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(54) **A METHOD AND SYSTEM FOR ASSIGNING PERFORMANCE INDICATORS TO OBJECTS OF A NETWORK**

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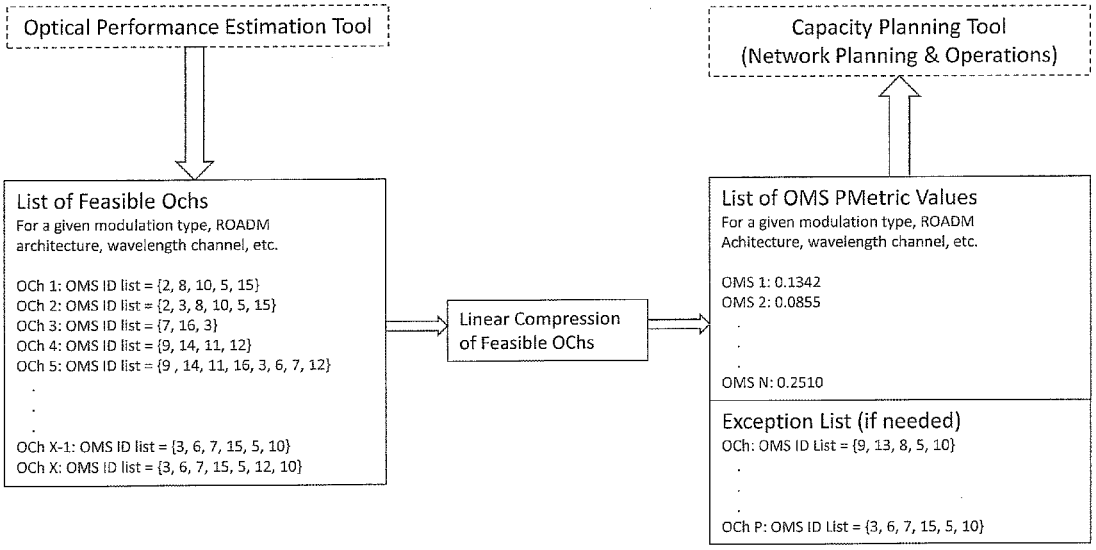
(57) **ABSTRACT**

A method of assigning performance indicators to objects of a network employing a computation to assign performance indicators to said objects of said network such that a sum of said performance indicators of objects along a given path in said network in relation to a first threshold value indicates whether said path fulfils a predetermined criterion, and/or indicates whether said path does not fulfil said predetermined criterion.

A method of evaluating a performance of a path in a network based on the performance indicators involves the steps of calculating a sum of performance indicators for said objects along said path and evaluating a performance of said path by comparing said sum against a first threshold value.



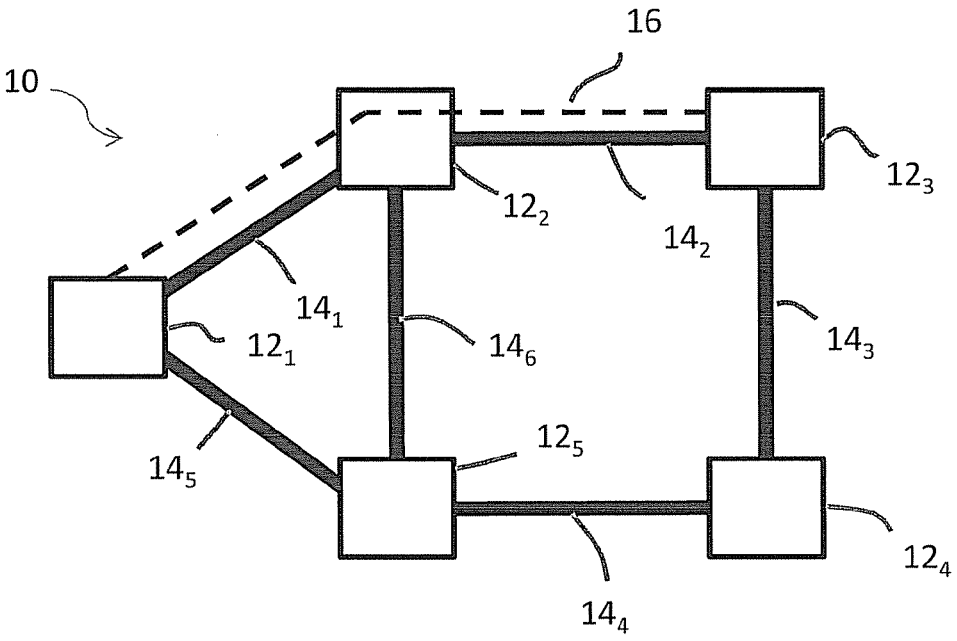


Fig. 1

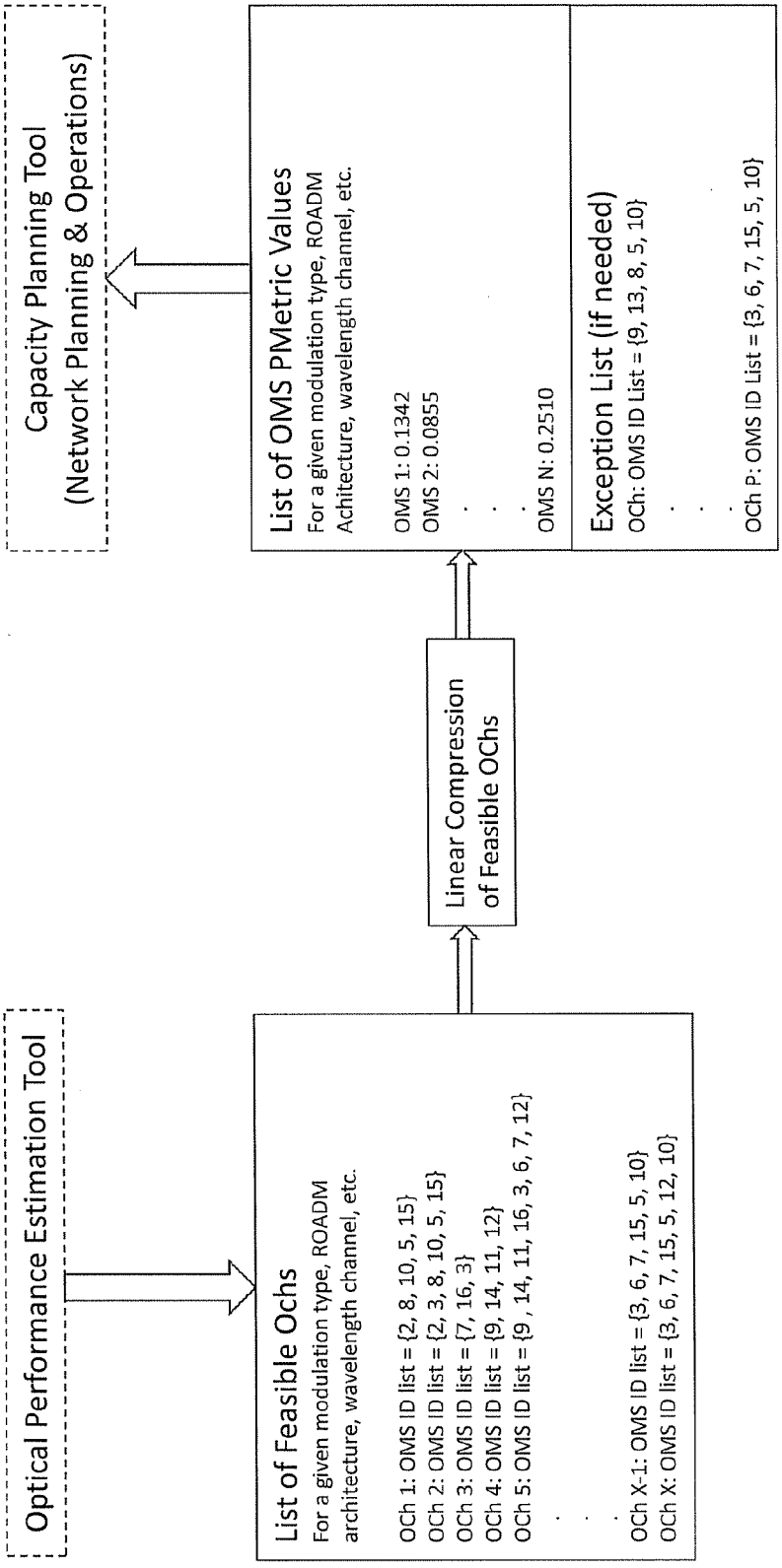

Capacity Planning Tool
(Network Planning & Operations)
List of OMS PMetric Values
For a given modulation type, ROADM
Achitecture, wavelength channel, etc.
OMS 1: 0.1342
OMS 2: 0.0855
OMS N: 0.2510
Exception List (if needed)
OCh: OMS ID List = {9, 13, 8, 5, 10}
OCh P: OMS ID List = {3, 6, 7, 15, 5, 10}
Linear Compression
of Feasible OChs
Optical Performance Estimation Tool
List of Feasible Ochs
For a given modulation type, ROADM
architecture, wavelength channel, etc.
OCh 1: OMS ID list = {2, 8, 10, 5, 15}
OCh 2: OMS ID list = {2, 3, 8, 10, 5, 15}
OCh 3: OMS ID list = {7, 16, 3}
OCh 4: OMS ID list = {9, 14, 11, 12}
OCh 5: OMS ID list = {9 , 14, 11, 16, 3, 6, 7, 12}
OCh X-1: OMS ID list = {3, 6, 7, 15, 5, 10}
OCh X: OMS ID list = {3, 6, 7, 15, 5, 12, 10}

Fig. 2

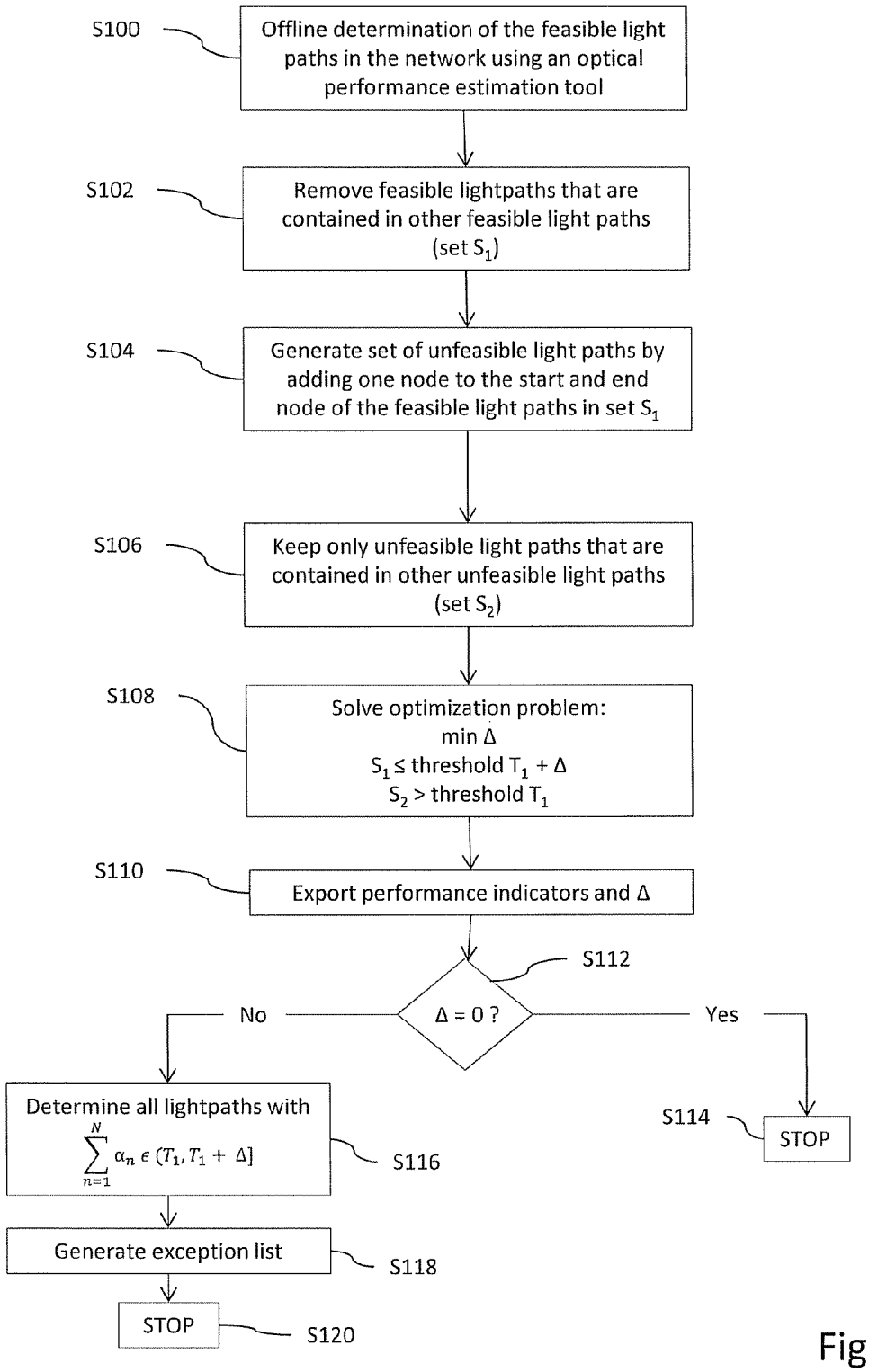

S100
Offline determination of the feasible light paths in the network using an optical performance estimation tool
S102
Remove feasible lightpaths that are contained in other feasible light paths (set S_1)
S104
Generate set of unfeasible light paths by adding one node to the start and end node of the feasible light paths in set S_1
S106
Keep only unfeasible light paths that are contained in other unfeasible light paths (set S_2)
S108
Solve optimization problem:
min Δ
$S_1 \leq$ threshold $T_1 + \Delta$
$S_2 >$ threshold T_1
S110
Export performance indicators and Δ
S112
Δ = 0 ?
No
Yes
Determine all lightpaths with $\sum_{n=1}^{N} \alpha_n \in (T_1, T_1 + \Delta]$
S116
Generate exception list
S118
STOP
S120
S114
STOP

Fig. 3

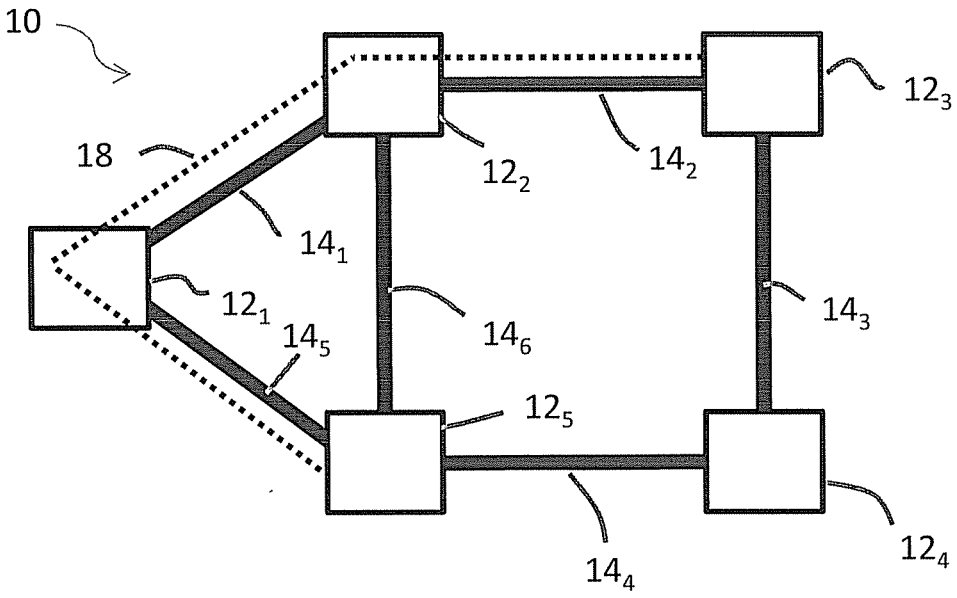


Fig. 4a

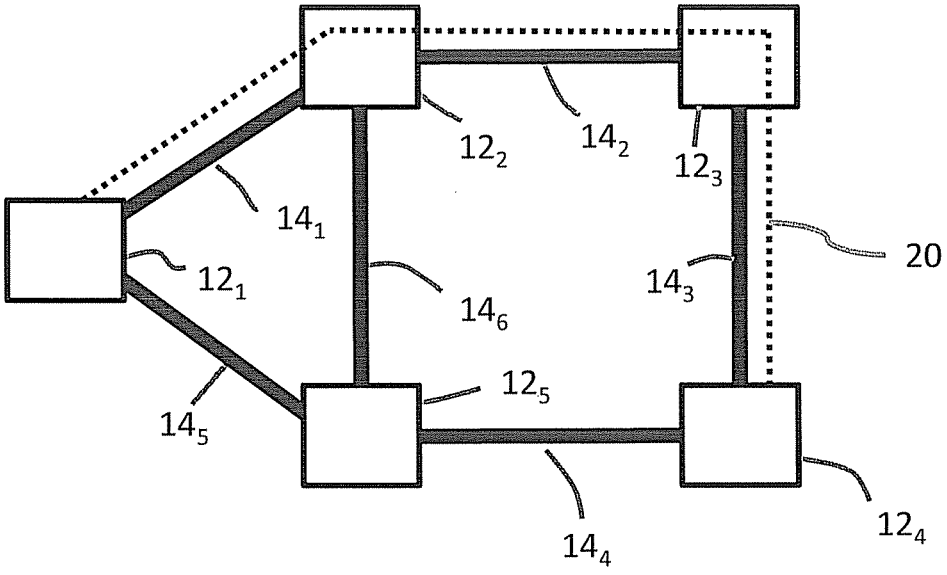


Fig. 4b

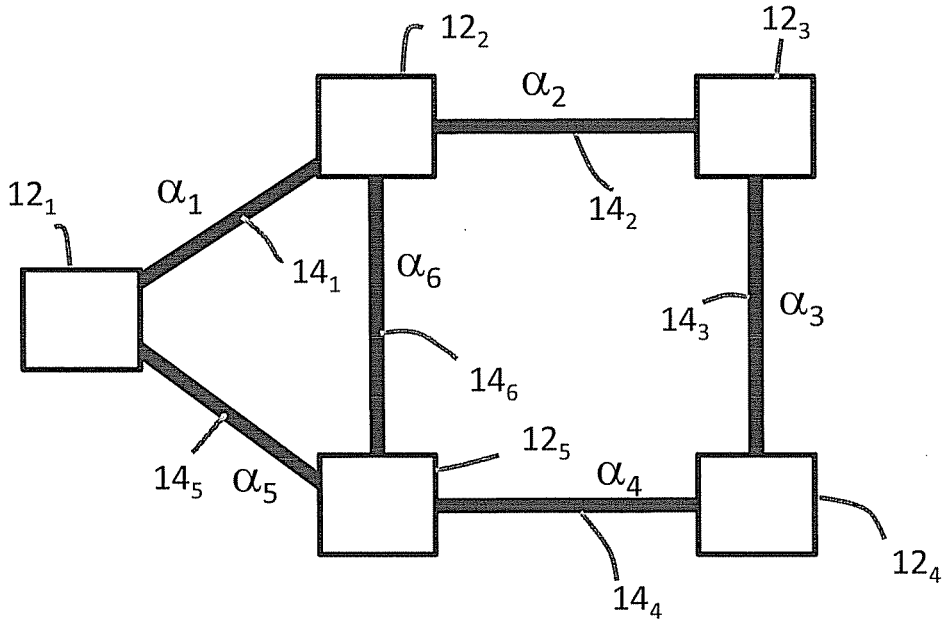

12_2
12_3
α_2
12_1
α_1
14_2
14_1
α_6
14_3
α_3
14_6
12_5
14_5
α_5
α_4
12_4
14_4

Fig. 5

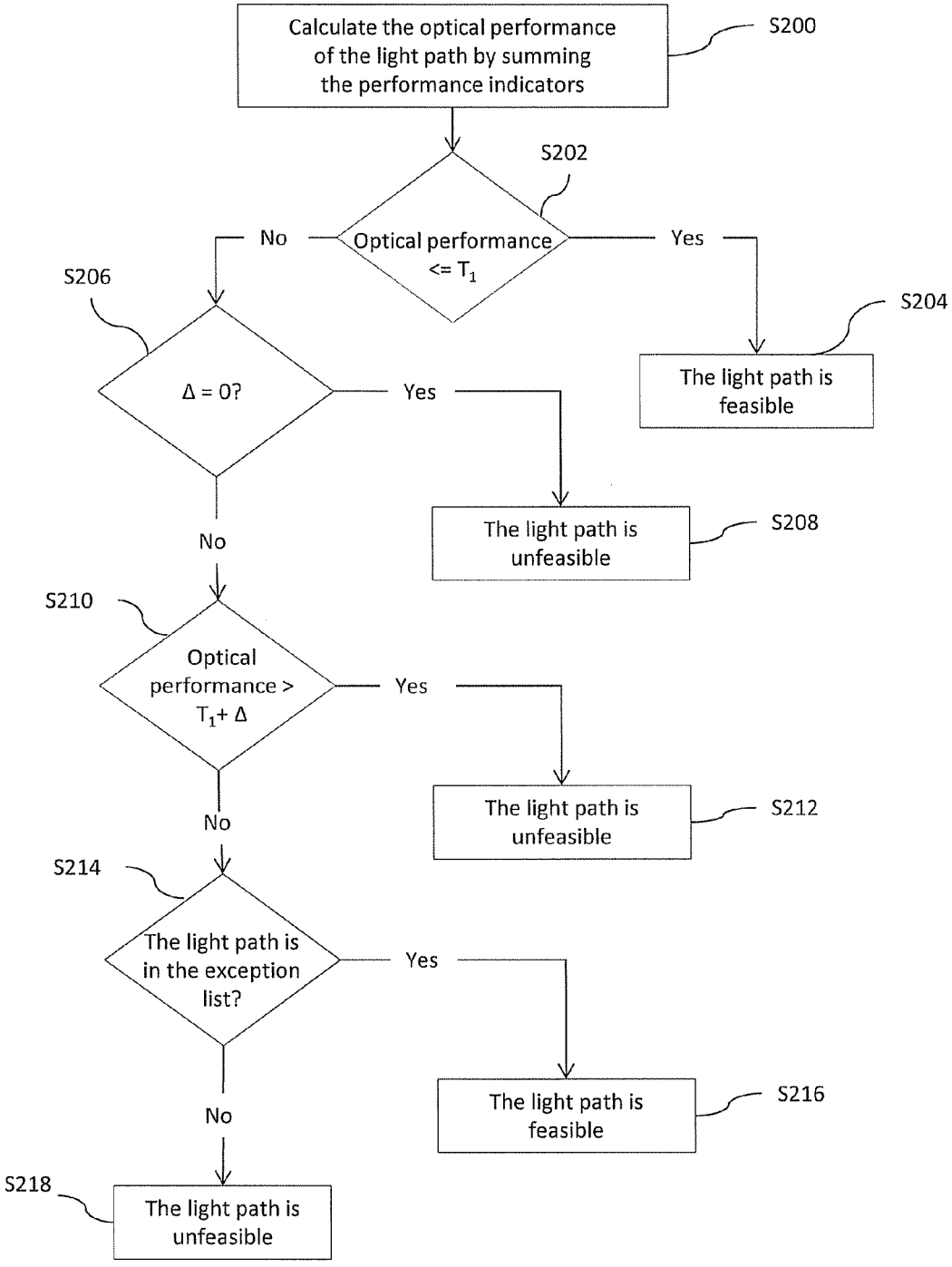

Calculate the optical performance of the light path by summing the performance indicators
S200
S202
Optical performance <= T_1
No
Yes
S204
The light path is feasible
S206
Δ = 0?
Yes
No
The light path is unfeasible
S208
S210
Optical performance > T_1+ Δ
Yes
No
The light path is unfeasible
S212
S214
The light path is in the exception list?
Yes
No
The light path is feasible
S216
S218
The light path is unfeasible

Fig. 6

A METHOD AND SYSTEM FOR ASSIGNING PERFORMANCE INDICATORS TO OBJECTS OF A NETWORK

FIELD OF THE INVENTION

[0001] The invention relates to the evaluation of performance in a network, in particular in an optical network.

BACKGROUND OF THE INVENTION

[0002] When a service is established in an optical network, a light path between the source of a signal and a destination node/nodes of a service needs to be computed. A light path may traverse a sequence of network objects connected by optical waveguides between the source and the destination node through which optical signals can travel. As the optical signal traverses the optical network objects, its quality may degrade due to the physical impairments imposed. Various optical performance parameters for measuring the optical signal quality exist, such as the optical signal to noise ratio (OSNR). If the OSNR is maintained above a given threshold, the correct detection of the optical signal is feasible. Otherwise, the light path is assumed to be unfeasible. An unfeasible light path may be made feasible by means of restoration of the distorted signals such as by means of 3R regeneration (comprising a re-shaping, a re-amplification and a re-timing of the distorted signal). However, 3R regeneration requires an intermediate node with optical-to-electrical-to-optical conversion capabilities and hence enhances the complexity and cost of the network. Network operators therefore try to reduce the number of transponders and 3R regenerators in the network, which requires a careful and accurate estimation of the optical performance and feasibility of light paths already at the planning stage and also during network operation. Transponders may be understood to realize "electrical-to-optical conversion" at the start node and "optical-to-electrical conversion" at the end node, whereas 3R regenerators perform "optical-to-electrical-to-optical conversion" at an intermediate node.

[0003] During network operation, the service setup time should be small and the control plane needs to be capable of quickly considering multiple paths using different 3R placement solutions, such as to restore the network service in case of sudden interruptions of individual network links or to establish a new service.

[0004] Optical performance estimation generally involves the assessment of the quality of the data channel and depends on a variety of aspects, such as the physical parameters of the network objects, the length of the optical multiplexing sections (OMS), the type of fibers that are used, the bit rate, the modulation format, wavelength, the type and number of channels, etc. The estimation of the optical performance of a given light path hence involves complex and time consuming computations. This poses challenges both for offline network planning and for online network restoration and/or operation.

[0005] Two approaches are conventionally used to estimate the optical performance and to check the feasibility of a light path: (i) a posteriori assessment via running a simulation or another optical performance model, and (ii) a priori assessment by computing all possible light paths in advance. However, both techniques have significant drawbacks. A posteriori calculation during routing is very time-consuming and generally makes use of various approximations to speed up the computation, which can introduce inaccuracies, thereby potentially making both single-layer and multi-layer planning inaccurate. A priori calculation is less time-consuming during routing, at the expense of additional offline computation effort in advance. However, the amount of information that needs to be (firstly) imported and (secondly) processed and utilized can be significant. Usually, large databases are needed in the form of a list or a reachability graph, and assembling and searching in the list/graph per routing instance is required, which slows down the routing process.

[0006] In summary, an assessment of the optical performance with high accuracy involves significant computational effort and huge amounts of stored data. Conversely, reducing the computational effort and the amount of data generally implies a loss of accuracy.

[0007] What is needed is an improved technique for optical performance estimation that is both accurate and requires less computational and storage resources.

OVERVIEW OF THE INVENTION

[0008] This objective is achieved with a method and system for assigning performance indicators to objects of a network according to independent claims **1** and **12**, respectively, as well as with a method and system for evaluating a performance of a path in a network according to independent claims **8** and **13**, respectively. The dependent claims relate to preferred embodiments.

[0009] The method of assigning performance indicators to objects of a network according to the present invention involves a step of determining a first set of paths in said network, each said path comprising a plurality of interconnected objects of said network, wherein said first set comprises paths that fulfil a predetermined criterion. The method further comprises a step of determining a second set of paths in said network, each said path comprising a plurality of interconnected objects of said network, wherein said second set comprises paths that do not fulfil said predetermined criterion. The method further comprises a step of assigning performance indicators to said objects of said network by means of a computation that is based on said first set of paths and said second set of paths such that a sum of said performance indicators of objects along a given path in relation to a first threshold value indicates whether said given path fulfils said predetermined criterion, and/or indicates whether said given path does not fulfil said predetermined criterion. The method according to the invention may be understood as a compression technique that converts the information content contained in said first set of paths and said second set of paths into an alternative formulation or representation in terms of performance indicators that are assigned to individual objects in said network. This conversion may preferably be achieved by means of a linear optimization algorithm. The optimization may likewise yield said first threshold value. For any given light path, summing up the performance indicators of the objects in said light path and comparing with said first threshold value provides a computationally simple and quick way to check whether said given path fulfils said predetermined criterion, and/or whether said given path does not fulfil said predetermined criterion.

[0010] The steps of determining said first set of paths and determining said second set of paths in said network as well

as the linear optimization and assigning of performance indicators to said objects in said network may be performed off-line during the planning stage of the network. These steps yield a set of performance indicators attributed to said objects of said network. Said performance indicators may be real numbers and hence require much less storage resources than the full set of feasible light paths.

[0011] Once an event occurs in the network where routing becomes necessary, feasibility of paths may be checked quickly by summing up the performance indicators of the respective network objects in the light paths and comparing with said first threshold value. This requires only relatively few computational resources, and hence can be done quickly and efficiently during the network operation.

[0012] Said method may comprise a step of determining said performance indicators by means of said computation before assigning said performance indicators to said objects.

[0013] Said computation may involve a linear optimization.

[0014] Linear optimization, sometimes called linear programming, is generally known as a method in mathematical optimization theory in which the model requirements are represented by linear relationships. More formally, linear optimization may be understood as a technique for the optimization of a linear objective function subject to linear equality and/or linear inequality constraints.

[0015] A network, in the sense of the present invention, may be an optical network, but may likewise be any other network suitable for signal and/or information transmission in which signal quality degrades, such as an electrical network.

[0016] Network objects, in the sense of the present invention, may be any components of the network. In particular, these may be (active or passive) components that have an effect on the information and/or data transmission in the network, such as components that affect the signal quality.

[0017] In case the network is an optical network, network objects may comprise active or passive components, including both network elements and network links, such as optical multiplexing sections (OMS), optical fibers, wave division multiplexers/demultiplexers, switches or splitters, or any other kind of network component or network element that may introduce signal degradations that may affect an optical performance metric, such as the optical signal-to-noise ratio (OSNR).

[0018] In general, said network may be represented in terms of a graph. Said network objects may be represented in terms of nodes or links of said graph.

[0019] A path in said network may be understood as a sequence or chain of interrelated or linked network objects in said network.

[0020] Said predetermined criterion may be any criterion relating to or characterizing a signal or data transmission along said path.

[0021] In particular, said path may fulfil said predetermined criterion in case said path is suitable for signal transmission according to said predetermined criterion, and/or said path may not fulfil said criterion in case said path is not suitable for signal transmission according to said predetermined criterion.

[0022] Said criterion may in particular relate to or involve an optical performance metric, such as OSNR.

[0023] In a preferred embodiment, said first set of paths is a subset of all the paths in the network that fulfil said predetermined criterion.

[0024] Similarly, said second set of paths may be a subset of all the paths in the network that do not fulfil said predetermined criterion

[0025] In a preferred embodiment, said given path fulfils said predetermined criterion if said sum of said performance indicators of objects along said path is below said first threshold value, or if said sum of said performance indicators of objects along said path is above said first threshold value.

[0026] There are usually various alternative or equivalent ways in which the computation can be cast in mathematical terms. In particular, the relation may depend on how the computation, in particular the linear optimization problem, is formulated.

[0027] Additionally or alternatively, in an embodiment said given path does not fulfil said predetermined criterion if said sum of said performance indicators of objects along said path is above said first threshold value, or if said sum of said performance indicators of objects along said path is below said first threshold value.

[0028] The computation according to the present invention may yield a first threshold value that provides a sharp separation between paths in said first set and paths in said second set. This is a particularly advantageous configuration, in the sense that it allows to uniquely assign either the first set or the second set to a given path based on a comparison with a single first threshold value.

[0029] However, in other embodiments the method further comprises a step of determining a second threshold value by means of said computation, wherein a sum of said performance indicators of objects along a given path in relation to said first threshold value indicates whether said path fulfils said predetermined criterion, and wherein a sum of said performance indicators of objects along a given path in relation to said second threshold value indicates whether said path does not fulfil said predetermined criterion, or vice versa.

[0030] Said second threshold value may be different from said first threshold value.

[0031] In a preferred embodiment, said first set of paths is a set of paths that cannot be lengthened in said network without failing to fulfil said predetermined criterion.

[0032] Hence, said first set of paths may be the set of the longest paths that fulfil said predetermined criterion.

[0033] Said second set of paths may be a set of paths that cannot be shortened in said network without fulfilling said predetermined criterion.

[0034] Hence, said second set of paths may be the set of the shortest paths that do not fulfil said predetermined criterion.

[0035] Assigning the first set of paths and the second set of paths according to these embodiments avoids redundancies in the computation, in particular the linear optimization and hence reduces the computational effort required for assigning the performance indicators.

[0036] In a preferred embodiment, the method comprises a step of storing said assigned performance indicators for said objects.

[0037] A routing algorithm may check whether a given path is feasible simply by reverting to the stored perfor-

mance indicators, computing their sum along the given path and comparing with the respective threshold value.

[0038] In a preferred embodiment, said computation is of the form

$$\min\Delta \qquad (1)$$

$$\Sigma_n \alpha_n \leq T_1 + \Delta,\ \Sigma_m \alpha_m \geq T_1,$$

[0039] wherein $\{\alpha_n\}$ denotes a set of said performance indicators attributed to objects $\{1, \ldots, N\}$, wherein the sum $\Sigma_n\ \alpha_n$ is over all paths in said first set, and wherein the sum $\Sigma_m\ \alpha_m$ is over all paths in said second set, and wherein T_1 denotes said first threshold. Δ is the objective function. A more complete description of the optimization will be given in Eq. (2) below in conjunction with the description of the preferred embodiments.

[0040] $T_2=T_1+\Delta$ may be understood to denote said second threshold value, and the computation strives to minimize the difference between T_1 and $T_2=T_1+\Delta$.

[0041] In case $\Delta=0$, the optimization yields a single threshold value, and paths can be checked to belong either to the first set of paths or to the second set of paths uniquely based on a comparison of the sum of the respective performance indicators with said single threshold value.

[0042] The previous embodiments were concerned with methods of assigning the performance indicators to objects in the network. However, in a preferred embodiment the method also comprises the calculation steps for evaluating the performance of a given path. In this embodiment, the method involves the steps of calculating a sum of said assigned performance indicators for said objects along said given path and evaluating a performance of said given path by comparing said sum against said first threshold value and/or against said second threshold value.

[0043] Evaluating a performance of a path in a network constitutes a second independent aspect of the invention. In this second aspect, the invention relates to a method for evaluating a performance of a path in the network, said path comprising a plurality of interconnected objects in said network, wherein performance indicators are assigned to said objects, said method comprising the steps of calculating a sum of performance indicators for said objects along said path, and evaluating a performance of said path by comparing said sum against a first threshold value.

[0044] In a preferred embodiment, said step of evaluating said performance comprises a step of determining whether said path fulfils a predetermined criterion by comparing said sum against said first threshold value, and/or determining whether said path does not fulfil said predetermined criterion by comparing said sum against said first threshold value.

[0045] Said step of evaluating said performance may, alternatively or additionally, also comprise a step of determining whether said path does not fulfil said predetermined criterion by comparing said sum against a second threshold value, and/or determining whether said path fulfils said predetermined criterion by comparing said sum against said second threshold value.

[0046] As described with respect to the embodiments above, said path may fulfil said predetermined criterion in case said path is suitable for signal transmission according to said predetermined criterion.

[0047] Similarly, in a preferred embodiment said path does not fulfil said criterion in case said path is not suitable for signal transmission according to said predetermined criterion.

[0048] In a configuration in which the computation, in particular the linear optimization yields a first threshold value and a second threshold value, said step of evaluating said performance of said path may comprise a step of reverting to a performance listing if said sum is in between said first threshold value and said second threshold value.

[0049] Said performance listing may comprise performance parameters of those paths whose sum of performance indicators is in between said first threshold value and said second threshold value, and hence may not allow a reliable assignment to either said first set or said second set based on the performance indicators alone.

[0050] Reverting to a separate performance listing provides an efficient way of dealing with these paths.

[0051] In said method of evaluating a performance of a path in a network according to the second aspect, said performance indicators may be determined according to the method of the first aspect of the invention.

[0052] In the first aspect, the invention further relates to a system for assigning performance indicators to objects of a network, comprising means for determining a first set of paths in said network, each said path comprising a plurality of interconnected objects of said network, wherein said first set comprises paths that fulfil a predetermined criterion. Said system further comprises means for determining a second set of paths in said network, each said path comprising a plurality of interconnected objects in said network, wherein said second set comprises paths that do not fulfil said predetermined criterion.

[0053] Said system further comprises means for assigning performance indicators to said objects of said network by means of a computation that is based on said first set of paths and said second set of paths, such that a sum of said performance indicators of objects along a given path in relation to a first threshold value indicates whether said given path fulfils said predetermined criterion, and/or indicates whether said given path does not fulfil said predetermined criterion.

[0054] Said system may be adapted to perform a method with some or all of the features described above in connection with the first aspect.

[0055] In a preferred embodiment, the system further comprises means for calculating a sum of said assigned performance indicators for said objects along said given path as well as means for evaluating a performance of said given path by comparing said sum against said first threshold value.

[0056] In the second aspect, the invention also relates to a system for evaluating a performance of a path in a network, said path comprising a plurality of interconnected objects in said network, wherein performance indicators are assigned to said objects, said system comprising means for calculating a sum of performance indicators for said objects along said path, as well as means for evaluating a performance of said path by comparing said sum against a first threshold value.

[0057] Said system may be adapted to perform a method with some or all of the features described above in connection with the second aspect of the invention.

[0058] Said system may further comprise a storage unit for storing said performance indicators for said objects.

[0059] The invention further relates to a computer program or computer program product comprising computer-readable instructions, wherein said computer-readable instructions, when read on a computing device connected to a system with some or all of the features described above implement on said computing device a method with some or all of the features described above.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0060] The features and numerous advantages of the method and system according to the present invention will be best apparent from a detailed description of preferred embodiments with reference to the accompanying drawings, in which:

[0061] FIG. **1** is a schematic drawing of an optical network topology in which the present invention may be employed;

[0062] FIG. **2** is a diagram showing the operation principle of a method of assigning performance indicators to objects of the network according to an embodiment of the invention;

[0063] FIG. **3** is a flow diagram illustrating a method of assigning performance indicators to objects of a network according to an embodiment of the invention;

[0064] FIGS. **4***a* and **4***b* illustrate how unfeasible optical paths may be generated from feasible optical paths in a step in the flow diagram of FIG. **3**;

[0065] FIG. **5** illustrates how performance indicators are assigned to network objects for the network topology of the example of FIG. **1**; and

[0066] FIG. **6** is a flow diagram that illustrates a method of evaluating the performance of a path in a network according to an embodiment of the invention.

[0067] The invention will now be described with reference to an optical network in which light signals are employed to transfer data between nodes via optical communication channels, such as optical fibers. However, this is merely one example of a network in which the present invention can be employed. In general, the invention can be used in any network for signal or data transmission.

[0068] In the optical network example that follows, the objects of the network to which performance indicators are assigned are network connections or network links that may comprise optical fibers and connect network elements such as wavelength division multiplexers or demultiplexers, optical switches, or splitters. However, this is merely an example. In more generality, network objects in the sense of the present invention may be understood to encompass any network equipment or network component, either passive or active, that may degrade the signal quality of optical signals traversing the network. Hence, network objects may include optical network connections such as fiber links, but also any other kind of device that can be employed in an optical network, such as network elements, in particular wavelength division multiplexers or demultiplexers, optical switches, or splitters.

[0069] FIG. **1** shows an example of an optical network **10** with optical network elements $\mathbf{12}_1$ to $\mathbf{12}_5$ that are interconnected by network links $\mathbf{14}_1$ to $\mathbf{14}_6$. The links $\mathbf{14}_1$ to $\mathbf{14}_6$ denote which of the optical network elements $\mathbf{12}_1$ to $\mathbf{12}_5$ are interconnected in the optical network **10**.

[0070] FIG. **1** shows an example of a small network, but this is merely for illustration purposes, and in general the optical network **10** can comprise any number of optical network elements **12** and corresponding links **14**.

[0071] An example of an optical path or light path **16** that comprises the optical network elements $\mathbf{12}_1$, $\mathbf{12}_2$ and $\mathbf{12}_3$ and network links $\mathbf{14}_1$ and $\mathbf{14}_2$ is shown in broken lines in FIG. **1**. The optical network links, such as the links $\mathbf{14}_1$ and $\mathbf{14}_2$ generally degrade the signal quality, which can be measured in terms of an optical performance metric such as the optical signal to noise ratio (OSNR). The light path **16** is considered to be feasible if an optical performance metric is maintained below a given threshold, indicating that the degradation of the optical signal is sufficiently small to allow for correct detection of the optical signal. Otherwise, the light path is assumed to be unfeasible, and 3R regeneration can be provided in an intermediate node to enhance the signal quality.

[0072] Optical performance estimation to distinguish between feasible and unfeasible light paths involves the assessment of the quality of the data channel and depends on various aspects such as the length and the type of optical fibers, the number and type of the optical network links traversed, the bit rate or the modulation format. The complexity of the optical performance evaluation usually requires large computational and storage resources. This provides a particular challenge in situations in which a network fault occurs, such as due to a cut in an optical fiber, and re-routing has to be performed quickly to restore the network operation, or when a new service needs to be quickly established. Alternatively, all feasible light paths may be computed in advance, thus avoiding time-consuming online computations in the re-routing process. However, the main disadvantage of the latter approach is that it may require maintaining a large set of data comprising all feasible light paths in the network for both offline and online applications. Exploiting this large data set in online applications can also be time-consuming.

[0073] The invention according to the preferred embodiment proposes a solution that assigns performance indicators to the objects, in particular the links of a network by means of an optimization computation, in particular by means of linear optimization. This results in a compression of the optical channel performance information that allows to evaluate the feasibility of an optical light path **16** in the network **10** simply by summing up the performance indicators of the optical network objects, such as along the network links $\mathbf{14}_1$ and $\mathbf{14}_2$ along the light path **16**, and comparing the sum with a threshold value that is a parameter in the linear optimization.

[0074] FIG. **2** is a high-level diagram that illustrates the idea underlying the invention. An optical performance estimation tool, such as TransNet, may be employed to determine all the feasible light paths in the network **10**. Feasibility may be determined based on a pre-defined criterion, such as optical signal to noise ratio (OSNR). Such optical performance estimation tools are generally known in the art, and hence a detailed description is omitted.

[0075] The optical performance estimation may yield a list of X feasible optical channels OChs **1** to X in the network.

[0076] The feasible optical channels OCh **1** to OCh X may be given in terms of ordered collections of network objects, in this case ordered collections of optical multiplexing sections (OMS), which denote the sections or links between consecutive WDM multiplexers/demultiplexers.

[0077] The calculation according to the present invention converts this information into a set of N performance indicators that are attributed to the network objects. Each of the optical multiplexing sections OMS **1** to OMS N may hence be assigned one performance indicator, e.g., one real number.

[0078] In addition, there may be an exception list of those P optical channels for which the assignment of performance indicators may not be fully conclusive to decide whether the channel is feasible or not.

[0079] The assigned performance indicators (and exception list, if needed) may then be used efficiently to evaluate the performance and feasibility of an optical path in the network during network planning and operations, such as in a capacity planning tool for routing algorithms such as the DIJKSTRA algorithm.

[0080] FIG. **3** is a flow diagram that shows an example of how performance indicators may be assigned to objects of a network, such as the optical multiplexing sections or links $\mathbf{14}_1$ to $\mathbf{14}_6$ by means of linear optimization.

[0081] In a first step S**100**, all the feasible light paths in the optical network **10** are determined by means of an optical performance estimation tool. As described above with reference to FIG. **2**, any conventional optical performance estimation tool, such as TransNet, may be employed for that purpose. Depending on the size and characteristics of the network and depending on the feasibility criterion, a determination of the feasible light paths may require significant computational resources. However, this is not a major concern, since step S**100** may be executed offline as part of the network planning, or as a background process when the network is operating.

[0082] In a subsequent step S**102**, those feasible light paths that are contained in other feasible light paths are removed from the set of feasible light paths in step S**100**. This will yield a first set of light paths in said network, which will henceforth be denoted set S_1. The set S_1 may alternatively be characterized as the set containing the longest feasible light paths.

[0083] For instance, referring to the example given in FIG. **1** and assuming that the light path **16** comprising of the optical network links $\mathbf{14}_1$ and $\mathbf{14}_2$ (as well as the network elements $\mathbf{12}_1$, $\mathbf{12}_2$ and $\mathbf{12}_3$) is feasible, the same will generally be true for subsections of the light path **16**, such as the light path comprising only the link $\mathbf{14}_1$ and the optical network elements $\mathbf{12}_1$ and $\mathbf{12}_2$. This is because additional network objects usually introduce additional signal distortions. Hence, a subsection of a feasible light path **16** will usually experience a lesser degree of signal degradation and hence will likewise be feasible. In step S**102**, the feasible light path consisting of the optical link $\mathbf{14}_1$ and the optical network elements $\mathbf{12}_1$ and $\mathbf{12}_2$ would be removed from the set of feasible light paths, since it is fully contained in the optical path **16** that is likewise feasible. Removing the feasible light paths that are contained in other feasible light paths excludes redundant light paths, thereby simplifying the computation.

[0084] Based on set S_1 of the longest feasible light paths, a set of unfeasible light paths is generated in step S**104** by adding one network object, in particular one network link, to the start node of the feasible light paths in set S_1 and by adding one network object, in particular one network link to the end node of the feasible light paths. Cycles are avoided, i.e. optical objects that are already in the light path are not considered as possible extensions.

[0085] Generation of the set of unfeasible light paths in step S**104** is illustrated in FIGS. **4***a* and **4***b* for the network configuration of FIG. **1**.

[0086] The feasible light path **16** shown in FIG. **1** has the start node $\mathbf{12}_1$ and the end node $\mathbf{12}_3$. Assuming that the light path **16** has no feasible extensions and hence is a longest feasible light path contained in set S_1, an extension from the start node $\mathbf{12}_1$ to node $\mathbf{12}_5$ via the additional link $\mathbf{14}_5$ will result in an unfeasible light path **18**, as shown in FIG. **4***a*.

[0087] Similarly, extending the feasible light path **16** from the end node $\mathbf{12}_3$ to node $\mathbf{12}_4$ via the additional link $\mathbf{14}_3$ will result in another unfeasible light path **20**, as shown in FIG. **4***b*.

[0088] In a subsequent step S**106**, among the set of unfeasible light paths determined in step S**104**, only those unfeasible light paths that are contained in other unfeasible light paths are kept. The resulting subset of unfeasible light paths is denoted set S_2. The set S_2 may be characterized as the set containing the shortest unfeasible light paths, in the sense that the light paths in the set S_2 become feasible if they are shortened by just one network object, in particular by just one network link.

[0089] Based on the set S_1 and S_2 a linear optimization problem can be formulated as follows:

$$\min\Delta \tag{2}$$

$$\left\{p \in S_1 \mid p = \{p_1, \ldots, p_N\}, \sum_{n=1}^{N} \alpha_n \le T_1 + \Delta\right\}$$

$$\left\{q \in S_2 \mid q = \{q_1, \ldots, q_M\}, \sum_{m=1}^{M} \alpha_m > T_1\right\}$$

[0090] In Equation (2), p denotes a light path in the set S_1, which is given as an ordered tuple $\{p_1, \ldots, p_N\}$ of interconnected network objects p_n that are traversed by an optical signal in this order. The parameters α_n denote performance indicators, which are real-valued numbers assigned to the network objects p_n. The parameter T_1 denotes a threshold value. Similarly, q denotes a light path in the set S_2, which are again given as an ordered tuple $q=\{q_1, \ldots, q_M\}$. The objective function Δ should be minimized, so to allow for the sharpest possible separation between the sets S_1 and S_2. The threshold value T_1 is a scaling parameter that can be fixed in advance, such as $T_1=1$. Equation (2) is a more complete representation of Equation (1), which describes the same optimization problem in a shorthand notation.

[0091] This optimization problem may be solved by means of standard techniques from linear optimization theory, and yields a set of real-valued performance indicators α_n, wherein a performance indicator is attributed to each object of the network, in particular each link of the network. The optimization further yields the objective function Δ (step S**110**).

[0092] As indicated in step S**112**, we can now distinguish two different cases. Ideally, $\Delta=0$. In this case, the optimization yields performance indicators that allow to distinguish completely between the feasible light paths and the unfeasible light paths simply by adding up the performance indicators an along the respective light path. In case Σ_n

$\alpha_n \leq T_1$, the respective light path is feasible, and otherwise the light path is unfeasible. In this case, no further steps are required, and the algorithm stops at step S**114**.

[0093] The $\Delta=0$ case corresponds to a lossless compression. An evaluation of the feasibility of an optical path can be fully reduced to a calculation of a sum of performance indicators α_n. Hence, only the performance indicators α_n need to be stored for network planning and operations.

[0094] FIG. **5** shows how, as a result of the optimization algorithm according to the preferred embodiments, performance indicator values α_1, α_2, α_3, α_4, α_5, α_6 are attributed to each one of the network links $\mathbf{14}_1$ to $\mathbf{14}_6$, respectively, for the optical network **10** of FIG. **1**. Only these performance indicators α_n need to be stored in order to allow the performance of an optical path to be evaluated. This is a significant advantage over prior art techniques that require to store a list of all feasible light paths, in particular for large networks.

[0095] Otherwise, if $\Delta\neq 0$, the outcome of the optimization algorithm does not allow to distinguish conclusively between feasible and unfeasible light paths. If $\Sigma_n \alpha_n \leq T_1$, the light path is feasible. If $\Sigma\alpha_n > T_1+\Delta =: T_2$, the light path is unfeasible. However, if $\Sigma_n \alpha_n$ is in between the first threshold value T_1 and a second threshold value $T_2=T_1+\Delta$, the decision whether the respective light path is feasible or unfeasible cannot be made conclusively. These light paths can be stored in an exception list to which the user may revert during network planning and operations. In order to create the exception list, in step S**116** all light paths are determined for which the sum of the respective performance indicators falls in the interval $(T_1, T_1+\Delta]$. The feasible light paths in the set may then be determined by comparison with the set of feasible light paths determined in step S**100**. These light paths constitute the exception list (step S**118**). The algorithm then ends in step S**120**.

[0096] In summary, the optimization according to the preferred embodiment yields a set of performance indicators α_n assigned to the network objects, a maximum error Δ, and (if needed) an exception list. The outcome of the optimization may result in two possible scenarios:

[0097] (i) Lossless compression, i.e., $\Delta=0$: In case the linear compression returns no exceptions, the obtained performance indicators enable to retrieve all feasible light paths and exclude all the unfeasible light paths by comparison of the sum of performance indicators $\Sigma_n \alpha_n$ of the respective light path with the threshold value T_1.

[0098] (ii) Lossy compression, i.e., $\Delta\neq 0$: In case a linear compression returns exceptions, the performance indicators do not allow to simultaneously recover all feasible light paths and exclude all the unfeasible ones. However, the optimization method minimizes Δ, and hence the number of exceptions. The optimization is conservative in that a given light path is guaranteed to be feasible if the sum of the respective performance indicators is below the first threshold value T_1. However, only if the sum of the performance indicators is above the second threshold $T_2=T_1+\Delta$, the light path is guaranteed to be unfeasible. If the sum of the performance indicators is in between the first threshold T_1 and the second threshold $T_2=T_1+\Delta$, the light path could be either feasible or unfeasible, and a search in the exception list is required to decide this.

[0099] The method illustrated in the flow diagram of FIG. **3** can be implemented as a computer program that receives the network topology and the list of feasible light paths calculated in an optical performance estimation tool, and manipulates that list in order to generate the sets S_1 and S_2. For the linear optimization method, both linear programming and integer linear programming models can be used and solved using a conventional server, such as Gurobi, CPLEX, LPsolver, or MATLAB.

[0100] Heuristic algorithms may also be employed for this step. The performance indicator values α_n obtained in the optimization method may then be employed together with a standard routing algorithm, such as Dijkstra or k-shortest path to create an exception list if necessary.

[0101] The inventors tested the method as described above with reference to the flow diagram of FIG. **3** for several real-world networks, and found that very often the optimization yields $\Delta=0$, and hence no exception list is required. Even in the cases $\Delta\neq 0$ where an exception list is required, the inventors found that it is usually rather short and comprises less than 5% of the feasible light paths. Hence, even with the exception list taken into account, the invention results in a significant simplification both in terms of online computational resources and storage resources.

[0102] FIG. **6** is a flow chart that shows in additional detail how the performance indicator values may be employed to check the feasibility or unfeasibility of a given light path according to an embodiment of the present invention.

[0103] In step S**200**, an optical performance of the given light path is calculated by summing up the performance indicator values α_n of the optical objects along the given light path, $\Sigma_n \alpha_n$.

[0104] In step S**202**, the optical performance is compared with the threshold value T_1. In case $\Sigma_n \alpha_n \leq T_1$, the light path is known to be feasible (step S**204**).

[0105] If, on the other hand, $\Sigma_n \alpha_n > T_1$, feasibility or unfeasibility of the light path depends on the obtained error quantity Δ (step S**206**).

[0106] If $\Delta=0$, the light path is unfeasible (step S**208**).

[0107] If, on the other hand, $\Delta\neq 0$, the method proceeds in step S**210** with a comparison of the optical performance $\Sigma \alpha_n$ with the second threshold value $T_2=T_1+\Delta$. If $\Sigma_n \alpha_n > T_1+\Delta$, the light path is unfeasible (step S**212**).

[0108] If, on the other hand, the optical performance $\Sigma_n \alpha_n \leq T_1+\Delta$, reference is made to the exception list (step S**214**). If the respective light path is contained in the exception list, the light path is determined feasible in step S**216**. Otherwise, the light path is unfeasible (step S**218**).

[0109] For the performance evaluation method illustrated in the flow diagram of FIG. **6**, a computer program implemented in the planning tool or in the control plane may be used. The evaluation method can be integrated into a routing algorithm such as DIJKSTRA that employs the performance indicators as weights for the nodes and edges of the graph that represents the network.

[0110] An important implementation of the method is in the control plane, as the method allows a quick evaluation of the feasibility of a light path while maintaining the best optical performance calculated with the optical performance estimation tool. The major advantages of the method are simplicity, scalability and accuracy.

[0111] Simplicity is achieved by avoiding over-engineering in the network planning and operation ecosystem. This may be achieved by keeping the optical performance details in the network planning tools, such as TransNet, rather than propagating the complexity of models and parameters to

higher layer planning and operation tools. As a result, the cost of maintaining the overall system may be significantly reduced.

[0112] Scalability is achieved by the reduction of the amount of data handed over between the tools. The invention facilitates the importing and maintaining of data for multiple optical channel types, as well as multi-layer planning and operation of very large networks and generalized multi-protocol label switching (GMPLS) impairment-aware routing.

[0113] Accuracy is achieved by preserving the high quality of the offline determination of the feasible light paths. In case of lossless compression or inclusion of the exception list, the most accurate optical performance estimation is fully kept, and there is no need to compromise accuracy by simplifications of the performance model. This may be particularly relevant to avoid degrading of tender planning results with upcoming channel formats, such as 16QAM.

[0114] In the example described above with reference to FIGS. **1** to **6**, the network links $\mathbf{14}_1$ to $\mathbf{14}_6$ were considered network objects which degrade the signal quality and to which performance indicators α_1 to α_6 are assigned. However, this is merely an example. In other configurations, the optical network elements $\mathbf{12}_1$ to $\mathbf{12}_5$ may be considered network objects that degrade the signal quality, and performance indicators may be assigned to the network elements $\mathbf{12}_1$ to $\mathbf{12}_5$, either additionally or instead of the network links $\mathbf{14}_1$ to $\mathbf{14}_6$.

[0115] The description of the preferred embodiments and the figures merely serve to illustrate the invention, but should not be understood to imply any limitation. The scope of the invention is to be determined based on the appended claims.

1. A method of assigning performance indicators to objects of a network, comprising:

determining a first set of paths in said network, each said path comprising a plurality of interconnected objects of said network, wherein said first set comprises paths that fulfill a predetermined criterion;

determining a second set of paths in said network, each said path comprising a plurality of interconnected objects of said network, wherein said second set comprises paths that do not fulfill said predetermined criterion; and

assigning performance indicators to said objects of said network by means of a calculation that is based on said first set of paths and said second set of paths such that a sum of said performance indicators of objects along a given path in relation to a first threshold value indicates whether said given path fulfills said predetermined criterion, and/or indicates whether said given path does not fulfill said predetermined criterion.

2. The method according to claim **1**, wherein said given path fulfills said predetermined criterion if said sum of said performance indicators of objects along said given path is below said first threshold value, or if said sum of said performance indicators of objects along said given path is above said first threshold value.

3. The method according to claim **1**, wherein said given path does not fulfill said predetermined criterion if said sum of said performance indicators of objects along said given path is above said first threshold value, or if said sum of said performance indicators of objects along said given path is below said first threshold value.

4. The method according to claim **1**, further comprising a step of determining a second threshold value by means of computation, wherein a sum of said performance indicators of objects along a given path in relation to said first threshold value indicates whether said path fulfills said predetermined criterion, and said sum of said performance indicators of said objects along said given path in relation to said second threshold value indicates whether said path does not fulfill said predetermined criterion, or vice versa.

5. The method according to claim **1**, wherein said first set of paths is a set of paths that, when extended in said network, fails to fulfill said predetermined criterion.

6. The method according to claim **1**, wherein said second set of paths is a set of paths that, when shortened in said network, fails to fulfill said predetermined criterion.

7. The method according to claim **1**, wherein said calculation is of the form

$$\min \Delta$$

$$\Sigma_n \alpha_n \leq T_1 + \Delta, \Sigma_m \alpha_m > T_1,$$

wherein $\{\alpha_n\}$ denotes a set of said performance indicators attributed to objects $\{1, \ldots, N\}$, wherein the sum $\Sigma_n \alpha_n$ is over all paths in said first set, and wherein the sum $\Sigma_m \alpha_m$ is over all paths in said second set, and wherein T_1 denotes said first threshold.

8. A method of evaluating a performance of a path in a network, said path comprising a plurality of interconnected objects in said network, wherein performance indicators are assigned to said objects, said method comprising the following steps:

calculating a sum of the performance indicators for said objects along said path; and

evaluating a performance of said path by comparing said sum against a first threshold value.

9. The method according to claim **8**, wherein said step of evaluating said performance comprises a step of determining whether said path fulfills a predetermined criterion by comparing said sum against said first threshold value, and/or determining whether said path does not fulfill said predetermined criterion by comparing said sum against said first threshold value.

10. The method according to claim **8**, wherein said step of evaluating said performance comprises a step of determining whether said path does not fulfill said predetermined criterion by comparing said sum against a second threshold value, and/or determining whether said path fulfills said predetermined criterion by comparing said sum against said second threshold value.

11. The method according to claim **10**, wherein said step of evaluating said performance of said path comprises a step of reverting to a performance listing if said sum is in between said first threshold value and said second threshold value.

12. A system for assigning performance indicators to objects of a network, comprising:

means for determining a first set of paths in said network, each said path comprising a plurality of interconnected objects of said network, wherein said first set comprises paths that fulfill a predetermined criterion;

means for determining a second set of paths in said network, each said path comprising a plurality of interconnected objects of said network, wherein said second set comprises paths that do not fulfill said predetermined criterion; and

means for assigning performance indicators to said objects of said network by means of a computation that is based on said first set of paths and said second set of paths, such that a sum of said performance indicators of objects along a given path in relation to a first threshold value indicates whether said given path fulfills said predetermined criterion, and/or indicates whether said given path does not fulfill said predetermined criterion.

13. A system for evaluating a performance of a path in a network, said path comprising a plurality of interconnected objects in said network, wherein performance indicators are assigned to said objects, said system comprising:

means for calculating a sum of performance indicators for said objects along said path; and

means for evaluating a performance of said path (**16**, **18**, **20**) by comparing said sum against a first threshold value.

14. The system according to claim **12**, further comprising a storage unit for storing said performance indicators for said objects.

15. A computer program product comprising computer-readable instructions, wherein said computer-readable instructions are adapted for executing a method of assigning performance indicators to objects of a network, comprising:

determining a first set of paths in said network, each said path comprising a plurality of interconnected objects of said network, wherein said first set comprises paths that fulfill a predetermined criterion;

determining a second set of paths in said network, each said path comprising a plurality of interconnected objects of said network, wherein said second set comprises paths that do not fulfill said predetermined criterion; and

assigning performance indicators to said objects of said network by means of a calculation that is based on said first set of paths and said second set of paths such that a sum of said performance indicators of objects along a given path in relation to a first threshold value indicates whether said given path fulfills said predetermined criterion, and/or indicates whether said given path does not fulfill said predetermined criterion.

16. The system according to claim **15**, further comprising a storage unit for storing said performance indicators for said objects.

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