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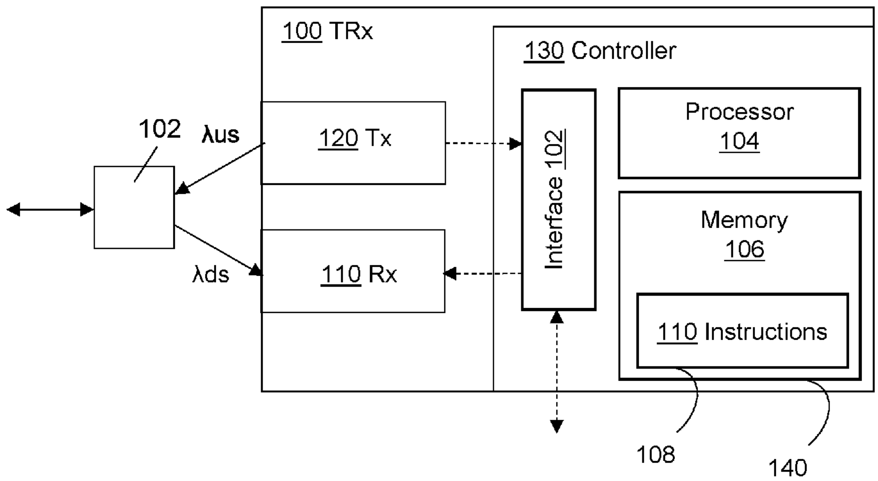

Fig. 1

(57) Abstract: An optical transceiver (100) comprising a tunable receiver (110), a tunable transmitter (120) and a controller (130). The optical transceiver is operative to configure the tunable transmitter switched off and the tunable receiver switched on and to determine available wavelength slots, slots comprising two different wavelengths. Further, the optical transceiver is operative to randomly select one slot from the available slots and if an optical signal is not received at each of a first wavelength and a second wavelength of the randomly selected wavelength slot, select one of the slot wavelengths, set an operating wavelength of the transmitter to the selected wavelength and set an operating wavelength the receiver to the other slot wavelength. Further, the optical transceiver is operative to switch on the transmitter and transmit a TRY message on the selected wavelength during a TRY period whereas if a TRY message at the other slot wavelength is received by the receiver during the TRY period, the optical transceiver is operative to determine that the transmitter operating wavelength and the receiver operating wavelength are correctly set; and continue operating on the set wavelengths.

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OPTICAL TRANSCEIVER AND METHOD OF SETTING OPERATING WAVELENGTHS

Technical Field

The invention relates to an optical transceiver. The invention further relates to a communication network device. The invention further relates to a communication network link. The invention further relates to a method of setting operating wavelengths of an optical transceiver.

Background

Transmitter Tunable small form factor pluggables, TT SPFs, and Self Tunability simplify installation phase requiring smaller SFP inventories and reducing the possibility for mis-cabling that doesn't allow connectivity. Alone, TT SPFs don't enable flexible end to end connectivity since they operate in a filtered selective infrastructure.

Bidirectionally Tunable, BDT, SPFs add, on top of transmitter, Tx, tunability, a tunable receiver, Rx, within the SFP to select the sole wavelength to be received. BDT SFPs relieve the optical infrastructure from the task of selecting a unique wavelength to be sent to SFP Rx, making possible the adoption of wavelength agnostic (also known as "colourless") optical infrastructures based on optical splitters/couplers. The practical limitation of this approach comes from the significant insertion loss introduced by splitters/couplers that limits optical signal reach. This limitation can be overcome by using an optical amplifier in conjunction with the splitter/coupler.

With TT SFP and filter based optical links, the tuning protocol is simple: the optical link with its filters, predetermines the only two ports that can communicate using a certain pair of wavelengths. Roughly speaking, tunable SFPs can transmit using all possible wavelength pairs and lock onto a specific once when they sense light sent from a mate SFP at the other end of the link. Filters make sure that SFPs used by different channels won't disturb each other during tuning. Several protocols exist for this approach, including those defined in the ITU-T "Multichannel bi-directional DWDM applications with port agnostic single-channel optical interfaces" G.metro standard G.698.4, for example 03/2018 version.

Leveraging BDT flexibility requires an agnostic colourless optical link where each pair of SFPs can be interconnected. However, this has major implications since during tuning the light transmitted by an SFP can be seen by all SFPs on the other side. Tuning a set of BDT SFPs connected to a shared infrastructure requires therefore a new approach. To our knowledge no automatic self-tuning methods exist for BDT transceivers over colourless infrastructure. The available Self Tuning Protocols do not prevent traffic disruption and cannot manage overlapping transmissions.

A possible alternative to usage of BDT consists in using tunable filters in the optical infrastructure. These filters, active devices, are external to transceivers and need to be controlled across some management connection. Previous patents to tune such external tunable filters made use of control plane and OSC to communicate pre-planned wavelength assignments, for example WO2012/143046

Summary

It is an object to provide an improved optical transceiver. It is a further object to provide an improved communication network device. It is a further object to provide an improved communication network link. It is a further object to provide an improved method of setting operating wavelengths of an optical transceiver.

An aspect provides an optical transceiver comprising a tunable receiver having a tunable operating wavelength, a tunable transmitter having a tunable operating wavelength and a controller. The controller comprises at least one processor and memory containing instructions executable by the at least one processor whereby the optical transceiver is operative as follows. To configure the tunable transmitter switched off and the tunable receiver switched on. To determine available wavelength slots, one wavelength slot comprising two different wavelengths, and to randomly select one of the wavelength slots from the determined available wavelength slots. To then, if an optical signal is not received at each of a first wavelength and a second wavelength of the randomly selected wavelength slot, select one of the first wavelength or the second wavelength, set the tunable transmitter operating wavelength to said selected wavelength and set the tunable receiver operating wavelength to the other one of the first wavelength or the second wavelength. To then transmit a TRY message from the tunable transmitter on the selected wavelength during a TRY period. The TRY message comprises an indication that the optical transceiver is trying the selected wavelength. To then, if a TRY message at the other one of the first wavelength or the second wavelength is received by the tunable receiver during the TRY period, determine that the tunable transmitter operating wavelength and the tunable receiver operating wavelength are correctly set, and to continue operating on the set tunable transmitter operating wavelength and the set tunable receiver operating wavelength.

The random selection of wavelength slots and TRY messaging advantageously enables the optical transceiver to be self-tunable, this may enable the optical transceiver to be used within a non-selective (colourless) optical distribution network (coupler/splitter) with single fibre working operation. The optical transceiver may enable physical layer automatic connectivity in a self-confined way, requiring no communication with a host communication network device or node, with no traffic disruption to existing connections during the wavelength setting process.

In an embodiment, the controller is operative at iv., if an optical signal is received by the tunable receiver at either of a first wavelength or a second wavelength of the randomly selected wavelength slot, to determine that the randomly selected wavelength slot is not available and to recommence at iii. The optical transceiver may enable physical layer automatic connectivity in a self-confined way, requiring no communication with a host communication network device or node, with no traffic disruption to existing connections during the wavelength setting process and in a reasonable number of steps.

In an embodiment, the memory further contains a wavelengths table containing information identifying wavelength slots and availability statuses of wavelength slots. The controller is operative at iii. to randomly select one of the wavelength slots having an availability status of available from the wavelengths table. The controller is operative at iv., if an optical signal is received by the tunable receiver at either of a first wavelength or a second wavelength of the randomly selected wavelength slot, to update the wavelengths table to change the availability status of the selected slot to unavailable and to then recommence at iii.

The use of random wavelength slot selection and wavelength usage tracking in the wavelengths table reduces the number of steps, and thus the amount of time, required to perform the wavelength setting process.

In an embodiment, the controller is operative at iv. to randomly select one of the first wavelength or the second wavelength of the randomly selected wavelength slot.

This means there is no predetermined direction for odd and even wavelengths, in other words there is no association of odd wavelengths with one communication direction and even wavelengths with the other. This may enable the optical transceiver to be used in fronthaul network connections used to interconnect naturally peering device like Routers and makes easier configuration of fronthaul when used for naturally “oriented” device interconnections.

In an embodiment, the respective wavelengths of the wavelength slots are two different adjacent wavelengths within a telecommunications wavelength grid. This may minimise a latency difference between two directions of an optical link using the optical transceiver at each end.

In an embodiment, the controller is further operative at v., if a TRY message at the other one of the first wavelength or the second wavelength is not received by the tunable receiver during the TRY period, switch off the tunable transmitter and recommence at iii. The may ensure that the operating wavelengths of the tunable transmitter and the tunable receiver are only set if there is a paired optical transceiver at the other end of an optical link using the same wavelength slot and transmitting at the other slot wavelength, i.e. the optical transceiver is one of a pair of optical transceivers using the same wavelength slot, with mirrored transmitter and receiver operating wavelengths.

In an embodiment, the TRY message comprises one of a first overmodulation tone, a first overmodulation pattern or a frame including a bit indicative of a TRY message. TRY messages can thus be sent using a traffic-agnostic implementation or a traffic based implementation.

In an embodiment, the controller is further operative, after vi., to cause the tunable transmitter to transmit a SET message on the set wavelength. The SET message comprises an indication that the optical transceiver operating wavelengths are set. Confirmation of the SET status of the optical transceiver may thus be provided.

In an embodiment, the SET message comprises one of a second overmodulation tone, a second overmodulation pattern, a frame not including a bit indicative of a TRY message or a frame including a bit indicative of a SET message. The SET message can thus be sent using a traffic-agnostic implementation or a traffic based implementation.

In an embodiment, the controller is operative as follows at vi. if a TRY message at the other one of the first wavelength or the second wavelength is received by the tunable receiver during the TRY period. To change the operating wavelength of the tunable receiver to the operating wavelength that the tunable transmitter is set at for a check period. In response to the tunable receiver receiving a SET message from a remote optical transceiver during the check period, to recommence at iii. In response to the tunable receiver not detecting an optical signal during the check period, to determine that the tunable transmitter operating wavelength and the tunable receiver operating wavelength are correctly set. In response to the tunable receiver receiving a SET message transmitted by the optical transmitter during the check period, to determine that the tunable transmitter operating wavelength and the tunable receiver operating wavelength are correctly set.

This enables the optical transceiver to perform a half-duplex wavelength check, to ensure that two different wavelengths are used for the two propagation directions across an optical link. This ensures that the same wavelength is not used for both propagation directions (full-duplex) reducing the risk of crosstalk between a received signal and reflections of the transmitted signal in single fiber operation of an optical link.

In an embodiment, the wavelengths table further contains information identifying wavelengths to be used for transmission in a first direction over an optical link and information identifying wavelengths to be used for transmission in a second, opposite, direction over the optical link. This may speed-up the wavelengths setting process and avoids potential full wavelength duplex operation without requiring any check to be performed.

In an embodiment, the optical transceiver is operative to commence at i. in response to receiving a trigger signal from a communication network device in response to the optical transceiver being plugged into the communication network device. The optical transceiver may therefore have a “plug & play” operation.

In an embodiment, the optical transceiver is further operative to recommence at ii. in response to receiving a command signal from a communication network control plane. This may enable a network control plane to cause a wavelengths reassignment for the optical transceiver.

In an embodiment, the tunable receiver is one of a non-coherent receiver including a tunable filter having a tunable passband wavelength or a coherent receiver including a local oscillator having a tunable output wavelength. The optical transceiver is operable to set the tunable receiver operating wavelength by setting one of the tunable passband wavelength or the tunable output wavelength respectively.

Corresponding embodiments and advantages also apply to the communication network device, communication network link and method described below.

An aspect provides a communication network device comprising at least one optical transceiver. The at least one optical transceiver comprises a tunable receiver having a tunable operating wavelength, a tunable transmitter having a tunable operating wavelength and a controller. The controller comprises at least one processor and memory containing instructions executable by the at least one processor whereby the optical transceiver is operative as follows. To configure the tunable transmitter switched off and the tunable receiver switched on. To determine available wavelength slots, one wavelength slot comprising two different wavelengths, and to randomly select one of the wavelength slots from the determined available wavelength slots. To then, if an optical signal is not received at each of a first wavelength and a second wavelength of the randomly selected wavelength slot, select one of the first wavelength or the second wavelength, set the tunable transmitter operating wavelength to said selected wavelength and set the tunable receiver operating wavelength to the other one of the first wavelength or the second wavelength. To then transmit a TRY message from the tunable transmitter on the selected wavelength during a TRY period. The TRY message comprises an indication that the optical transceiver is trying the selected wavelength. To then, if a TRY message at the other one of the first wavelength or the second wavelength is received by the tunable receiver during the TRY period, determine that the tunable transmitter operating wavelength and the tunable receiver operating wavelength are correctly set, and to continue operating on the set tunable transmitter operating wavelength and the set tunable receiver operating wavelength.

An aspect provides a communication network link comprising a single optical fibre optical link and a plurality of optical transceivers. A first plurality of optical transceivers are connected to a west side of the optical link. A second plurality of optical transceivers are connected to an east side of the optical link. Optical transceivers comprise a tunable receiver having a tunable operating wavelength, a tunable transmitter having a tunable operating wavelength and a controller. The controller comprises at least one processor and memory containing instructions executable by the at least one processor whereby the optical transceiver is operative as follows. To configure the tunable transmitter switched off and the tunable receiver switched on. To determine available wavelength slots, one wavelength slot comprising two different wavelengths, and to randomly select one of the wavelength slots from the determined available wavelength slots. To then, if an optical signal is not received at each of a first wavelength and a second wavelength of the randomly selected wavelength slot, select one of the first wavelength or the second wavelength, set the tunable transmitter operating wavelength to said selected wavelength and set the tunable receiver operating wavelength to the other one of the first wavelength or the second wavelength. To then transmit a TRY message from the tunable transmitter on the selected wavelength during a TRY period. The TRY message comprises an indication that the optical transceiver is trying the selected wavelength. To then, if a TRY message at the other one of the first wavelength or the second wavelength is received by the tunable receiver during the TRY period, determine that the tunable transmitter operating wavelength and the tunable receiver operating wavelength are correctly set, and to continue operating on the set tunable transmitter operating wavelength and the set tunable receiver operating wavelength.

An aspect provides a method of setting operating wavelengths of an optical transceiver comprising a tunable receiver having a tunable operating wavelength and a tunable transmitter having a tunable operating wavelength. The method comprises the following. Configuring the tunable transmitter switched off and the tunable receiver switched on. Determining available wavelength slots, one wavelength slot comprising two different wavelengths, then randomly selecting one of the wavelength slots from the determined available wavelength slots. If an optical signal is not received at each of a first wavelength and a second wavelength of the randomly selected wavelength slot, selecting one of the first wavelength or the second wavelength, setting the tunable transmitter operating wavelength to said selected wavelength and setting the tunable receiver operating wavelength to the other one of the first wavelength or the second wavelength. Then, transmitting a TRY message from the tunable transmitter on the selected wavelength during a TRY period. The TRY message comprises an indication that the optical transceiver is trying the selected wavelength. If a TRY message at the other one of the first wavelength or the second wavelength is received by the tunable receiver during the TRY period, determining that the tunable transmitter operating wavelength and the tunable receiver operating wavelength are correctly set, then continuing operating on the set tunable transmitter operating wavelength and the set tunable receiver operating wavelength.

An aspect provides a computer program comprising instructions which, when executed on at least one processor, cause the at least one processor to carry out the any of the operations of the above method of setting operating wavelengths of an optical transceiver.

An aspect provides a computer program product which comprises a computer readable storage medium on which the above computer program is stored.

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings.

Brief Description of the drawings

Figures 1 to 3 are block diagrams illustrating embodiments of an optical transceiver;

Figures 4 and 5 are flowchart illustrating operation of embodiments of optical transceivers;

Figure 6 is a block diagram illustrating an embodiment of a communication network device;

Figure 7 is a block diagram illustrating an embodiment of a communication network link;

Figures 8 to 14 show simulation results of embodiments of a communication network link; and

Figure 15 is a flowchart illustrating an embodiment of method steps;

Detailed description

The same reference numbers will be used for corresponding features in different embodiments.

Referring to Figure 1, an embodiment provides an optical transceiver 100 comprising a tunable receiver 110 having a tunable operating wavelength, a tunable transmitter 120 having a tunable operating wavelength and a controller 130. The controller comprises a processor 104 and memory 106 containing instructions 110 executable by the processor whereby the optical transceiver is operative to:

i. configure the tunable transmitter switched off and the tunable receiver switched on;

ii. determine available wavelength slots, one wavelength slot comprising two different wavelengths;

iii. randomly select one of the wavelength slots from the determined available wavelength slots;

iv. if an optical signal is not received at each of a first wavelength and a second wavelength of the randomly selected wavelength slot, select one of the first wavelength or the second wavelength, set the tunable transmitter operating wavelength to said selected wavelength and set the tunable receiver operating wavelength to the other one of the first wavelength or the second wavelength;

v. transmit a TRY message from the tunable transmitter on the selected wavelength during a TRY period, the TRY message comprising an indication that the optical transceiver is trying the selected wavelength; and

vi. if a TRY message at the other one of the first wavelength or the second wavelength is received by the tunable receiver during the TRY period, determine that the tunable transmitter operating wavelength and the tunable receiver operating wavelength are correctly set; and

vii. continue operating on the set tunable transmitter operating wavelength and the set tunable receiver operating wavelength.

A wavelength slot is a pair of wavelengths that can be assigned for bi-directional communication between paired optical transceivers.

The optical transceiver 100 is adapted for connection to an external coupling device 102, for example a multiplexer/demultiplexer, for coupling down stream optical signals, λds, to the tunable receiver 110 and for coupling upstream optical signals, λus, from the tunable transmitter 120. The coupling device may alternatively be provided within the optical transceiver 100.

Referring to Figure 2, in an embodiment the memory 106 further contains a wavelengths table 212 containing information identifying wavelength slots and availability statuses of wavelength slots. The controller is operative at ii. to determine available wavelength slots by inspecting the wavelengths table. The controller 230 is operative at iii. to randomly select one of the wavelength slots having an availability status of available from the wavelengths table.

In an embodiment, the controller 230 is operative at iv., if an optical signal is received by the tunable receiver at either of a first wavelength or a second wavelength of the randomly selected wavelength slot, to update the wavelengths table to change the availability status of the selected slot to unavailable, so that it will not be tried again, and to then recommence at iii.

In an embodiment the controller 230 is operative as follows, to perform ii. and iii. together:

a. randomly select a wavelength slot having an availability status of available from the wavelengths table;
b. set the tunable receiver operating wavelength to each of the first wavelength and the second wavelength of the randomly selected wavelength slot in turn and check whether an optical signal is received;
c. if an optical signal is received at either wavelength, recommence at a.; and
d. if no optical signal is received at both wavelengths, proceed to iv.

The controller 230 may be further operative at c. to update the wavelengths table to change the availability status of the randomly selected slot to unavailable, so that it will not be tried again.

The optical transceiver 200 is adapted for connection to an external coupling device 102, for example a multiplexer/demultiplexer, for coupling down stream optical signals, λds, to the tunable receiver 110 and for coupling upstream optical signals, λus, from the tunable transmitter 120. The coupling device may alternatively be provided within the optical transceiver 200.

In an embodiment, the respective wavelengths of the wavelength slots are two different adjacent wavelengths within a telecommunications wavelength grid. This minimizes any latency difference between the two directions in an optical communication link using an optical transceiver 100, 200 at each end.

Alternatively, the respective wavelengths of the wavelength slots may be non-adjacent wavelengths within a telecommunications wavelength grid. This may enable additional flexibility in wavelength setting.

In the above embodiments, there is no predetermined direction for odd and even wavelengths of the wavelength grid, in other words there is no association of odd wavelengths with one network end (e.g. Radio) and even wavelengths with the other end (e.g. Baseband). This enables the optical transceiver 100, 200 to be used in optical links to interconnect naturally peering network devices, such as routers, and makes easier configuration of fronthaul links when used for naturally “oriented” network device interconnections.

In an alternative embodiment, the wavelengths table further contains information identifying wavelengths to be used for transmission in a first direction over an optical link and information identifying wavelengths to be used for transmission in a second, opposite, direction over the optical link. For example, wavelengths corresponding to a first set of channels of the telecommunications wavelength grid may be identified as East to West wavelengths or upstream wavelengths and a second set of different channels of the telecommunications wavelength grid may be identified as West to East wavelengths or downstream wavelengths. The first set of channels may be odd channels and the second set even channels of the wavelength grid.

In an embodiment, the controller 130, 230 is operative at iv. to randomly select one of the first wavelength or the second wavelength of the randomly selected wavelength slot. The operating wavelength of the tunable transmitter is set to the randomly selected wavelength and operating wavelength of the tunable receiver is set to the other wavelength of the wavelength slot.

In an embodiment, the controller 130, 230 is further operative at v., if a TRY message at the other one of the first wavelength or the second wavelength is not received by the tunable receiver during the TRY period, to switch off the tunable transmitter and recommence at iii.

In an embodiment, the controller 130, 230 is further operative, after vi., to cause the tunable transmitter to transmit a SET message on the set wavelength. The SET message comprises an indication that the optical transceiver operating wavelengths are set.

In an embodiment, the TRY message is a first overmodulation tone and the SET message is a second overmodulation tone. Alternatively, the TRY message may be a first overmodulation pattern and the SET message is a second overmodulation pattern. Overmodulation tones or patterns may be used in traffic-agnostic implementations.

Further alternatively, the TRY message may be a frame including a bit indicative of a TRY message and the SET message comprises a frame not including a bit indicative of a TRY message or a frame including a bit indicative of a SET message.

In an embodiment, the controller 130, 230 is operative at vi., if a TRY message at the other one of the first wavelength or the second wavelength is received by the tunable receiver during the TRY period, to:

change the operating wavelength of the tunable receiver to the operating wavelength that the tunable transmitter is set at for a check period;

in response to the tunable receiver receiving a SET message from a remote optical transceiver during the check period, recommence at iii.;

in response to the tunable receiver not detecting an optical signal during the check period, determine that the tunable transmitter operating wavelength and the tunable receiver operating wavelength are correctly set; and

in response to the tunable receiver receiving a SET message transmitted by the optical transmitter during the check period, determine that the tunable transmitter operating wavelength and the tunable receiver operating wavelength are correctly set.

In an embodiment, the optical transceiver 100, 200 is operative to commence at i. in response to receiving a trigger signal from a communication network device in response to the optical transceiver being plugged into the communication network device.

In an embodiment, the optical transceiver 100, 200 is operative to recommence at ii. in response to receiving a command signal from a communication network control plane.

Referring to Figure 3a, an embodiment provides an optical transceiver 300 in which the tunable receiver is a non-coherent receiver 310 comprising a tunable filter 312 and a photodetector 314. The tunable filter has a tunable passband wavelength. The controller 330 is operative as described above, with the memory 106 containing instructions 310 executable by the processor 104 whereby the optical transceiver 300 is operative to set the tunable receiver 310 operating wavelength by setting the tunable passband wavelength of the tunable filter 312.

The optical transceiver 300 additionally comprises a coupling device 302 for coupling down stream optical signals, λds, to the tunable filter 312 and for coupling upstream optical signals, λus, from the tunable transmitter 120. The coupling device, for example a multiplexer/demultiplexer, may alternatively be provided externally to the optical transceiver 300.

Referring to Figure 3b, an embodiment provides an optical transceiver 350 in which the tunable receiver 360 comprising a local oscillator 362 and a coherent receiver 364. The local oscillator has a tunable output wavelength. The controller 370 is operative as described above, with the memory 106 containing instructions 380 executable by the processor 104 whereby the optical transceiver 350 is operative to set the tunable receiver 360 operating wavelength by setting the output wavelength of the local oscillator 362.

The optical transceiver 350 additionally comprises a coupling device 302 for coupling down stream optical signals, λds, to the coherent receiver 364 and for coupling upstream optical signals, λus, from the tunable transmitter 120. The coupling device, for example a multiplexer/demultiplexer, may alternatively be provided externally to the optical transceiver 350.

Figure 4 illustrates a Finite State Machine, FSM, 400 representing operation of an optical transceiver 200, as illustrated in Figure 2, according to an embodiment. The FSM has three states: a SENSE state; a TRY state; and a SET state.

The tuning of the tunable transmitter 120 and the tunable receiver 210 starts by the optical transceiver entering the SENSE State. The transmitter is off (to avoid possible interference with wavelengths already used in an optical link to which the transceiver is connected). The optical transceiver iteratively selects random wavelengths slots, and senses, tuning the Rx filter 212, both wavelengths in the slot. If the slot is free the optical transceiver attempts wavelength matching by transitioning to the TRY state. To speed up convergence every time an operating wavelength is sensed (already working channels) the corresponding wavelengths are marked as used within the wavelengths table so that the slots are not tried again.

In the TRY state, the transceiver starts transmitting a TRY message for a short period of time. If a TRY message is not received the transceiver switches off the transmitter and returns to the SENSE state to try a different wavelength slot. Otherwise, after a defined hold time the optical transceiver moves to the SET state.

The SET state is the final state when wavelength tuning of the tunable transmitter and the tunable receiver is completed and stable. The tuning process can be restarted by external commands or conditions. In this state a SET message can be transmitted or, alternatively, if the TRY message was un unframed pattern, the reception of a valid frame can alone be identified as a set condition.

Figure 5 illustrates an FSM 500 representing operation of an optical transceiver 200, as illustrated in Figure 2, according to an embodiment. The FSM has four states: a SENSE state; a TRY state; a CHECK state; and a SET state.

In this embodiment, an additional CHECK state is provided between the TRY state and the SET state to avoid the case of a full-duplex wavelength assignment (two transceiver pairs operating in the same slot with mirrored Tx and Rx wavelengths) which is not desirable.

In the CHECK state, if after a short hold time full-duplex wavelength assignment is not detected, the optical transceiver moves from the CHECK state to the SET state as described above.

In an embodiment, the SENSE state is also responsible to track and update the wavelengths table in order to avoid trying already assigned wavelength slots and to therefore speed up the wavelength setting process. Given λrx and $\lambda rx'$ the adjacent wavelengths of the slot where the Rx filter tunes at a given step in the SENSE state and *Prx1* and *Prx2* the signal detected at those wavelengths:

Prx1 = P (λrx); Prx2 = P (λrx')

If (Prx1 = 'Set' and Prx2 = 'Off') or (Prx1 = 'Off' and Prx2 = 'Set') → W_table (λrx, λrx') = 1

else → W_table (λrx, λrx') = 0

The wavelengths table is an array where, for each wavelength slot, a value 1 means the slot is "used" and 0 means the slot is "free". The slot is recognized as already in use if a SET message is present on one wavelength and no signal on the other one. Once marked as "used" the wavelength slot is not selected for future iterations.

In an embodiment, the optical transceiver 200 is operative to perform a Half Duplex Wavelength Check. To avoid crosstalk between received signal and the reflections of the transmitted signal when the optical transceiver is used in an optical link having single fibre operation, two different wavelengths are used for the two propagation directions (typically adjacent wavelengths to minimize latency difference). Using the same wavelength would double the capacity of the system (also known as full-duplex) but with the risk to introduce crosstalk. The optical transceiver 200 is thus operative to perform a test to avoid selecting full-duplex configuration by accident.

If the compromises the signal integrity, the condition is automatically detected by the optical transceiver 200 since it will not receive a clear "TRY" message at vi. and will therefore leave the TRY state to start a new SENSE phase, returning to ii.

However, if the crosstalk is weak and doesn't harm the transmission of the TRY message, the method could lead to a SET state where the same wavelengths are used in both directions. Since this could be forbidden by system policy, a dedicate check can be added in the SET state. If this condition is detected within a short hold time the optical transceiver returns to the SENSE status to retry, recommencing at ii. Otherwise, the SET state is confirmed at vi. and the optical transceiver continues operating at the set wavelengths.

The check is performed by tuning the receiver on the Tx Wavelength and checking for incoming signal. There are 3 possible outcomes of this check:

- No power detected: the tuning is correct
- A valid SET message is received from the remote optical transceiver at the other end of the optical link: the tuning is not correct
- A valid SET message is detected that is a reflection of the SET message being transmitted by the optical transceivers own transmitter: the tuning is correct.

To enable messages transmitted by different optical transceivers to be distinguished from one another, each optical transceiver includes a unique identifier, for example its serial number or a combination of part number and serial number, within all messages that it transmits.

The above described operation of the optical transceiver 200 is based on the following:

- Wavelength setting attempts are based on random wavelength selection among available wavelengths
- The optical transceiver first senses if a selected wavelength slot is free
- If a free slot is sensed, an attempt is made by transmitting a “TRY” message for a defined period of time. If during this time no clear “TRY” message is received from an optical transceiver at the other side of the optical link, the attempt is aborted and a new attempt with a random wavelength slot selection is made
- If the attempt succeeds, a final check is made to avoid bidirectional usage of the same wavelength slot and then the pairing of the optical transceivers at the two ends of the optical link is completed.

It is possible that more than two optical transceivers tentatively select the same wavelength slot; this situation (collision case) is automatically managed by the hold time during the TRY phase.

Corresponding embodiments and advantages also apply to the communication network device, communication network link and method described below.

Referring to Figure 6, an embodiment provides a communication network device 600 comprising at least one optical transceiver 100, 200, 300, 350 as described above.

The communication network device 600 may, for example, be one of a router, a switch or a transponder.

Referring to Figure 7, an embodiment provides a communication network link 700 comprising an optical link and a plurality of optical transceivers 100, 200, 300, 350, as described above.

The optical link comprises a single optical fibre 704. A first plurality of optical transceivers 100 W1 to 100 Wn are connected to a West side of the optical link via a first optical splitter 702. A second plurality of optical transceivers 100 E1 to 100 En are connected to an East side of the optical link via a second optical splitter 706.

Operation of the communication network link 700 has been modelled by simulation, in the case of optical transceivers 200 including a wavelengths table which is updated when a wavelength is determined to be unavailable, as described above. In the first example, illustrated in simulation results shown in Figures 8 to 10, 48 optical transceivers 100 are all connected simultaneously to the optical link in a 48-wavelengths system; optical transceivers 1-24 are connected to the West side of the optical link and optical transceivers 25-48 are connected to the East side of the optical link.

This is a worst case in terms of potential wavelength overlapping and collision between the optical transceivers as they simultaneously tune their operating wavelengths, as described above. Figure 8 shows the State evolution of the transceivers through the SENSE, TRY, CHECK and SET states illustrated in Figure 5, and Figure 9 shows the progress of tuning being completed for the 48 optical transceivers. It can be seen that the tuning completion proceeds quite regularly after a fast start thanks to the tracking of wavelengths identified as already being in use in the wavelengths table, as described above.

Figure 10 shows the final allocation of Tx and Rx wavelengths among the optical transceivers. Squares represents Tx wavelengths while crosses are Rx wavelengths. It can be seen that all transceivers are set to pairs of adjacent Tx and Rx wavelengths with no predetermined direction for odd and even wavelengths.

Figure 11 shows an unacceptable allocation of Tx and Rx wavelengths among the optical transceivers, which can occur if a half-duplex wavelength check as described above is not carried out. Each circle represents a Tx or an Rx; a pair of circles thus represents a transceiver. It can be seen that, in this example, wavelengths 37 and 38 are never used (box A) while wavelengths 17 and 18 are used by two transceivers (box B) in a full duplex configuration. West Transceiver 13 uses wavelength 18 for Tx and wavelength 17 for Rx and talks to East Transceiver 43. On the same wavelengths slot, West Transceiver 19 uses wavelength 17 for Tx and wavelength 18 for Rx and talks to East Transceiver 31.

A second, and opposite, case is the case when a last pair of transceivers is connected when all the other 46 are already tuned, set and operating (23 bidirectional channels). Figure 12 illustrates the state transitions for this last pair of transceivers. As can be seen, after a number of attempts the new pair finds its operating wavelengths, while the other transceivers stay stable in the SET state meaning that no disruption of traffic occurred during the new channel tuning process.

Since the optical transceivers make a random choice of wavelength slot to try, the process of the optical transceivers finding their operating wavelengths has a statistical behaviour. The histogram in Figure 13 shows the distribution, over 1000 simulations, of the number of tuning steps required for the case of 48 optical transceivers simultaneously connected to the optical link. Figure 14 shows the average number of tuning steps as a function of the total system wavelength slots available in the two cases of “all-channel” loaded at the same time and 1-channel only loaded in the empty system simulated above. The number of tuning steps required scales approximately linearly with the number of wavelengths slots. In the simulations one step involves a Tx and Rx tuning to a given wavelength slot and a receiver reading.

The steps can be translated into actual time if the Rx and Tx tuning times are known.

Referring to Figure 15, an embodiment provides a method of setting operating wavelengths of an optical transceiver comprising a tunable receiver having a tunable operating wavelength and a tunable transmitter having a tunable operating wavelength.

The method comprises:

i. configuring 802 the tunable transmitter switched off and the tunable receiver switched on;

ii. determining 804 available wavelength slots, one wavelength slot comprising two different wavelengths;

iii. randomly selecting 806 one of the wavelength slots from the determined available wavelength slots;

iv. if 808 an optical signal is not received at each of a first wavelength and a second wavelength of the randomly selected wavelength slot, selecting one of the first wavelength or the second wavelength, setting the tunable transmitter operating wavelength to said selected wavelength and setting the tunable receiver operating wavelength to the other one of the first wavelength or the second wavelength;

v. transmitting (810) a TRY message from the tunable transmitter on the selected wavelength during a TRY period, the TRY message comprising an indication that the optical transceiver is trying the selected wavelength; and

vi. if 812 a TRY message at the other one of the first wavelength or the second wavelength is received by the tunable receiver during the TRY period, determining that the tunable transmitter operating wavelength and the tunable receiver operating wavelength are correctly set.

The method enables self-tunability of an optical transceiver, as described above, in a non-selective (colourless) fibre network (coupler/splitter) with single fibre working operation. Thanks to a simple state machine, as described above, with random wavelength selection and wavelength usage tracking, the method enables physical layer automatic connectivity in a self-confined way (no host communication) with no traffic disruption during the wavelength setting process and in a reasonable number of steps.

The method is based on a Finite State Machine, as described above, comprising:

- A SENSE state where laser is off and free wavelength slots are searched. The state transitioning to a TRY state once a free wavelength is found.
- A TRY state where laser is on and a “TRY” message is transmitted. The TRY state transitioning to a SET state once a “TRY” message match is found, reverting to SENSE state otherwise.
- A SET state where tuning is checked and confirmed.

The method advantageously avoids disturbing all other connections already established on an optical link during wavelength setting of optical transceiver wavelengths.

An embodiment provides a computer program 108 comprising instructions 110 which, when executed on a processor 104, cause the processor to carry out the method described above.

An embodiment provides a computer program product 140 which comprises a computer readable storage medium on which a computer program 108 as described above is stored.

An embodiment provides a computer program 208 comprising instructions 210 which, when executed on a processor 104, cause the processor to carry out the method described above.

An embodiment provides a computer program product 240 which comprises a computer readable storage medium on which a computer program 208 as described above is stored.

An embodiment provides a computer program 308 comprising instructions 310 which, when executed on a processor 104, cause the processor to carry out the method described above.

An embodiment provides a computer program product 340 which comprises a computer readable storage medium on which a computer program 308 as described above is stored.

An embodiment provides a computer program 358 comprising instructions 380 which, when executed on a processor 104, cause the processor to carry out the method described above.

An embodiment provides a computer program product 390 which comprises a computer readable storage medium on which a computer program 358 as described above is stored.

CLAIMS

1. An optical transceiver comprising:
a tunable receiver having a tunable operating wavelength;
a tunable transmitter having a tunable operating wavelength; and
a controller comprising at least one processor and memory containing instructions executable by the at least one processor whereby the optical transceiver is operative to:
    i. configure the tunable transmitter switched off and the tunable receiver switched on;
    ii. determine available wavelength slots, one wavelength slot comprising two different wavelengths;
    iii. randomly select one of the wavelength slots from the determined available wavelength slots;
    iv. if an optical signal is not received at each of a first wavelength and a second wavelength of the randomly selected wavelength slot, select one of the first wavelength or the second wavelength, set the tunable transmitter operating wavelength to said selected wavelength and set the tunable receiver operating wavelength to the other one of the first wavelength or the second wavelength;
    v. transmit a TRY message from the tunable transmitter on the selected wavelength during a TRY period, the TRY message comprising an indication that the optical transceiver is trying the selected wavelength;
    vi. if a TRY message at the other one of the first wavelength or the second wavelength is received by the tunable receiver during the TRY period, determine that the tunable transmitter operating wavelength and the tunable receiver operating wavelength are correctly set; and
    vii. continue operating on the set tunable transmitter operating wavelength and the set tunable receiver operating wavelength.

2. The optical transceiver of claim 1, wherein the controller is operative at iv., if an optical signal is received by the tunable receiver at either of a first wavelength or a second wavelength of the randomly selected wavelength slot, to determine that the randomly selected wavelength slot is not available and to recommence at iii.

3. The optical transceiver of any one of claim 1 or claim 2, wherein the memory further contains a wavelengths table containing information identifying wavelength slots and availability statuses of wavelength slots, and wherein the controller is operative at iii. to randomly select one of the wavelength slots having an availability status of available from the wavelengths table and the controller is operative at iv., if an optical

signal is received by the tunable receiver at either of a first wavelength or a second wavelength of the randomly selected wavelength slot, to update the wavelengths table to change the availability status of the selected slot to unavailable and to then recommence at iii.

4. The optical transceiver of any one of claims 1 to 3, wherein the controller is operative at iv. to randomly select one of the first wavelength or the second wavelength of the randomly selected wavelength slot.

5. The optical transceiver of any one of claims 1 to 4, wherein the respective wavelengths of the wavelength slots are two different adjacent wavelengths within a telecommunications wavelength grid.

6. The optical transceiver of any one of claims 1 to 5, wherein the controller is further operative at v., if a TRY message at the other one of the first wavelength or the second wavelength is not received by the tunable receiver during the TRY period, to switch off the tunable transmitter and recommence at iii.

7. The optical transceiver of any one of claims 1 to 6, wherein the TRY message comprises one of a first overmodulation tone, a first overmodulation pattern or a frame including a bit indicative of a TRY message.

8. The optical transceiver of any one of claims 1 to 7, wherein the controller is further operative, after vi., to cause the tunable transmitter to transmit a SET message on the set wavelength, the SET message comprising an indication that the optical transceiver operating wavelengths are set.

9. The optical transceiver of claim 8, wherein the SET message comprises one of a second overmodulation tone, a second overmodulation pattern, a frame not including a bit indicative of a TRY message or a frame including a bit indicative of a SET message.

10. The optical transceiver of any one of claims 1 to 9, wherein the controller is operative at vi., if a TRY message at the other one of the first wavelength or the second wavelength is received by the tunable receiver during the TRY period, to:
   - change the operating wavelength of the tunable receiver to the operating wavelength that the tunable transmitter is set at for a check period;
   - in response to the tunable receiver receiving a SET message from a remote optical transceiver during the check period, recommence at iii.;
   - in response to the tunable receiver not detecting an optical signal during the check period, determine that the tunable transmitter operating wavelength and the tunable receiver operating wavelength are correctly set;
   - in response to the tunable receiver receiving a SET message transmitted by the optical transmitter during the check period, determine that the tunable

transmitter operating wavelength and the tunable receiver operating wavelength are correctly set; and

– operating on the set tunable transmitter operating wavelength and the set tunable receiver operating wavelength.

11. The optical transceiver of claim 3, wherein the wavelengths table further contains information identifying wavelengths to be used for transmission in a first direction over an optical link and information identifying wavelengths to be used for transmission in a second, opposite, direction over the optical link.

12. The optical transceiver of any one of claims 1 to 11, wherein the optical transceiver is operative to commence at i. in response to receiving a trigger signal from a communication network device in response to the optical transceiver being plugged into the communication network device.

13. The optical transceiver of claim 12, wherein the optical transceiver is further operative to recommence at ii. in response to receiving a command signal from a communication network control plane.

14. The optical transceiver of any one of claims 1 to 13, wherein the tunable receiver is one of a non-coherent receiver including a tunable filter having a tunable passband wavelength or a coherent receiver including a local oscillator having a tunable output wavelength, and wherein the optical transceiver is operable to set the tunable receiver operating wavelength by setting one of the tunable passband wavelength or the tunable output wavelength respectively.

15. A communication network device comprising at least one optical transceiver according to any one of claims 1 to 14.

16. A communication network link comprising:
a single optical fibre optical link;
a first plurality of optical transceivers according to any one of claims 1 to 14 connected to a west side of the optical link; and
a second plurality of optical transceivers according to any one of claims 1 to 14 connected to an east side of the optical link.

17. A method of setting operating wavelengths of an optical transceiver comprising a tunable receiver having a tunable operating wavelength and a tunable transmitter having a tunable operating wavelength, the method comprising:

i. configuring the tunable transmitter switched off and the tunable receiver switched on;

ii. determining available wavelength slots, one wavelength slot comprising two different wavelengths;

iii. randomly selecting one of the wavelength slots from the determined available wavelength slots;

iv. if an optical signal is not received at each of a first wavelength and a second wavelength of the randomly selected wavelength slot, selecting one of the first wavelength or the second wavelength, setting the tunable transmitter operating wavelength to said selected wavelength and setting the tunable receiver operating wavelength to the other one of the first wavelength or the second wavelength;

v. transmitting a TRY message from the tunable transmitter on the selected wavelength during a TRY period, the TRY message comprising an indication that the optical transceiver is trying the selected wavelength; and

vi. if a TRY message at the other one of the first wavelength or the second wavelength is received by the tunable receiver during the TRY period, determining that the tunable transmitter operating wavelength and the tunable receiver operating wavelength are correctly set.

18. A computer program comprising instructions which, when executed on at least one processor, cause the at least one processor to carry out the method according to claim 17.

19. A computer program product which comprises a computer readable storage medium on which a computer program according to claim 18 is stored.

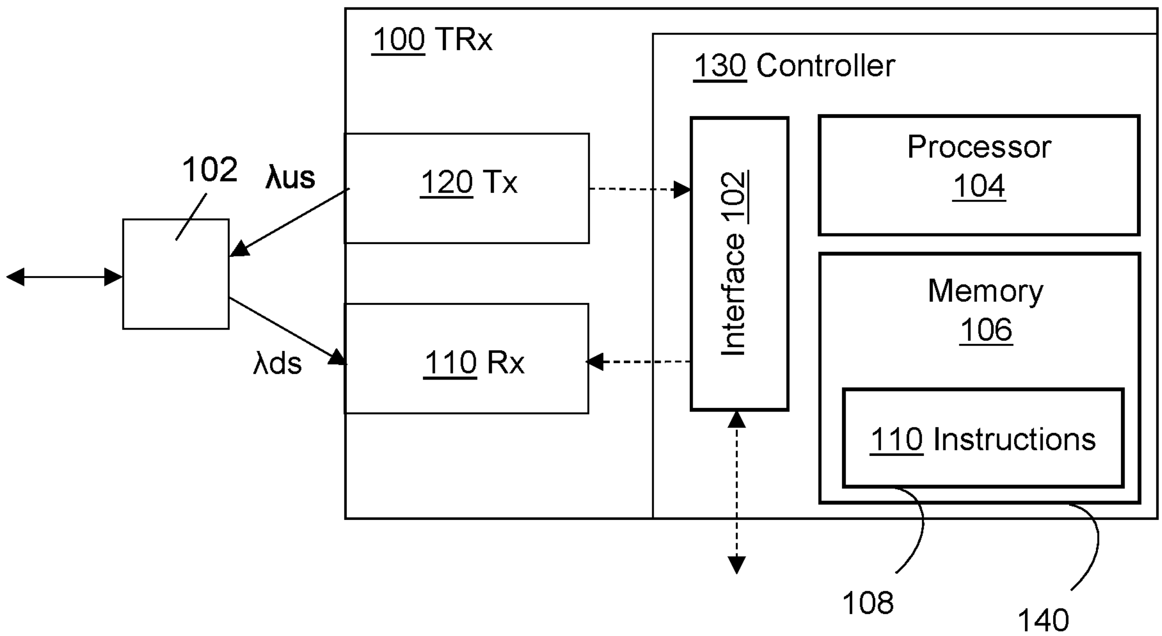
100 TRx
130 Controller
102
λus
120 Tx
Interface 102
Processor
104
Memory
106
λds
110 Rx
110 Instructions
108
140

Fig. 1

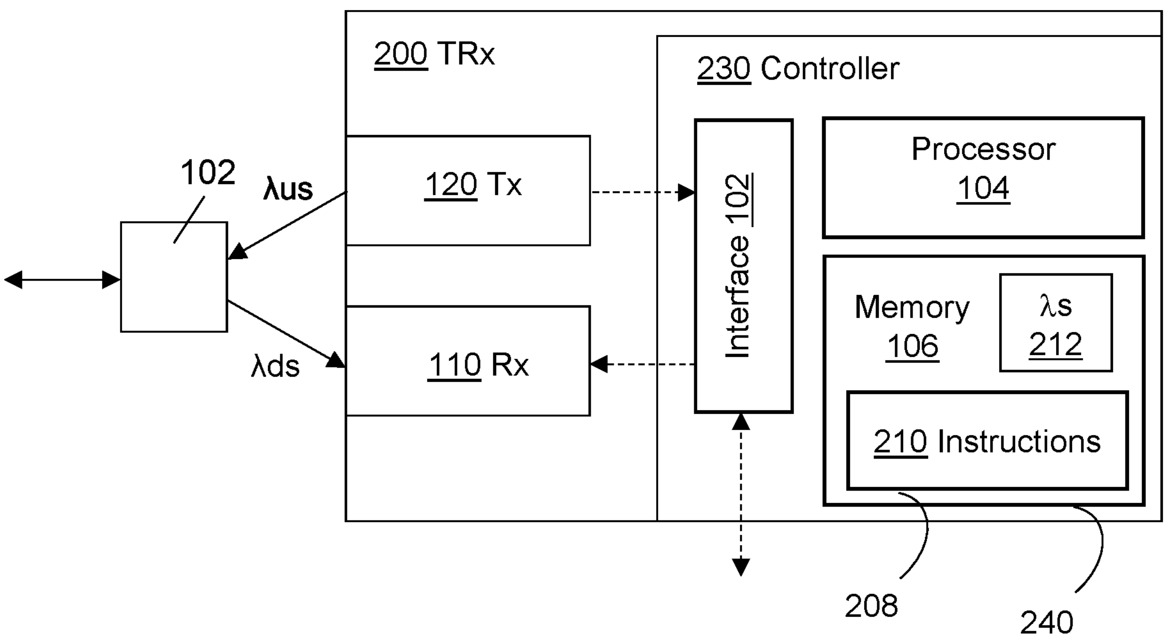
200 TRx
230 Controller
102
λus
120 Tx
Interface 102
Processor
104
Memory
106
λs
212
λds
110 Rx
210 Instructions
208
240

Fig. 2

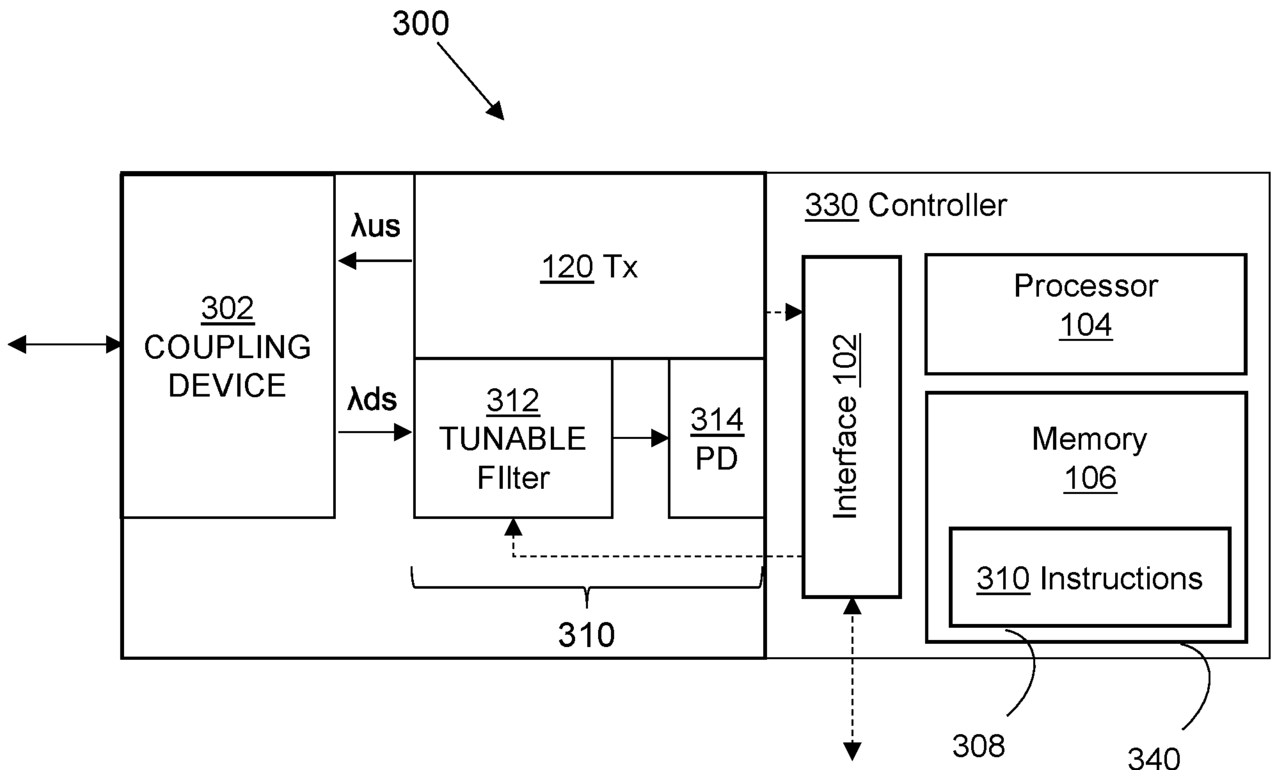
300
λus
λds
302
COUPLING
DEVICE
120 Tx
312
TUNABLE
FIlter
314
PD
310
330 Controller
Interface 102
Processor
104
Memory
106
310 Instructions
308
340

Fig. 3a

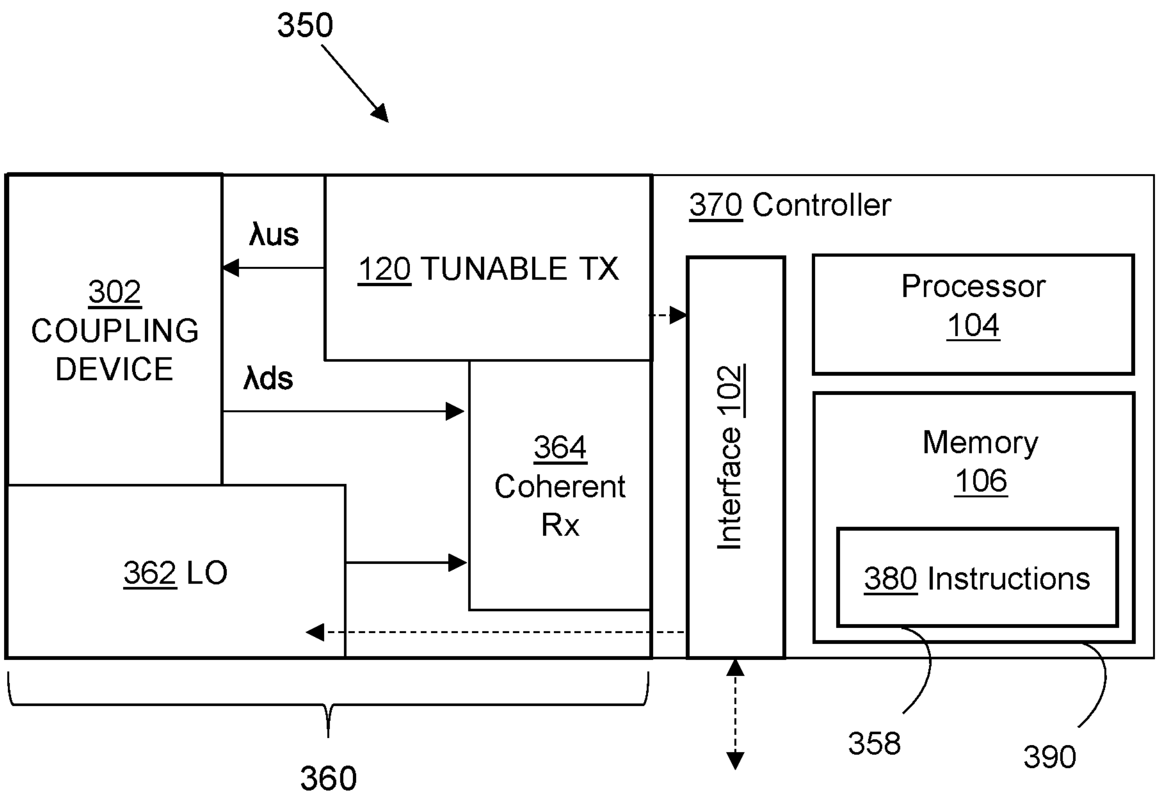
350
302
COUPLING
DEVICE
λus
λds
120 TUNABLE TX
364
Coherent
Rx
362 LO
360
370 Controller
Interface 102
Processor
104
Memory
106
380 Instructions
358
390

Fig. 3b

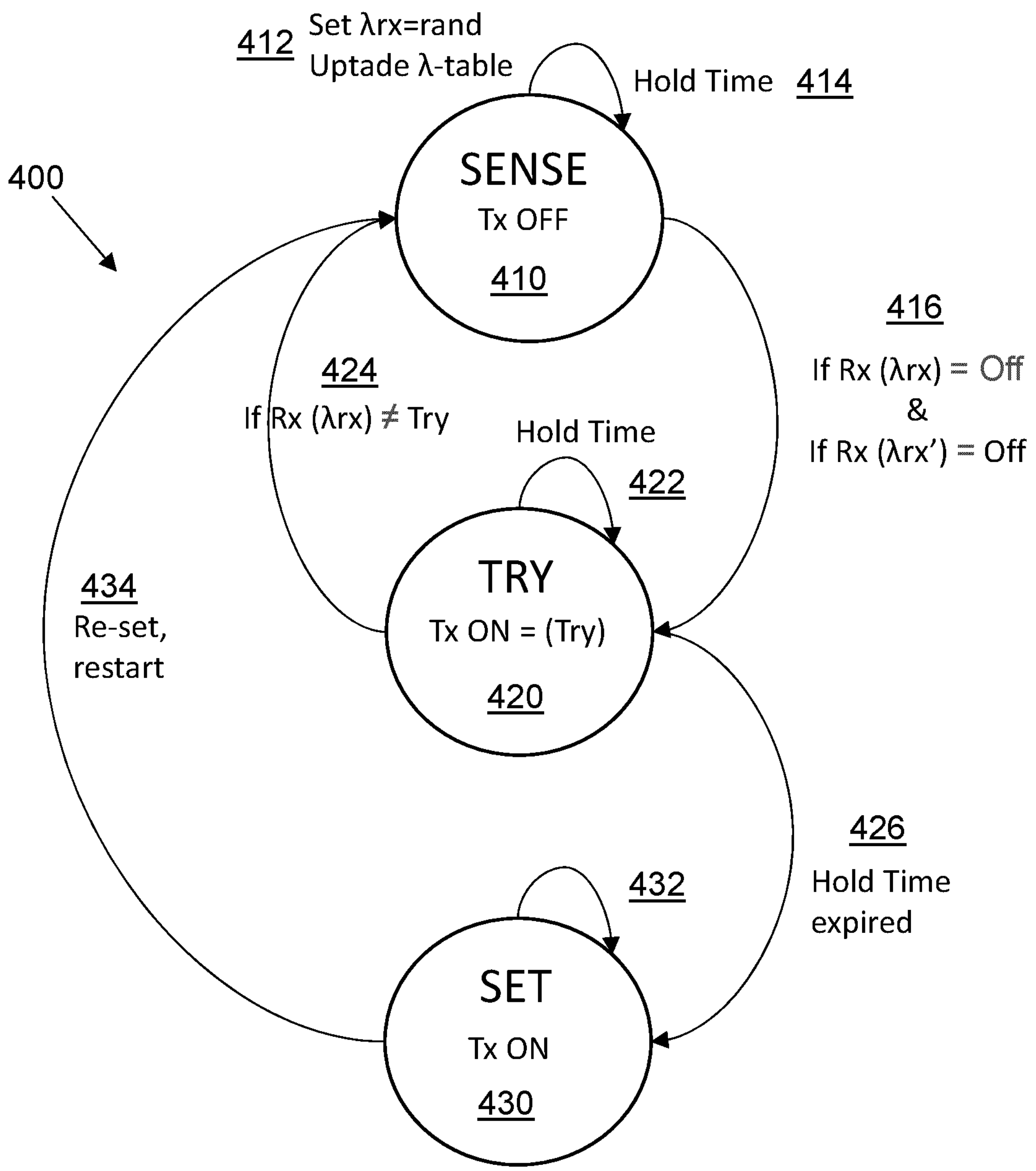
412
Set λrx=rand
Uptade λ-table
Hold Time
414
400
SENSE
Tx OFF
410
416
If Rx (λrx) = Off
&
If Rx (λrx') = Off
424
If Rx (λrx) ≠ Try
Hold Time
422
TRY
Tx ON = (Try)
420
434
Re-set,
restart
426
Hold Time
expired
432
SET
Tx ON
430

Fig. 4

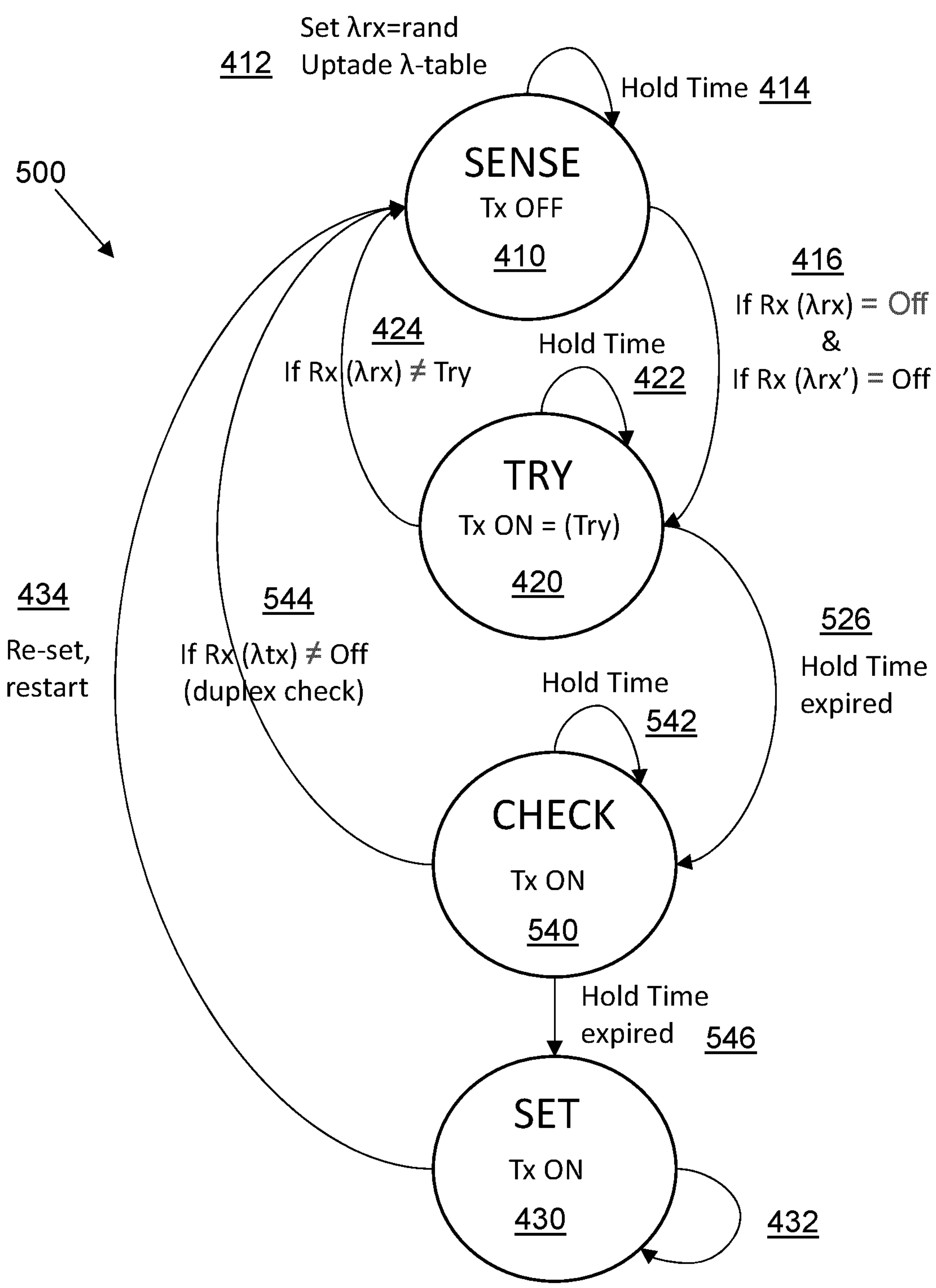
Set λrx=rand
412 Uptade λ-table
Hold Time 414
500
SENSE
Tx OFF
410
416
If Rx (λrx) = Off
&
If Rx (λrx') = Off
424
If Rx (λrx) ≠ Try
Hold Time
422
TRY
Tx ON = (Try)
420
434
Re-set,
restart
544
If Rx (λtx) ≠ Off
(duplex check)
526
Hold Time
expired
Hold Time
542
CHECK
Tx ON
540
Hold Time
expired
546
SET
Tx ON
430
432

Fig. 5

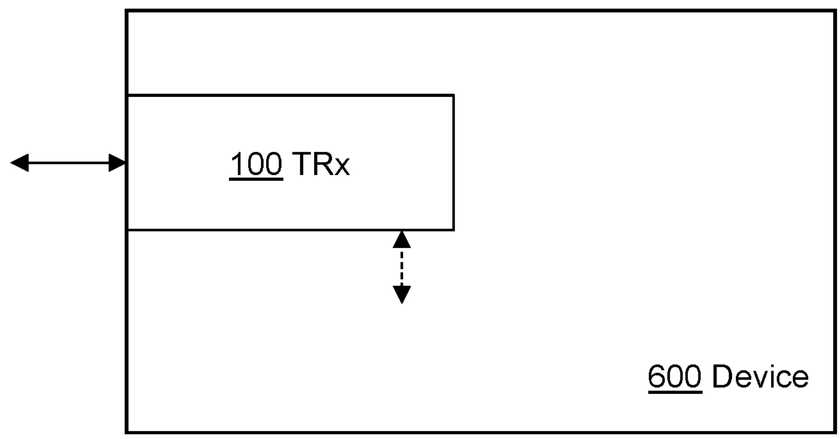
100 TRx
600 Device

Fig. 6

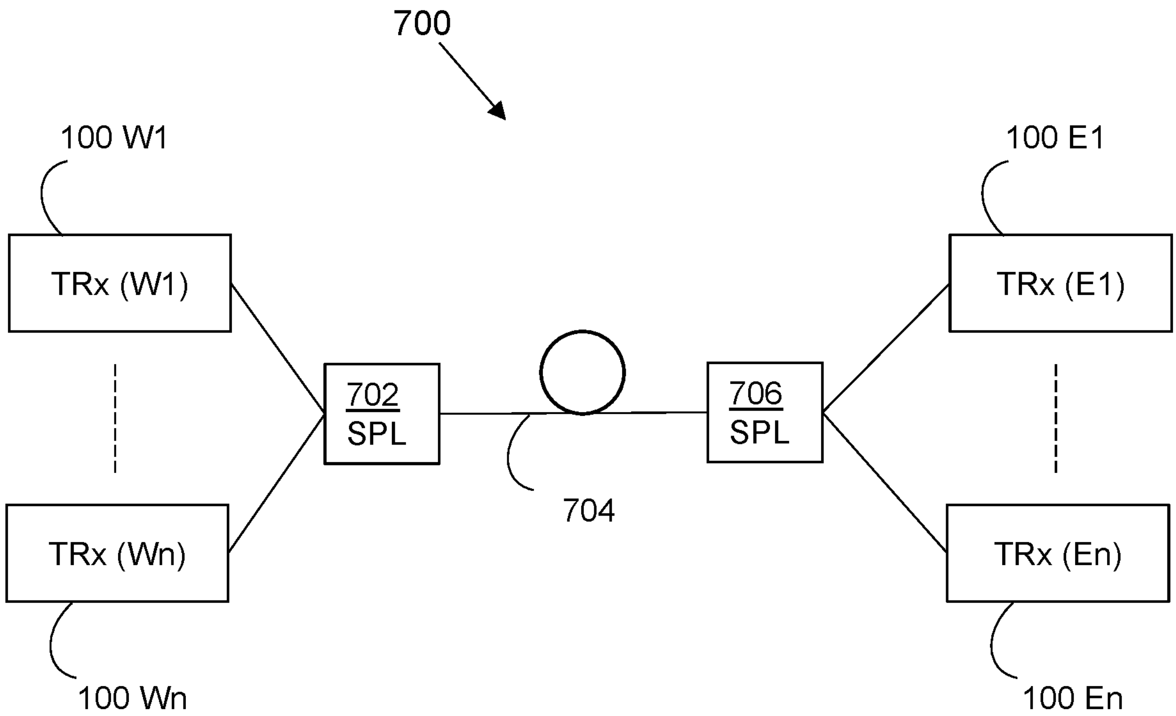
700
100 W1
TRx (W1)
TRx (Wn)
100 Wn
702
SPL
704
706
SPL
100 E1
TRx (E1)
TRx (En)
100 En

Fig. 7

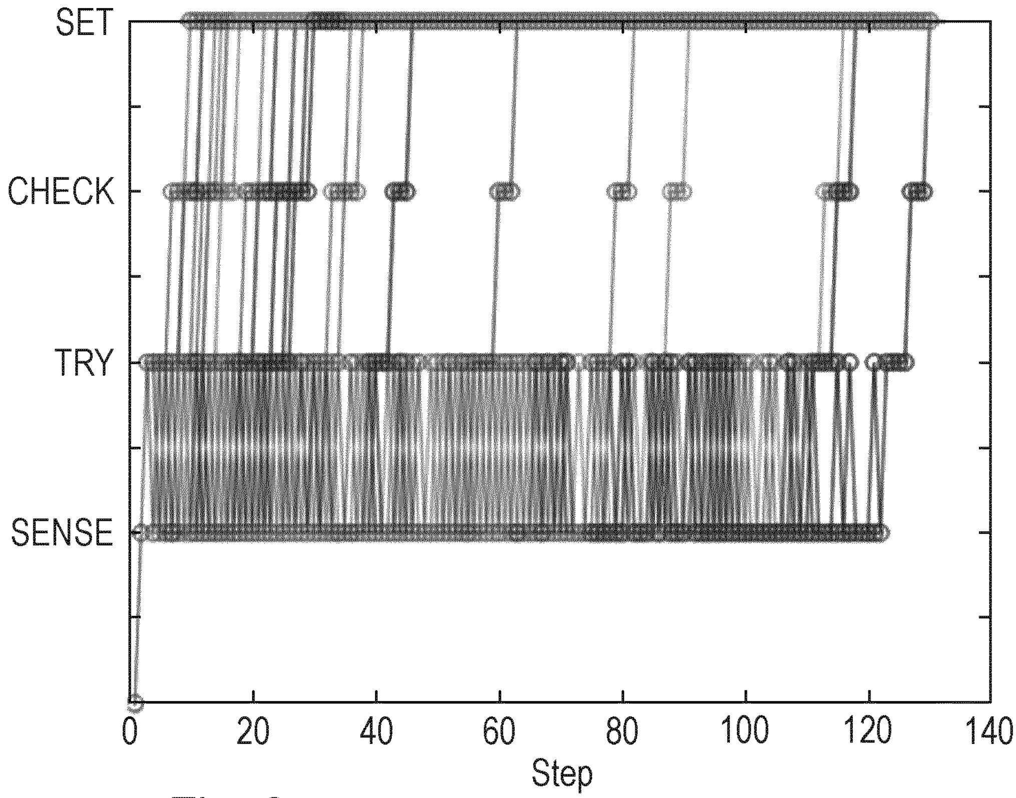
SET
CHECK
TRY
SENSE
0
20
40
60
80
100
120
140
Step

Fig. 8

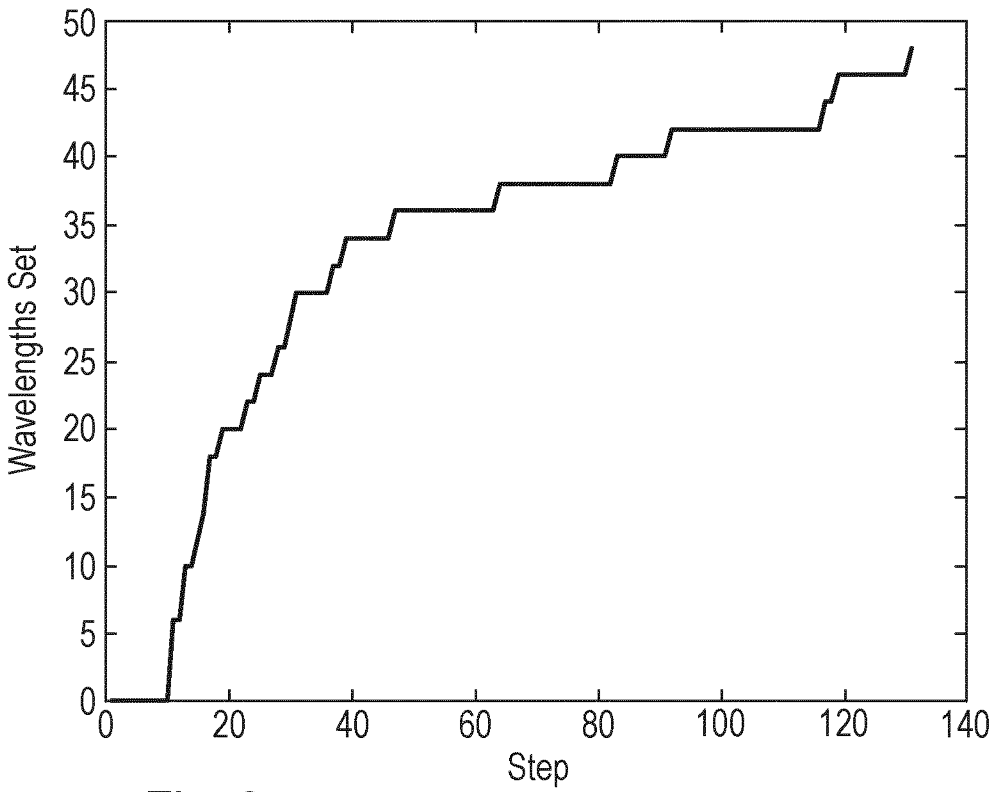
50
45
40
35
30
25
20
15
10
5
0
Wavelengths Set
0
20
40
60
80
100
120
140
Step

Fig. 9

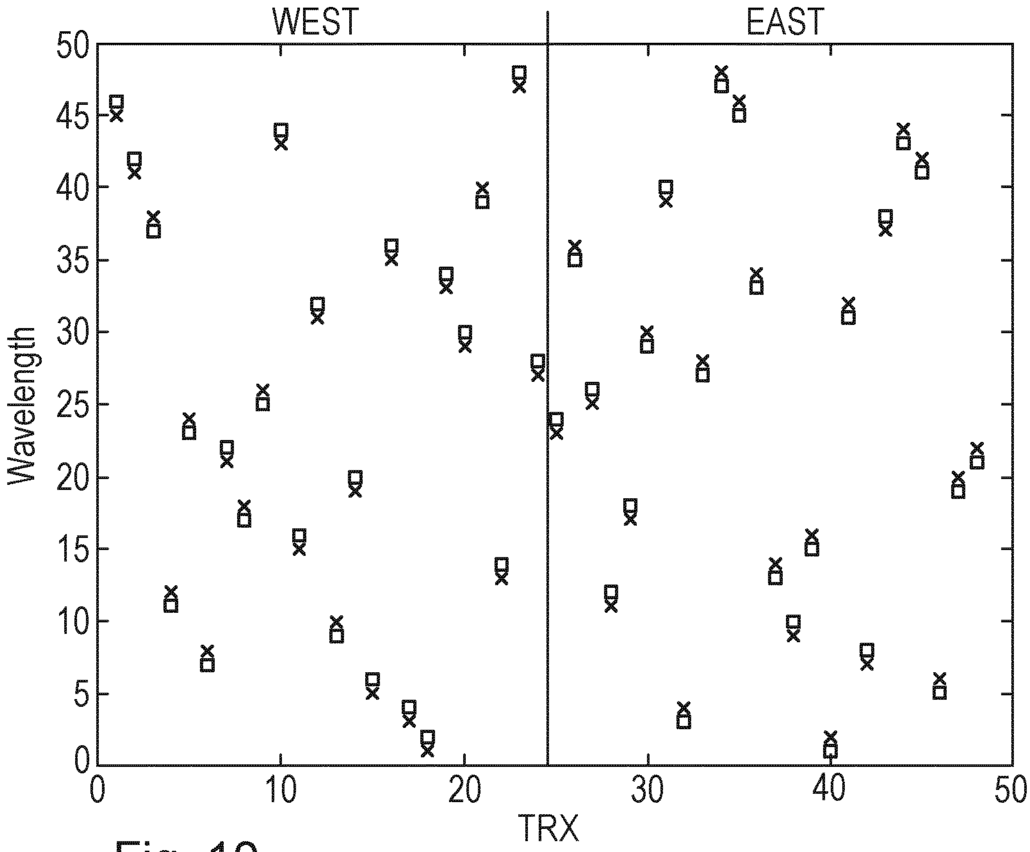
WEST
EAST
Wavelength
TRX
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50

Fig. 10

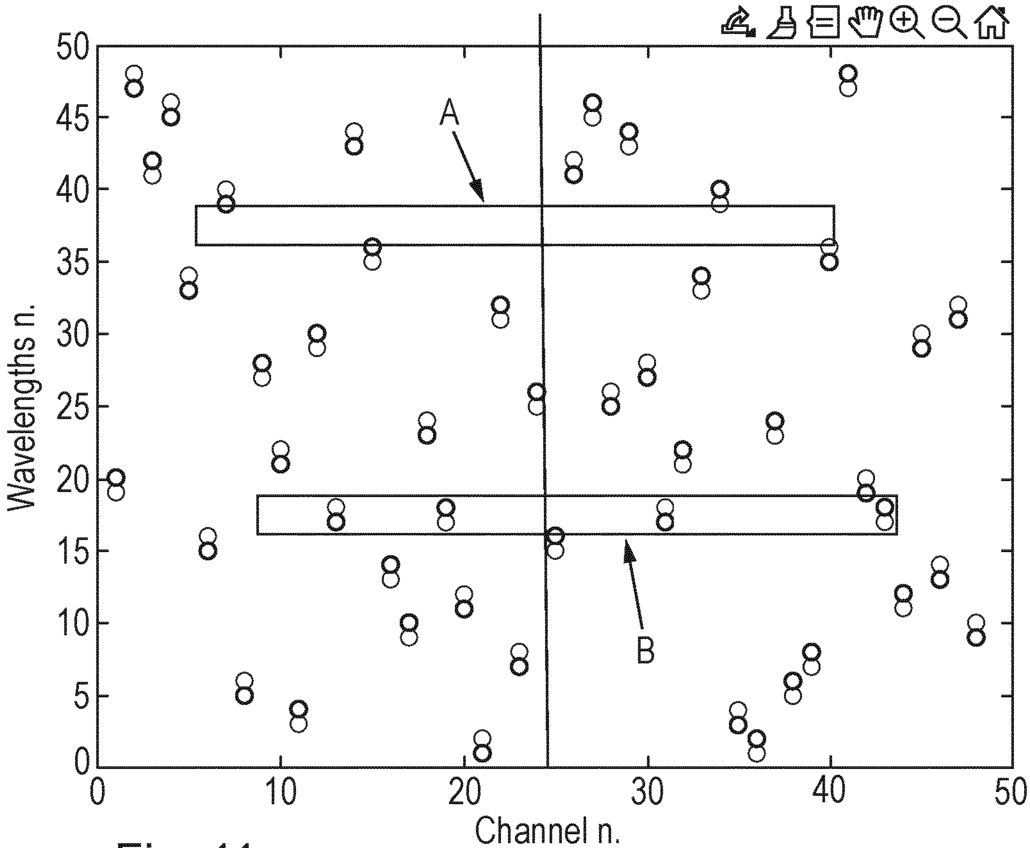
A
B
Wavelengths n.
Channel n.
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50

Fig. 11

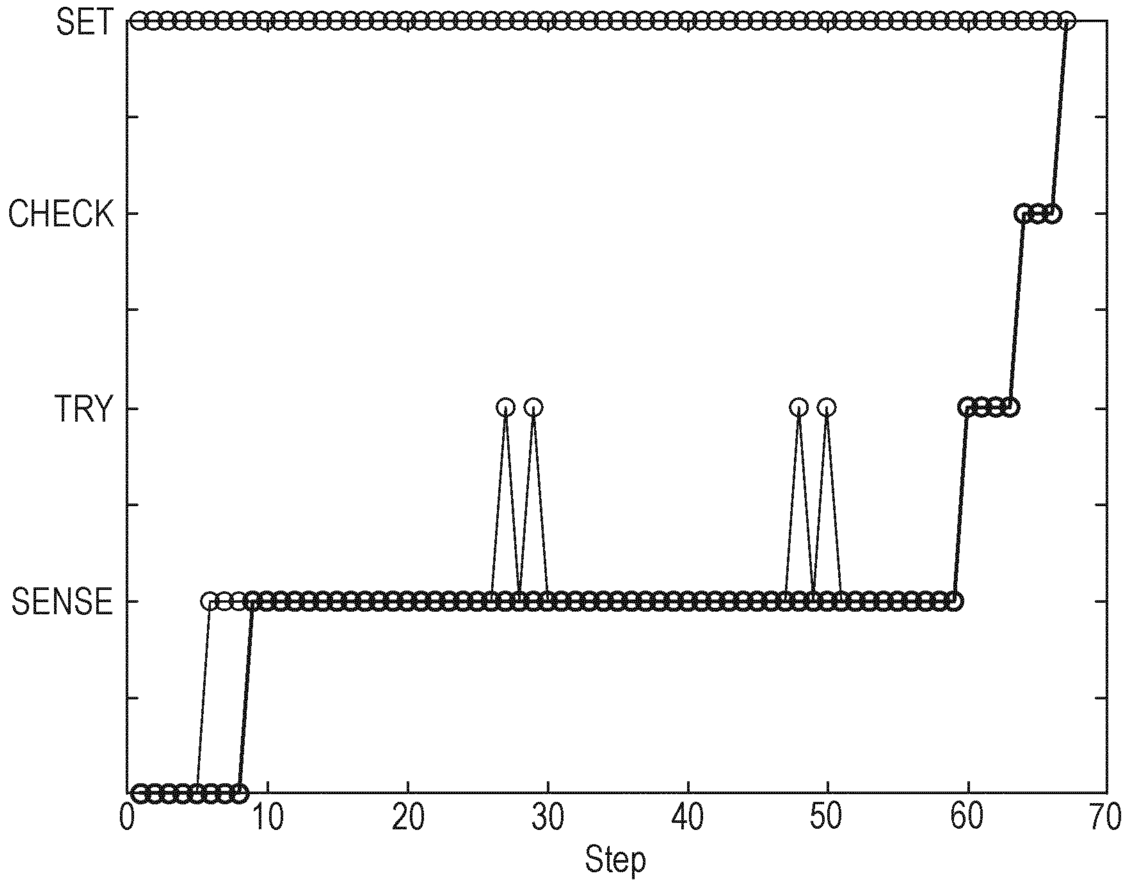

Fig. 12

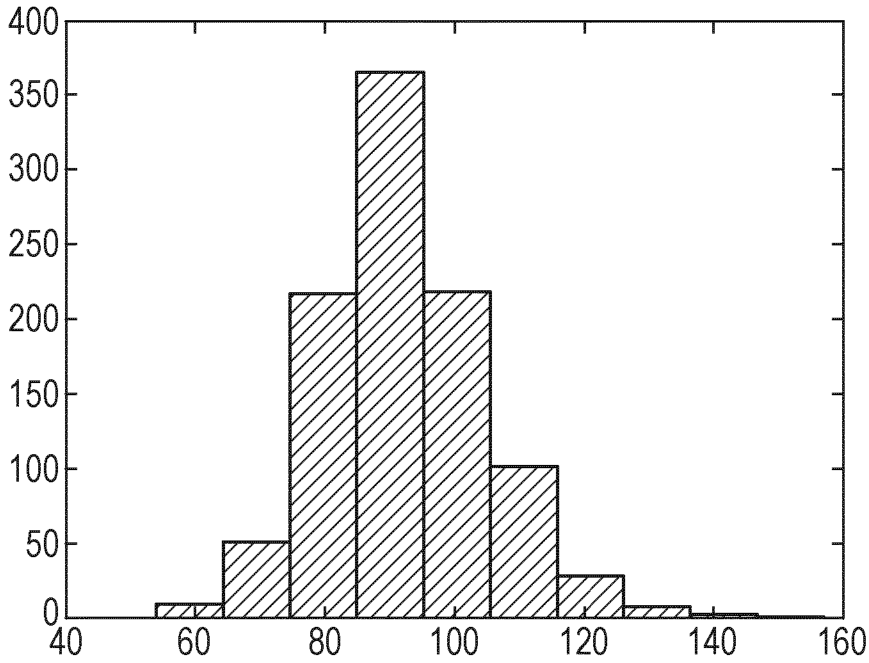
400
350
300
250
200
150
100
50
0
40
60
80
100
120
140
160

Fig. 13

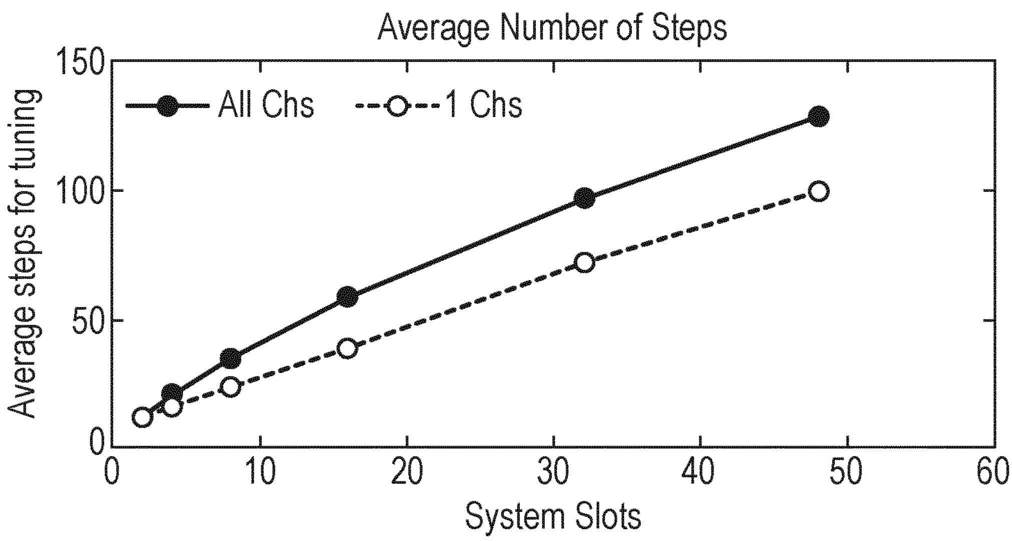
Average Number of Steps
Average steps for tuning
All Chs
1 Chs
150
100
50
0
0
10
20
30
40
50
60
System Slots

Fig. 14

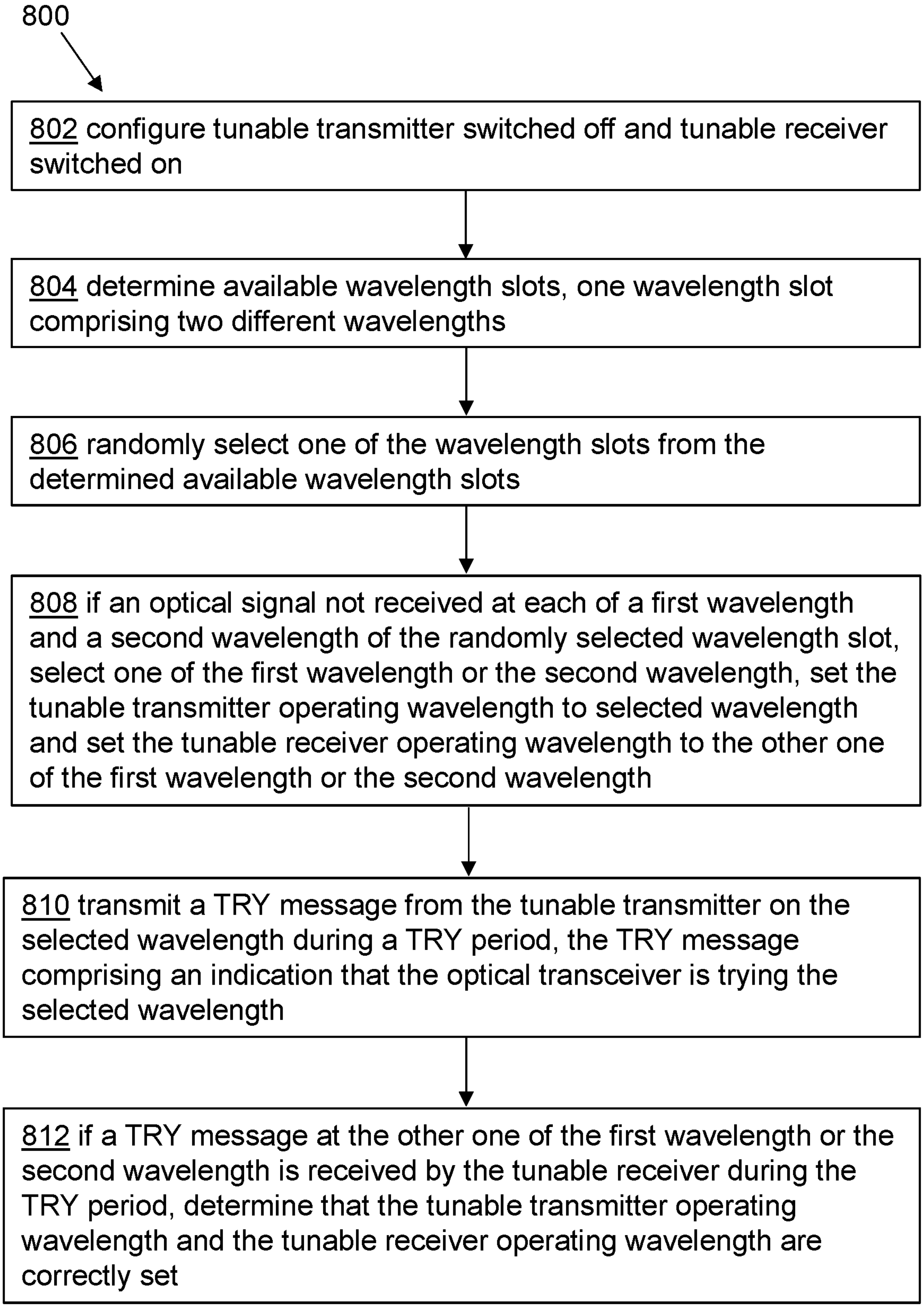
800
802 configure tunable transmitter switched off and tunable receiver switched on
804 determine available wavelength slots, one wavelength slot comprising two different wavelengths
806 randomly select one of the wavelength slots from the determined available wavelength slots
808 if an optical signal not received at each of a first wavelength and a second wavelength of the randomly selected wavelength slot, select one of the first wavelength or the second wavelength, set the tunable transmitter operating wavelength to selected wavelength and set the tunable receiver operating wavelength to the other one of the first wavelength or the second wavelength
810 transmit a TRY message from the tunable transmitter on the selected wavelength during a TRY period, the TRY message comprising an indication that the optical transceiver is trying the selected wavelength
812 if a TRY message at the other one of the first wavelength or the second wavelength is received by the tunable receiver during the TRY period, determine that the tunable transmitter operating wavelength and the tunable receiver operating wavelength are correctly set

Fig. 15

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2022/062968

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B10/25 H04B10/40 H04B10/67 H04B10/572
ADD.

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)
H04B

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)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 978 653 B1 (NIPPON TELEGRAPH & TELEPHONE [JP]) 20 June 2018 (2018-06-20) figures 4, 5 table 1 paragraph [0037] - paragraph [0040] paragraphs [0028], [0030] -----	1-19
A	US 9 496 980 B2 (CIENA CORP [US]) 15 November 2016 (2016-11-15) column 3, line 51 - line 63 -----	1-19
A	US 10 014 938 B2 (CALIX INC [US]) 3 July 2018 (2018-07-03) column 11, line 46 - column 12, line 9 -----	1-19
A	US 2015/139651 A1 (XUEJIN YAN [US] ET AL) 21 May 2015 (2015-05-21) paragraphs [0045], [0068] -----	1-19

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

☒ See patent family annex.

* Special categories of cited documents :

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"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
9 January 2023	16/01/2023

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Ganzmann, Anna

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2022/062968

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 1978653 B1	20-06-2018	CA 2601559 A1	02-08-2007
		CN 101213776 A	02-07-2008
		EP 1978653 A1	08-10-2008
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		KR 20070101296 A	16-10-2007
		US 2009016726 A1	15-01-2009
		WO 2007086514 A1	02-08-2007
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		US 2016072609 A1	10-03-2016
US 10014938 B2	03-07-2018	NONE	
US 2015139651 A1	21-05-2015	US 2015139651 A1	21-05-2015
		US 2016337071 A1	17-11-2016
		WO 2015073733 A2	21-05-2015