmitter 66a during the time slot for which the switch 10 is currently being configured.

The method 10 then checks 34 whether all of the wavelengths have been allocated to a tunable optical transmitter 66. One wavelength remains to be allocated and the method therefore returns to identifying 28 the counter 63 with the next highest count,

30

which in this example is 15. The counter with the next highest count is associated with wavelength λ_4 . A check 30 is made to determine whether λ_4 has been previously allocated to a tunable optical transmitter 66. λ_4 has previously been allocated so the method 10 reverts to identifying 28 with the next highest count 63, which in this example is 14. The

5 counter with the next highest count is associated with wavelength λ_2 . A check 30 is made to determine whether λ_2 has been previously allocated to a tunable optical transmitter 66. λ_2 has not previously been allocated so it is allocated to the tunable optical transmitter 66b with which the counter is associated and for which the cells were received, as indicated by the solid line 65b in Figure 6. This tunable optical transmitter 66b will therefore transmit a

10 packet of data cells at λ_2 and the received data cells at $\lambda_{1,3,4}$ will not be transmitted by this tunable optical transmitter 66b during the time slot for which the switch 10 is currently being configured.

The allocation of the wavelengths to the transmitters 66 is performed using an

15 algorithm which selects the longest queue. An example of a suitable algorithm is:

```

queue_length[n][l] is a matrix containing the cell count for transmitter n
(n goes from 1 to L) that want to be transmitted over wavelength l (l goes from 1
to L)
20 temp_vector=sort( queue_length[n][l] );
for each element in temp_vector:
    if(transmitter n is unassigned):
        transmitter n is assigned wavelength l;
    endif
25 endfor

```

The wavelengths may alternatively be allocated according to cell age, as illustrated in Figure 2(b). The allocation of wavelengths proceeds in the same manner as described above, with the modification that instead of identifying the counter with the highest count,

30 the method 10 identifies the oldest cell and allocates the wavelength associated with that cell to the tunable optical transmitter 66 for which the cell was received.

Once all of the wavelengths have been allocated to a different one of the transmitters 66, a control signal is generated for controlling the operating wavelengths of the transmitters 66, to cause the transmitters to tune to the wavelengths allocated to them.

5

Each of the transmitters 66 in each of the transmitter modules 64a, 64b, 64c now has a wavelength allocated to it, for transmitting the received data cells in its VOQs 62 at its allocated wavelength. The method 10 now proceeds to configuring the optical back plane 76, to allocate 16 each transmitter 66 a connection 74 to an optical receiver 62
10 configured to receive at the wavelength allocated to the respective transmitter 66. The optical connections 74 are allocated such that each optical switch transmitter module 64a, 64b, 64c has no more than one connection 74 exiting it at each wavelength and each optical receiver module 70 has no more than one connection entering it at each wavelength, as follows.

15

In the method 10, the tunable optical transmitters 66 that have been allocated a selected wavelength, for example λ_1 , are considered as a set of source nodes 78a and the optical receivers 62 configured to receive that same wavelength (λ_1) are considered as a set of destination nodes 78b in a bipartite graph 78, as shown in Figure 7(b).

20

The method 10 applies an iterative maximal matching scheduling algorithm to find the best matching in the bipartite graph 78. In this example, the iterative maximal matching scheduling algorithm used is the well known iterative serial-line IP (iSLIP) matching algorithm (see for example McKeown, N., "The iSLIP scheduling algorithm for
25 input-queued switches," IEEE/ACM Trans. Netw., vol.7, no.2, pp.188–201, Apr. 1999). It will be appreciated that other scheduling algorithms may alternatively be use, such as an iterative dual round-robin matching (DRRM) algorithm, or a parallel iterative matching (PIM) algorithm, both of which are also well known as scheduling algorithms.

30

Referring to Figure 7(a), the iSLIP algorithm schedules the connections between the tunable optical transmitters 66 at λ_1 and the optical receivers 72 configured to receive at λ_2 , allocating optical connections 74 through the optical backplane 76 as follows: the

tunable optical transmitter 66 at λ_1 in the first transmitter module 64a is allocated the connection 74a to the optical receiver 72 at λ_1 in the first receiver module 70a; the tunable optical transmitter 66 at λ_1 in the second transmitter module 64b is allocated the connection 74b to the optical receiver 72 at λ_1 in the third receiver module 70c; and the
5 tunable optical transmitter 66 at λ_1 in the third transmitter module 64c is allocated the connection 74c to the optical receiver 72 at λ_1 in the second receiver module 70b. The best matching is summarized in the bipartite graph representation of the λ_1 tunable optical transmitters 66 and optical receivers 72.

10 The method 10 simultaneously schedules the tunable optical transmitters 66 at λ_2 , λ_3 and λ_4 and the optical receivers 72 configured to receive at λ_2 , λ_3 and λ_4 allocating optical connections 74 through the optical backplane 76 for each wavelength.

The method 10 then generates a second control signal to configure the optical
15 connections 74 within the synchronous optical switch 60, as allocated, to connect each tunable optical transmitter 66 to a respective optical connection 74.

The synchronous optical switch 60 is now configured to route received data cells at each of the four wavelengths.

20

Referring to Figure 8, a second embodiment of the invention provides a router 80 comprising a synchronous optical switch 60. The synchronous optical switch 60 is of the same type as shown in Figures 3 and 7, but is here shown in more detail.

25 The synchronous optical switch 60 comprises a switch control unit 82, three optical switch transmitter modules 64a, 64b, 64c, three optical switch receiver modules 70, and an optical backplane 76 providing twelve optical connections (not shown in Figure 8).

Each transmitter module 64a, 64b, 64c comprises four tunable optical transmitters 66 and a transmitter module control unit 68. Each optical switch receiver module 70 comprises four optical receivers.

5 Each transmitter module control unit 68 is arranged to assign wavelengths associated with received data cells to the tunable optical transmitters within its respective transmitter module 64a, 64b, 64c, according to the method 10 as described above. Each transmitter module control unit 68 is further operable to generate a control signal for controlling the wavelength setting of each tunable optical transmitter 66 within its
10 respective transmitter module 64a, 64b, 64c.

The switch control unit 82 is arranged to configure the optical back plane 76, to allocate each transmitter 66 a connection 74 to an optical receiver 62 configured to receive at the wavelength allocated to the respective transmitter 66. The optical connections 74 are
15 allocated such that each optical switch transmitter module 64a, 64b, 64c has no more than one connection 74 exiting it at each wavelength and each optical receiver module 70 has no more than one connection entering it at each wavelength, according to the method 10 as described above.

20 The switch control unit 82 is further arranged to generate a control signal to configure the optical connections 74 within the synchronous optical switch 60, as allocated, to connect each tunable optical transmitter 66 to a respective optical connection 74.

25 Various modifications may be made to the described embodiments without departing from the scope of the invention. In particular, the method may be used to configure a synchronous optical switch having a different number of optical transmitter modules and optical receiver modules to that described, and each module may respectively have a different number of tunable optical transmitters and optical receivers to that
30 described. It will be appreciated that if the number of tunable optical transmitters and optical receivers is changed then the number of wavelengths and optical connections

through the backplane will correspondingly change. It will also be appreciated that the method may be applied to a synchronous optical switch having a different number of optical transmitter modules and optical receiver modules, but that the method will only act on the number of optical transmitter modules for which there is a corresponding number of receiver modules; if, for example, there are more optical receiver modules than optical transmitter modules, the method will only be applied to a subset of optical receiver modules equal to the number of optical transmitter modules. The person skilled in the art will also appreciate that the optical transmitter modules and optical receiver modules are only shown as being physically separate for reasons of clarity of the drawings, and they may in fact be provided adjacently, within a single transmitter/receiver card.

Where it is described that the wavelength allocation occurs simultaneously for each optical transmitter module it will be appreciated that the allocation may alternatively take place serially. Similarly, where the allocation of optical connections is described as occurring simultaneously for each wavelength it may alternatively occur serially. The received data cells may be stored in a different manner to that described.

The method is described as being applied to received data cells within a single cell time, however the method steps may be pipelined, such that the method is implemented over two or more cell times, the routing of data at time t may take place based on the cells received at time $t-2t$, i.e. at 2 cell times earlier.

CLAIMS

1. A method of configuring a synchronous optical switch to route received data cells, the synchronous optical switch comprising a first plurality of optical switch transmitter modules each comprising a second plurality of tunable optical transmitters, a said first plurality of optical switch receiver modules each comprising a said second plurality of optical receivers, and a third plurality of optical connections between the said transmitter modules and the said receiver modules, the method comprising the steps:
 - a. for each optical switch transmitter module, assigning wavelengths associated with the received data cells to said transmitters such that each said wavelength is assigned to a different one of said transmitters;
 - b. for each said module, generating a first control signal for controlling the operating wavelength of each said transmitter;
 - c. for each said wavelength, allocating to each transmitter assigned said wavelength one of said optical connections coupled to an optical receiver configured to receive said wavelength, such that each optical switch transmitter module has no more than one connection exiting it at said wavelength and each optical receiver module has no more than one connection entering it at said wavelength; and
 - d. generating a second control signal for connecting each said transmitter to the respective said optical connection.
2. A method as claimed in claim 1, wherein the method further comprises, prior to step a., for each tunable optical transmitter storing said received data cells according to wavelength and destination optical switch receiver module data associated with each data cell.
3. A method as claimed in claim 2, wherein the received data cells are stored in an input buffer, the input buffer being partitioned into a number of virtual output queues equal to the said plurality of wavelengths multiplied by the said plurality of

optical switch receiver modules, and the method comprises storing said received data cells in respective virtual output queues according to said wavelength and destination optical switch receiver module data.

4. A method as claimed in claims 2 or 3, wherein step a. comprises assigning said wavelengths to said transmitters by:
 - i. identifying the greatest number of cells stored at any of said wavelengths for any of said transmitters;
 - ii. allocating the wavelength for which said greatest numbers of cells are stored to the respective said transmitter;
 - iii. identifying the transmitter having the next greatest number of cells stored at any of said wavelengths for any of said transmitters;
 - iv. allocating the wavelength for which said next greatest numbers of cells are stored to the respective said transmitter, unless the said wavelength has already been allocated to another transmitter; and
 - v. repeating steps iii. and iv. until a different one of said wavelengths has been allocated to each of said transmitters.
5. A method as claimed in claim 4, wherein the method further comprises, for each tunable optical transmitter, counting the number of cells stored in each said virtual output queue for each of said plurality of wavelengths and storing the counted number of cells in a counter for each said wavelength, and step i. comprises identifying the greatest number of cells stored at any of said wavelengths for any of said transmitters by identifying the counter having the largest number of counted cells.
6. A method as claimed in any of claims 3 to 5, step a. is implemented using a select-longest algorithm.

7. A method as claimed in claims 2 or 3, wherein step a. comprises assigning said wavelengths to said transmitters by:
 - i. identifying the oldest cell stored at any of said wavelengths for any of said transmitters;
 - ii. allocating the wavelength for which said oldest cell is stored to the respective said transmitter;
 - iii. identifying the next oldest cell stored at any of said wavelengths for any of said transmitters;
 - iv. allocating the wavelength for which said next oldest cell is stored to the respective said transmitter, unless the said wavelength has already been allocated to another transmitter; and
 - v. repeating steps iii. and iv. until a different one of said wavelengths has been allocated to each of said transmitters.
8. A method as claimed in any preceding claim, wherein step a. is carried out simultaneously for each of said plurality of optical switch transmitter modules.
9. A method as claimed in any preceding claim, wherein step b. further comprises generating a second control signal for transmitting information identifying the wavelength setting for each said transmitter for use in step c.
10. A method as claimed in any preceding claim, wherein in step c. said allocation to each transmitter of one of said optical connections comprises, for each said wavelength, considering the transmitters allocated said wavelength as a set of source nodes of a bipartite graph and considering the receivers configured to receive said wavelength as a set of destination nodes of a bipartite graph and applying a maximal matching scheduling algorithm to find the best matching in the bipartite graph. In an embodiment, the maximal matching scheduling algorithm is an iterative maximal matching scheduling algorithm. In an embodiment, the iterative maximal matching scheduling algorithm comprises one of an iterative

serial-line IP (iSLIP) matching algorithm, an iterative dual round-robin matching (DRRM) algorithm, and a parallel iterative matching (PIM) algorithm.

11. A method as claimed in claim 10, wherein the maximal matching scheduling algorithm is an iterative maximal matching scheduling algorithm.
12. A method as claimed in claim 11, wherein the iterative maximal matching scheduling algorithm comprises one of an iterative serial-line IP (iSLIP) matching algorithm, an iterative dual round-robin matching (DRRM) algorithm, and a parallel iterative matching (PIM) algorithm.
13. A method as claimed in any preceding claim, wherein step c. is carried out simultaneously for each of said plurality of wavelengths.
14. A router comprising a synchronous optical switch comprising:
 - a switch control unit;
 - a first plurality of optical switch transmitter modules each comprising a second plurality of tunable optical transmitters and a module control unit;
 - a said first plurality of optical switch receiver modules each comprising a said second plurality of optical receivers; and
 - a third plurality of optical connections between the said transmitter modules and the said receiver modules,each said module control unit being arranged to assign wavelengths associated with received data cells to the said transmitters of its respective said module, such that each said wavelength is assigned to a different one of said transmitters, and to generate a first control signal for controlling the wavelength setting of each said transmitter, and
the switch control unit being arranged to, for each said wavelength, allocate to each transmitter assigned said wavelength one of said optical connections coupled to an optical receiver configured to receive said wavelength, such that each optical switch transmitter module has no more than one connection exiting

it at said wavelength and each optical receiver module has no more than one connection entering it at said wavelength, and to generate a second control signal for connecting each said transmitter to the respective said optical connection.

15. A computer program product comprising program code for performing the method of any of claims 1 to 13.
16. A data carrier having computer readable instructions embodied therein for providing access to resources available on a router, the computer readable instructions comprising instructions to cause the router to perform the method as claimed in any of claims 1 to 13.

1/8

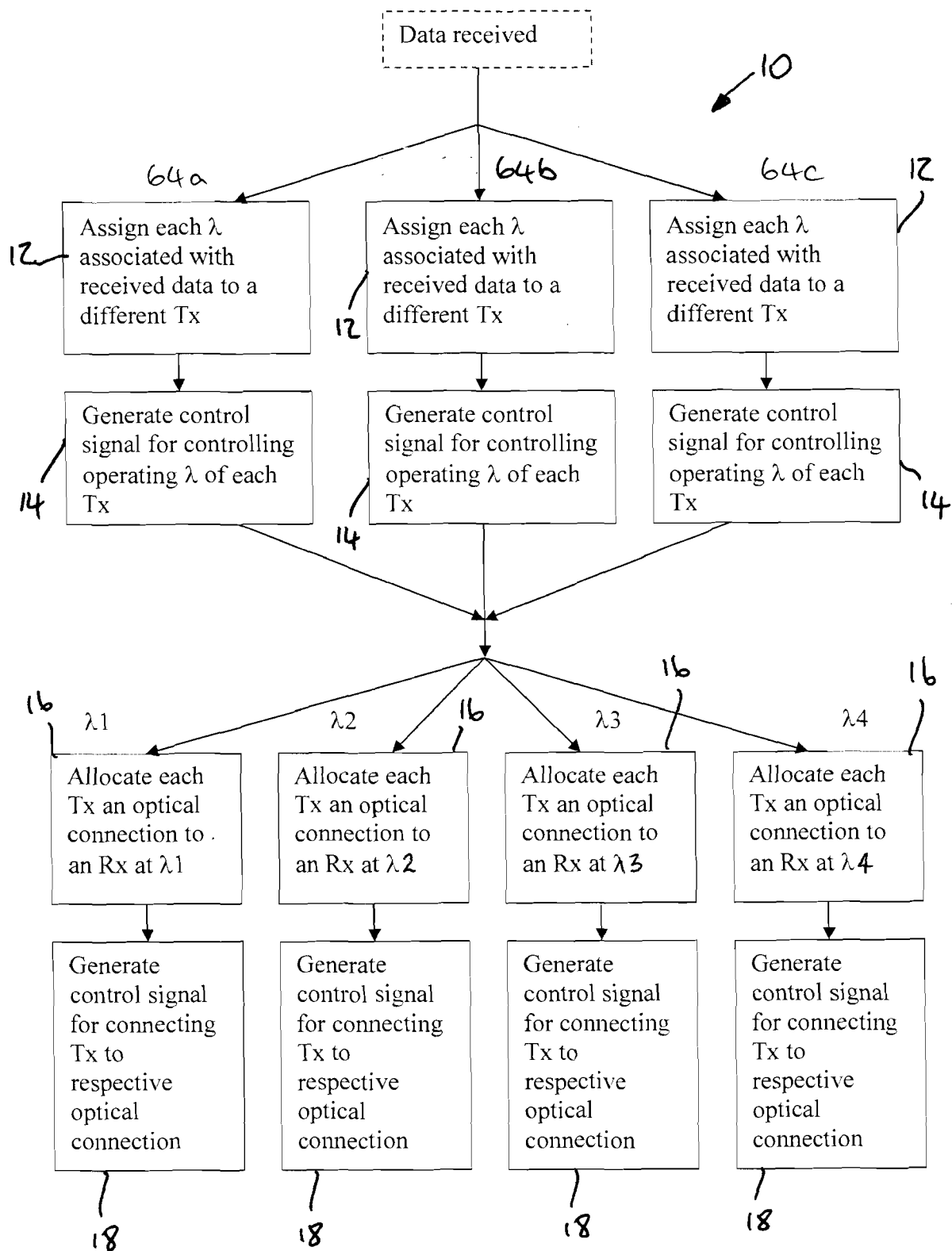


Fig. 1

2/8

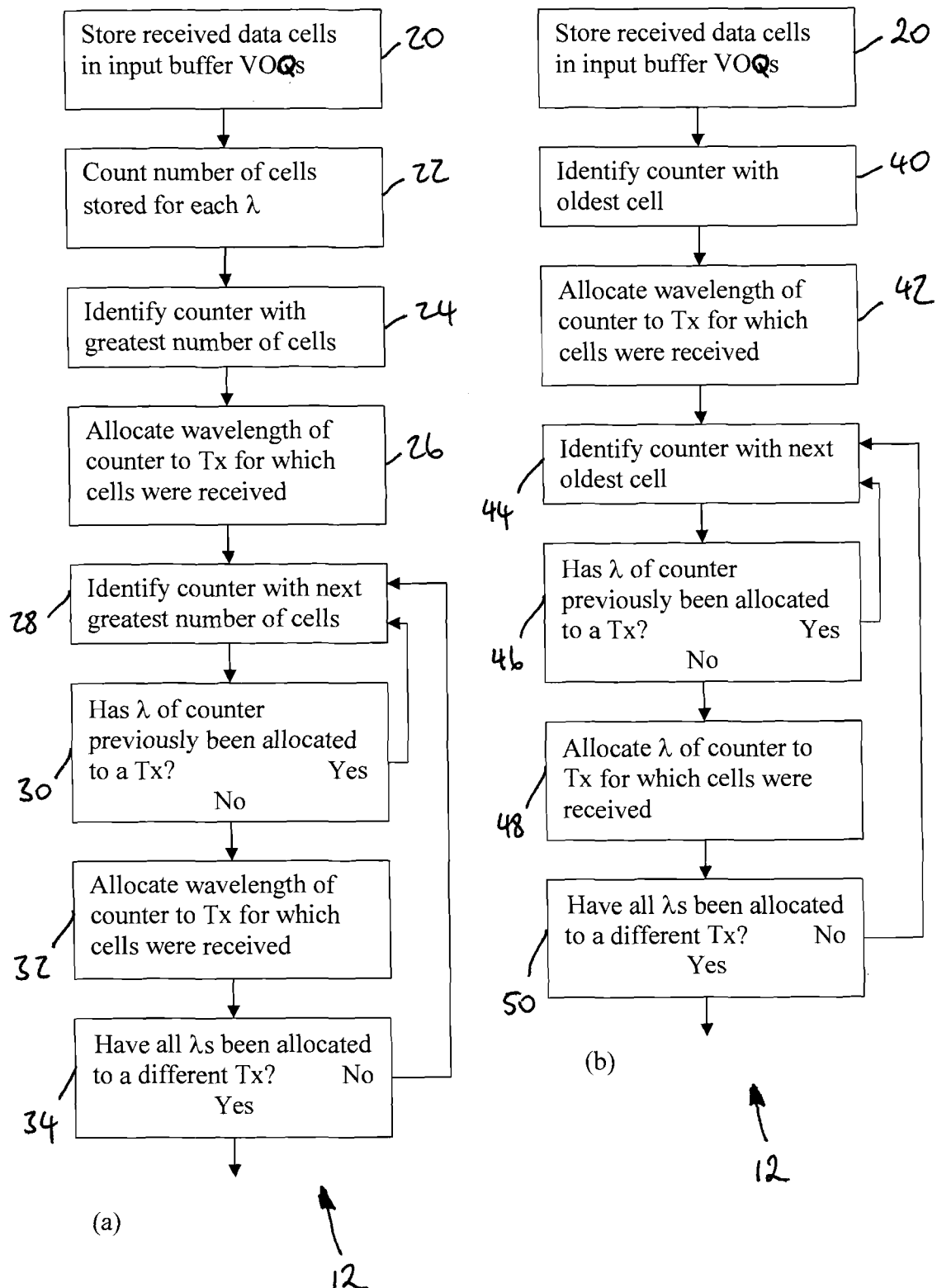


Fig. 2

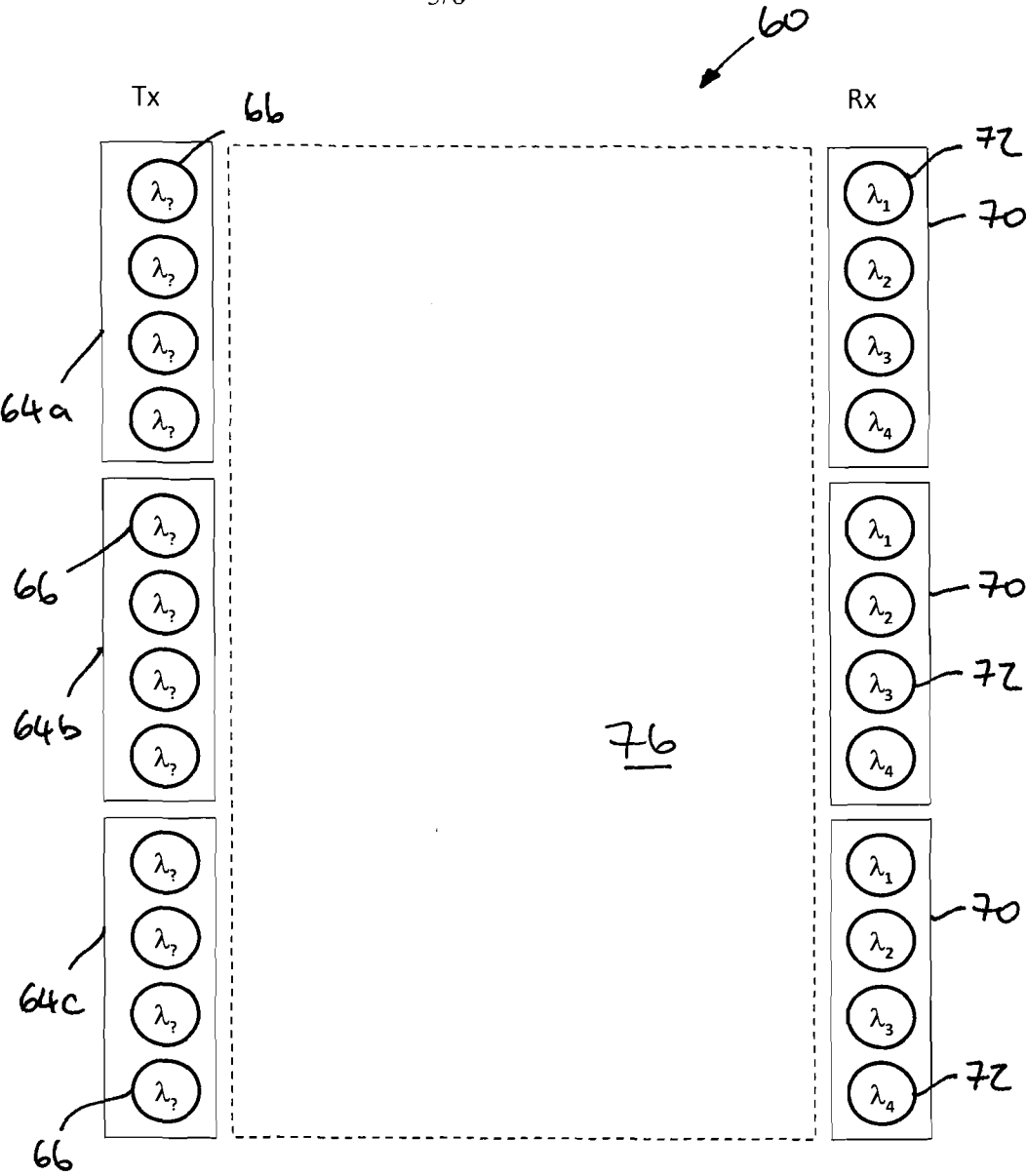


Fig. 3

4/8

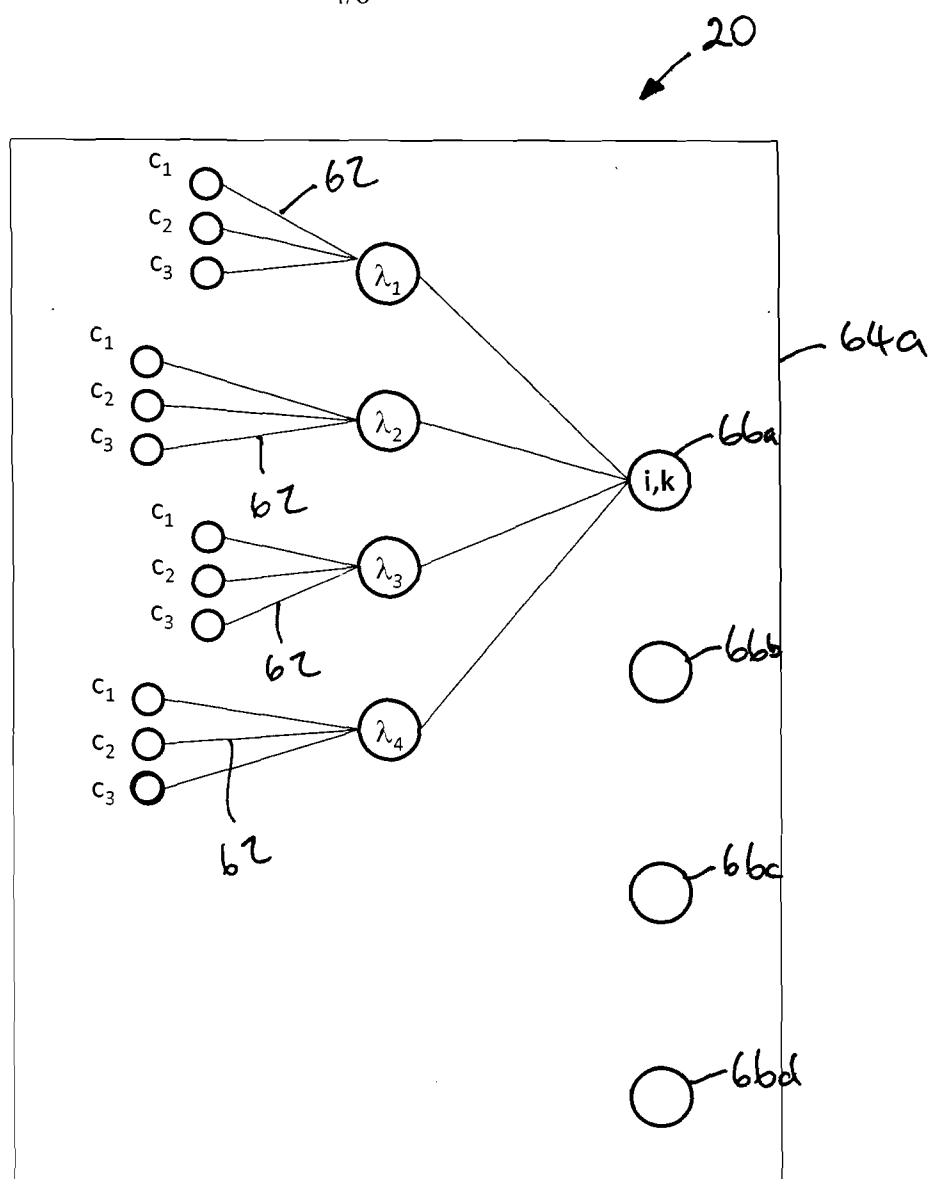


Fig. 4

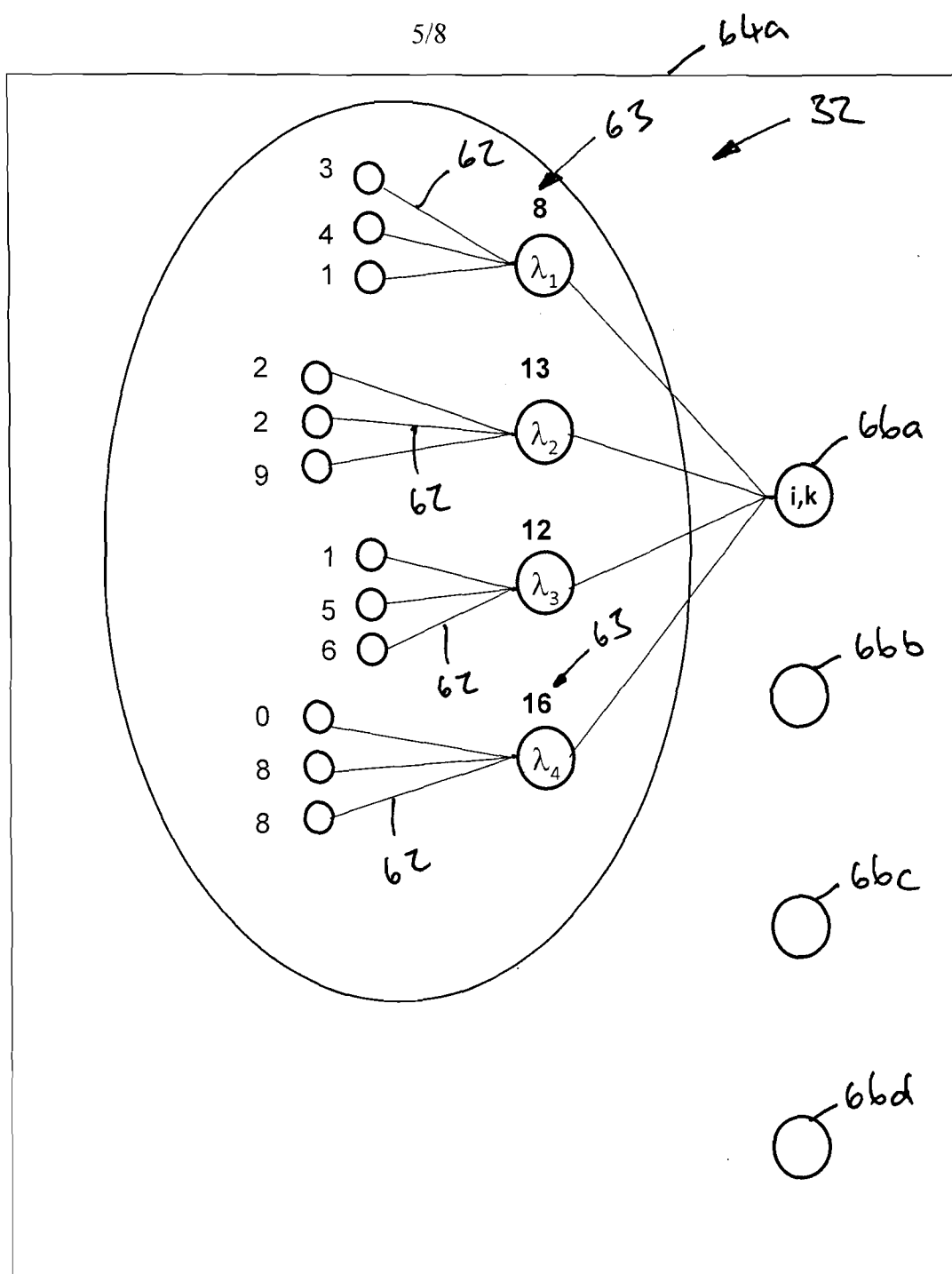


Fig. 5

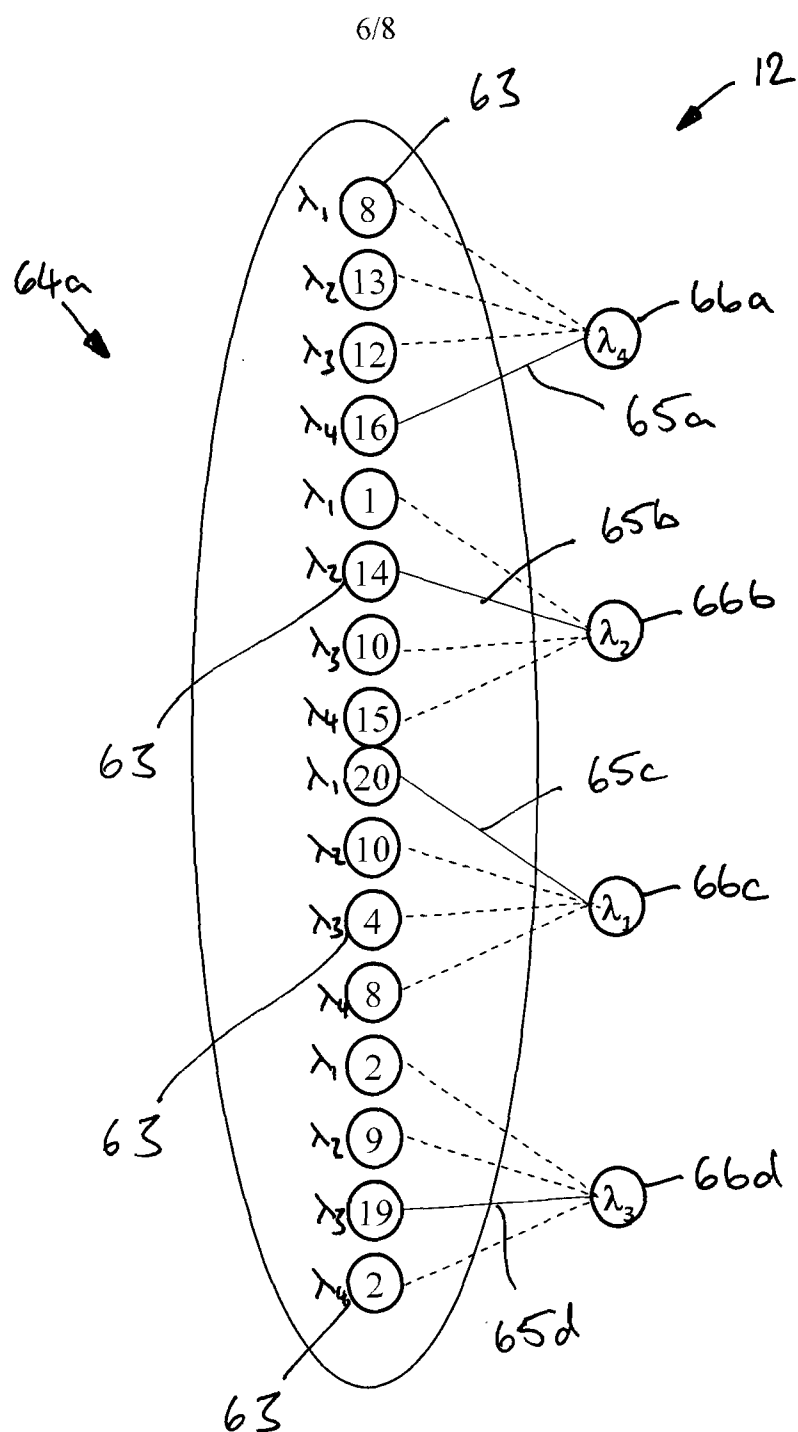


Fig. 6

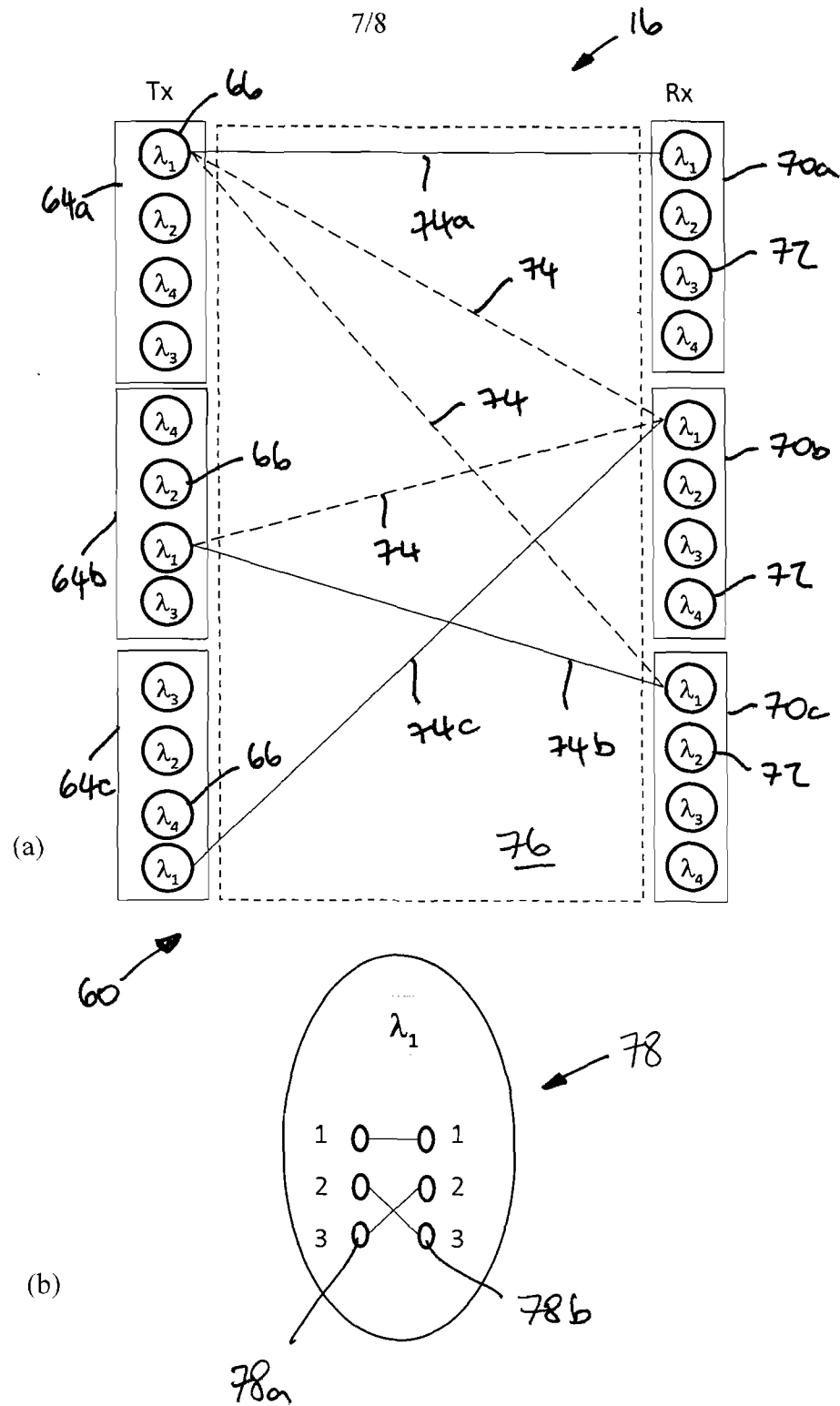


Fig. 7

8/8

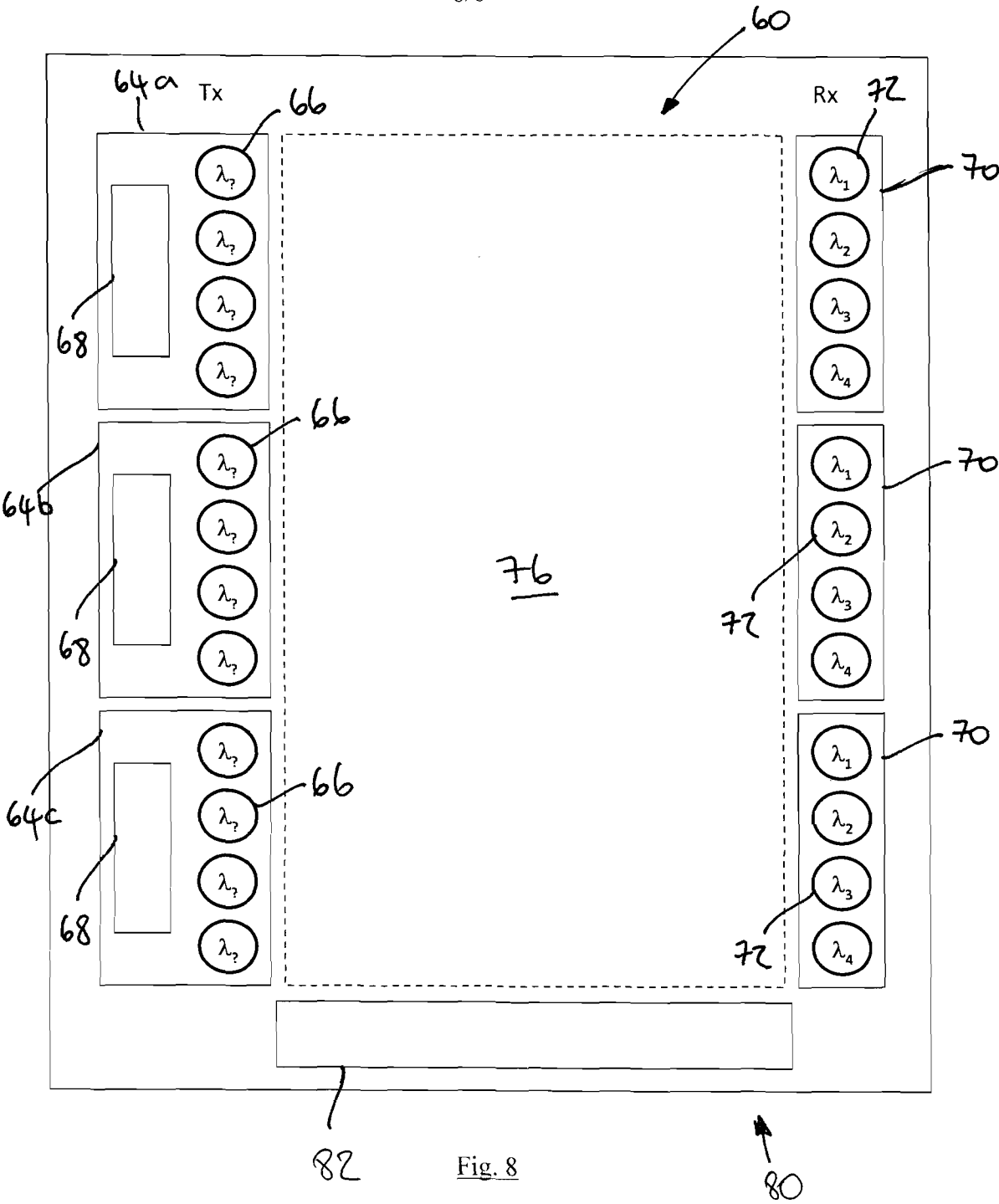


Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/068148

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04Q11/00

ADD. H04L12/56

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)

H04Q

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 466 343 B1 (LAHAT AMIR [IL] ET AL) 15 October 2002 (2002-10-15) abstract	1-16
A	----- KESLASSY I ET AL: "SCALING INTERNET ROUTERS USING OPTICS" COMPUTER COMMUNICATION REVIEW, ACM, NEW YORK, NY, US, vol. 33, no. 4, 1 October 2003 (2003-10-01), pages 189-200, XP001224080 ISSN: 0146-4833 figures 2,4,8 ----- -/--	1-16



Further documents are listed in the continuation of Box C.



See patent family annex.

* 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 document 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

16 October 2009

Date of mailing of the international search report

26/10/2009

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Dhondt, Erik

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/068148

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KESSELMAN A ET AL: "Non-preemptive scheduling of optical switches" GLOBAL TELECOMMUNICATIONS CONFERENCE, 2004. GLOBECOM '04. IEEE DALLAS, TX, USA 29 NOV.-3 DEC., 2004, PISCATAWAY, NJ, USA, IEEE, PISCATAWAY, NJ, USA, vol. 3, 29 November 2004 (2004-11-29), pages 1840-1844, XP010757836 ISBN: 978-0-7803-8794-2 page 1840 - page 1841 -----	1-16

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2008/068148

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6466343	B1	15-10-2002	NONE