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- (54) **Title:** METHOD AND SYSTEM FOR WORKING AND PROTECTION PATHS DETERMINATION IN A WIRELESS BACKHAUL NETWORK

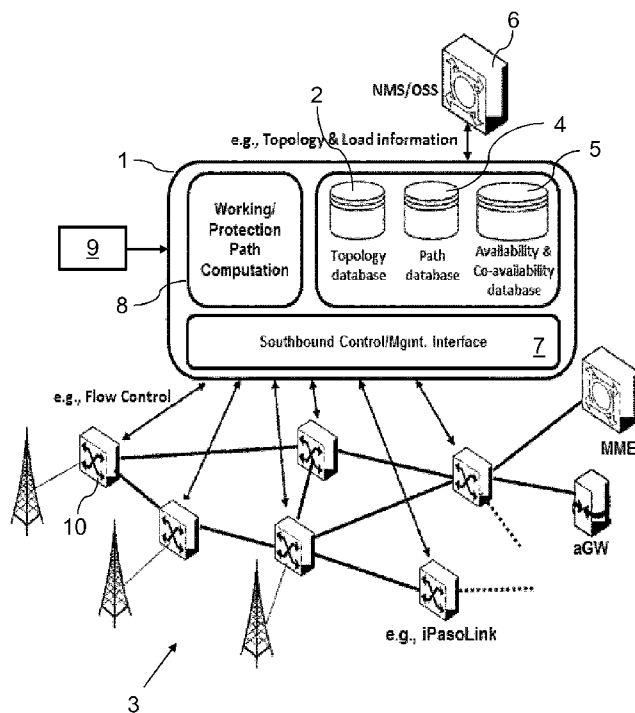


Fig. 2

- (57) **Abstract:** A method for working and protection paths determination in a wireless backhaul network (3), wherein the modulation and coding schemes (MCSs) used by a link of said network (3) are adaptable to the link quality, and wherein said paths determination is performed on the basis of information about the availability of each link on the granularity of the MCS level, is characterized in that said paths determination, in addition to said availability information, takes into consideration co-availability information, which is information about the correlation of availabilities among different links on the granularity of the MCS level. Furthermore, a corresponding system for working and protection paths determination in a wireless backhaul network (3) is disclosed.

METHOD AND SYSTEM FOR WORKING AND PROTECTION PATHS DETERMINATION IN A WIRELESS BACKHAUL NETWORK

The present invention relates to a method for working and protection paths
5 determination in a wireless backhaul network, wherein the modulation and coding
schemes (MCSs) used by a link of said network are adaptable to the link quality,
and wherein said paths determination is performed on the basis of information
about the availability of each link on the granularity of the MCS level.

10 Furthermore, the present invention relates to a system for working and protection
paths determination in a wireless backhaul network, wherein the modulation and
coding schemes (MCSs) used by a link of said network are adaptable to the link
quality.

15 For increased microwave link capacity, adaptive modulation and coding (AMC) is
adopted in modern microwave link products. According to AMC; the modulation
and coding schemes (MCSs) used by a microwave link can be adapted to the link
quality, as it results from, e.g., weather conditions and equipment aging.
Generally, the different MCSs employed by a microwave link exhibit different
20 availability properties, as described e.g. in Ceragon Networks Ltd., "Flex your
backhaul network with adaptive coding & modulation," white paper, Oct. 2010. For
performance optimization, path computation in wireless backhaul networks shall
take into consideration respective availability information.

25 It is an object of the present invention to improve and further develop a method
and a system of the initially described type in such a way that the network
resources in wireless backhaul networks can be used more efficiently.

In accordance with the invention, the aforementioned object is accomplished by a
30 method comprising the features of claim 1. According to this claim, such a method
is characterized in that said paths determination, in addition to said availability
information, takes into consideration co-availability information, which is
information about the correlation of availabilities among different links on the
granularity of the MCS level.

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Furthermore, the aforementioned object is accomplished by a system comprising the features of claim 13. According to this claim, such a system is characterized in that it comprises a control entity including a database that contains information about the availability of each link on the granularity of the MCS level as well as co-availability information, which is information about the correlation of availabilities among different links on the granularity of the MCS level, and a working and protection paths computation engine that is configured to determine said paths on the basis of information about both availability and co-availability on the granularity of the MCS level retrieved from said database.

According to the invention it has first been recognized that correlations exist among the failures and/or degradations of different links in wireless backhaul networks consisting of microwave links, for instance due to weather conditions in the same geographic region. Thus, availabilities and unavailabilities of different (wireless) links are correlated. Due to the correlations of availabilities among links, the availabilities and unavailabilities of different paths are also correlated. In particular, this is the case for working and protection paths, also referred to in the art as primary and backup paths. The present invention proposes to exploit the availability-correlations among different links by collecting the co-availability information of any two links and utilizing this information, also on the granularity of the MCS level of each (microwave or next generation millimeter) link, in the path computation procedures.

Embodiments of the invention address the problem of exploiting availability and co-availability information of (MCS, Link) pairs in order to compute working and protection paths for a certain service such as to achieve a combined total availability for the service. This allows using network resources more efficiently in wireless backhaul networks, in particular because unexpected concurrent downtimes of equipment along working and protection paths are effectively avoided. The design objective can be any traffic engineering performance metrics, such as throughput and link utilization.

In summary, the present invention presents a method and a management system for availability-aware working and protection paths computation in wireless

backhaul networks, which exploits both availability and co-availability information on the granularity of the MCS level. Existing works on multipath routing and traffic protection in communication networks take into account only the correlations of path and link availabilities that result from sharing of physical network resources (e.g. fiber ducts) in wired networks and co-channel interference in wireless networks (for reference, see W.-D. Cui et al.: "Backup path allocation based on a correlated link failure probability model in overlay networks", in Proc. of 10th IEEE International Conference on Network Protocols, pp.236-245, France, Paris, Nov. 2002, or A.M. Abbas, B.N. Jain: "Mitigating Path Correlation in Node-Disjoint Multipath Routing for Mobile Ad hoc Networks", in Proc. of 1st IEEE International Conference on COMmunication SoftWARE and MiddlewaRE (COMSWARE'06), New Delhi, India, Jan. 2006).

Further, the granularity of availability-correlation considered in prior works is on the link level. In contrast to this, the present invention introduces and makes use of both availability and availability-correlation on the granularity of modulation and coding scheme (MCS) level. The MCS level granularity of availability and availability-correlation is particularly applicable to microwave (and millimeter wave) backhaul networks that employ link adaptation (a.k.a. adaptive bandwidth/capacity). This is because each MCS on a wireless link leads to a different link capacity and link availability. Hence, it is not really adequate to talk about the availability of a wireless link as one single entity. In embodiments of the present invention, the co-availability information on the MCS level is exploited in the working and protection path computation procedure for each traffic demand.

Finally, it should be noted that it is more likely that a protection path is made of (MCS, Link) pairs that have large capacities. As compared to methods that only consider link level availability, this enables a more efficient and flexible use of network resources, i.e., link capacities (higher MCSs may be used for premium traffic).

According to an embodiment it may be provided that the working and protection paths are established for a given traffic demand (i.e. service class) between a source node and a destination node in the wireless backhaul networks (e.g., a

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VLAN, Virtual Local Area Network, in Ethernet based backhaul networks) as two node- or link-disjoint paths. For scenarios with multiple traffic demands (or service classes) between multiple source nodes and destination nodes, the proposed method can be applied to compute working and protection paths for each traffic demand. That is, the traffic demands can be processed in a one-by-one manner. A protection path and the associated network resources can possibly be shared by many traffic demands.

According to an embodiment the path availability of a working path may be calculated based on said co-availability information. Specifically, it may be provided that the path availability of a single-hop working path is determined to be the availability of the (MCS, link) pair selected for the working path. On the other hand, the path availability of a multi-hop working path may be conservatively determined to be the co-availability of the {(MCS, link), (MCS, link)} pair that has the minimum co-availability among all {(MCS, link), (MCS, link)} pairs on the working path.

With respect to the computation of an associated protection path, it may be provided that the working path together with the availability and co-availability information is taken into account. In particular, it may be provided that a path availability requirement of a protection path is calculated based on a maximum allowable co-unavailability of the working and protection paths (which may be pre-defined based on service level agreements) in view of an unavailability of the working path.

Advantageously, the availability and/or co-availability information is calculated based on measured data, for instance measured by the wireless backhaul network equipment. Alternatively or additionally, it may be provided that the availability and/or co-availability information is retrieved from recorded MCS time series. In this regard, according to a preferred implementation the recorded MCS time series are passed on from the network management system to the working and protection paths computation engine.

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According to an embodiment may be provided that the availability and/or co-availability information is managed by the control entity that collects the information either by means of communicating directly with the network equipment via a southbound interface and/or with the network management system (NMS).

5

According to another embodiment the availability and/or co-availability information may be provided together with temporal information in order to account for time variations of the availability and/or co-availability, for instance in consequence of seasonal weather conditions. Specifically, it may be provided that the relevant
10 databases in the control entity and/or in the network management system (NMS) are updated regularly, e.g., by operators.

After having calculated the working and protection paths, it may be provided that these paths are provisioned to the network equipment directly or via the network
15 management system (NMS).

There are several ways how to design and further develop the teaching of the present invention in an advantageous way. To this end it is to be referred to the patent claims subordinate to patent claims 1 and 13 on the one hand and to the
20 following explanation of preferred embodiments of the invention by way of example, illustrated by the figure on the other hand. In connection with the explanation of the preferred embodiments of the invention by the aid of the figure, generally preferred embodiments and further developments of the teaching will be explained. In the drawing

25

Fig. 1 is a schematic view of an example of MCS time series for two different links,

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Fig. 2 is a schematic view illustrating the basic architecture of a system in accordance with embodiments of the present invention,

Fig. 3 is a diagram illustrating a method for availability-aware working and protecting path computation in accordance with an embodiment of the present invention, and

Fig. 4 is a diagram illustrating the calculation of an availability requirement of a protection path in accordance with an embodiment of the present invention.

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Today, many modern microwave link products adopt adaptive modulation and coding (AMC), i.e. the modulation and coding schemes (MCSs) used by a microwave link can be adapted to the current link quality. With link adaptation (e.g., adapting MCSs according to weather conditions) in wireless backhaul networks, it is more accurate to represent "links" by (MCS, Link) pairs. The link availability information is collected on each (MCS, Link) pair level. Tab. 1 shows one example of availability information, with the granularity on each (MCS, Link) pair level. As can be noted, the availability of a link degrades with the quality or effectiveness of the applied MCS, e.g. from a very high availability of 99.999 % in case of QPSK (Quadrature Phase-Shift Keying), which is a robust MCS with rather low performance in terms of spectral efficiency, to an availability of 99.97 % (corresponding to a downtime of more than 2.6 hours per year) in case of high capacity 256-QAM (Quadrature amplitude modulation).

20

(MCS m , Link k)	Availability	Yearly downtime [Seconds]
(QPSK, Link k)	99.999%	315.36
(8-QAM, Link k)	99.995%	1576.80
(16-QAM, Link k)	99.993%	2207.52
(32-QAM, Link k)	99.988%	3784.32
(64-QAM, Link k)	99.986%	4415.04
(128-QAM, Link k)	99.98%	6307.20
(256-QAM, Link k)	99.97%	9460.80

Table 1: Exemplary data of availability information of a (MCS, Link) pair

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Similarly to the availability information described above, the co-availability information can be collected for each $\{(MCS, Link), (MCS, Link)\}$ combination/pair. Tab. 2 shows one example of co-availability information, with the granularity on each $\{(MCS, Link), (MCS, Link)\}$ combination/pair level. In the context of the present invention, the co-availability of a given $\{(MCS_m, Link_k), (MCS_n, Link_l)\}$ pair refers to the probability that the two pairs $(MCS_m, Link_k)$ and $(MCS_n, Link_l)$ are simultaneously available. Hence, the co-availability reflects the correlation of the availabilities (and unavailabilities) of the two pairs $(MCS_m, Link_k)$ and $(MCS_n, Link_l)$.

$(m, k) \backslash (n, l)$	(1, 1)	(2, 1)	(3, 1)	(1, 2)	(2, 2)	(3, 2)	...
(1, 1)	n/a	n/a	n/a	99.999%	99.995%	99.993%	...
(2, 1)	n/a	n/a	n/a	99.995%	99.995%	99.993%	...
(3, 1)	n/a	n/a	n/a	99.993%	99.993%	99.993%	...
(1, 2)	99.999%	99.995%	99.993%	n/a	n/a	n/a	...
(2, 2)	99.995%	99.995%	99.993%	n/a	n/a	n/a	...
(3, 2)	99.993%	99.993%	99.993%	n/a	n/a	n/a	...
...	...	...	...	...	...	...	...

Table 2: Exemplary data of co-availability information of $(MCS, Link)$ pairs (with 100% correlation)

In practice, when the MCS used by a link is changed (e.g., due to weather conditions), a signal is generated and sent to, e.g., the network management system (NMS). The newly adopted MCS and the timestamp are recorded. An operator (and/or NMS) keeps record of such changes in the form of MCS time series of all the links in a wireless backhaul network. Fig. 1 shows one example of such MCS time series for two links with three candidate MCSs. The availability information of a $(MCS, Link)$ pair can be calculated/estimated from such MCS time series. For instance, from Fig. 1, the availability of the pair $(MCS_1, Link_1)$ can be

computed as the fraction of the accumulated time that “MCS 1 is feasible to be used on Link 1” in one year. In Fig. 1 it is assumed that the grading of the illustrated MCSs is such that MCS1 has the highest capacity/lowest robustness, MCS3 on the other hand has the lowest capacity/highest robustness, while the performance characteristic of MCS2 is in between. Therefore, it is justified to assume that, when MCS1 is available for a particular link, MCS2 and MCS3 are also available (and that, similarly, MCS3 is available, whenever MCS2 is available). Consequently, it is always possible to calculate from MCS time series recorded by an operator the availability of all possible pairs (MCS m , Link k).

Similarly, the co-availability information of the {(MCS m , Link k), (MCS n , Link l)} pairs can also be calculated/estimated from the MCS time series. There are several ways to do this, and it is important to note that the present invention is not limited to any specific way. As one example, the co-availability information of the pair {(MCS 1, Link 1), (MCS 2, Link 2)} can be computed as the fraction of the accumulated time that “MCS 1 is feasible to be used on Link 1 and at the same time MCS 2 is feasible to be used on Link 2” in one year. Moreover, due to seasonal weather differences, for instance, the availability and co-availability information may also vary over time. In such time-varying cases, the examples shown in Tab. 1 and Tab. 2 should also contain time information, e.g., summer, winter, etc. Further, (co-) availability might evolve in the longer term due to e.g. climate change or equipment aging. Hence, an operator should keep the time series correlation up-to-date rather than relying on fixed values once and for all.

A possible system architecture in accordance with an embodiment of the present invention is depicted in Fig. 2. An integral part of the system is a centralized control entity 1 with a topology database 2 storing the topology of the (wireless backhaul) network 3 and a path database 4 storing the currently allocated paths, as well as an availability and co-availability database 5 storing availability and co-availability information for all (MCS, link) combinations.

The centralized control entity 1 may be implemented as a logical functional entity and could physically be part of the NMS 6 or an independent entity. Also, it could obtain the database information, in particular the availability and co-availability

database 5 information, either by communicating with the network equipment directly via a southbound interface 7 (as indicated in Fig. 2) or via the NMS 6. In any case, all database information is fed to a working and protection paths computation engine 8. The availability-aware path computation procedure is carried out, probably under some specific policies and configurations 9, as will be exemplarily described in connection with Fig. 3 below. The computed working and protection paths are then provisioned to the switches/routers of the wireless backhaul network 3 via the southbound control interface 7 or via the NMS 6 directly.

In accordance with an embodiment of the present invention, Fig. 3 illustrates a systematic method for working and protection paths computation that make use of the availability information of (MCS, Link) pairs (see, e.g., Table 1) and the co-availability information of {(MCS, Link), (MCS, Link)} pairs (see, e.g., Table 2). As depicted in the embodiment of Fig. 3, it is assumed that a specific traffic demand (i.e. service class) is specified in the form of (Source, Destination, Capacity, QoS-class, Timeslot) and the proposed path computation method comprises of 4 steps.

Step 1: For a given traffic demand (Source, Destination, Capacity, QoS-class, Timeslot), compute a working path using, e.g., Dijkstra's algorithm. The parameters "Capacity" and "QoS-class" are used jointly to select (MCS, Link) pairs for the working path. Particularly, the parameter "QoS-class" is interpreted as the "priority-level" of a given traffic demand. Traffic demands that have high "QoS-class" values are mapped to (MCS, Link) pairs that have high availability values. Co-availability among links of the working path is also taken into account to ensure that the path availability of the working path is above the prescribed level.

Step 2: Calculate the availability of the working path that is obtained in Step 1, based on the co-availability information of the links that are on the path. The allowable unavailability of the working path can readily be obtained from the availability of the working path. The path availability of a single-hop path is the availability of the (MCS, Link) pair selected for the path. The path availability of a multi-hop path is conservatively approximated by the co-availability of the {(MCS,

Link), (MCS, Link)) pair that has the minimum co-availability among all {(MCS, Link), (MCS, Link)} pairs on said path.

Step 3: Calculate the availability requirement of a protection path. As shown in Fig. 4, given the maximum allowable co-unavailability (predefined based on service level agreement) of the working and protection paths and the unavailability of the working path obtained in Step 2, the maximum allowable unavailability of a protection path can be estimated. Here, **co-unavailability** of working and protection paths refers to the probability that both the working and protection paths are **simultaneously** unavailable. The minimum availability requirement of a protection path can readily be obtained from the maximum allowable unavailability of a protection path.

Step 4: Compute a protection path. The working and protection paths are typically node- or link-disjoint, which can be realized using, e.g., Suurballe's algorithm. The availability of the working path should not be changed in this step. The availability of the working path can be preserved by considering the co-availability information. That is, only the (MCS, Link) pairs that do not affect the availability of the working path can be considered when computing the protection paths.

It should be explicitly noted that there are various ways of how to compute a combination of working and protection path that – in combination – supports the availability requirements of a given service class and the description above is just meant to be indicative of the principal steps that need to be considered. Still, these steps could be executed in a different order and with different path searching strategies (e.g. depth-first search), as will be easily appreciated by those skilled in the art.

Many modifications and other embodiments of the invention set forth herein will come to mind the one skilled in the art to which the invention pertains having the benefit of the teachings presented in the foregoing description and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although

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specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

Claims

1. Method for working and protection paths determination in a wireless backhaul network (3),
5 wherein the modulation and coding schemes (MCSs) used by a link of said network (3) are adaptable to the link quality, and
 wherein said paths determination is performed on the basis of information about the availability of each link on the granularity of the MCS level,
c h a r a c t e r i z e d i n that said paths determination, in addition to said
10 availability information, takes into consideration co-availability information, which is information about the correlation of availabilities among different links on the granularity of the MCS level.
2. Method according to claim 1, wherein said working and protection paths are
15 established for a given service class as two node- or link-disjoint paths.
3. Method according to claim 1 or 2, wherein the path availability of a working path is calculated based on said co-availability information.
- 20 4. Method according to claim 3, wherein the path availability of a single-hop working path is determined to be the availability of the (MCS, link) pair selected for said working path.
- 25 5. Method according to claim 3, wherein the path availability of a multi-hop working path is determined to be the co-availability of the {(MCS, link), (MCS, link)} pair that has the minimum co-availability among all {(MCS, link), (MCS, link)} pairs on said working path.
- 30 6. Method according to any of claims 1 to 5, wherein a working path together with said availability and co-availability information is taken into account for determining a protection path.
7. Method according to any of claims 1 to 6, wherein a path availability requirement of a protection path is calculated based on a maximum allowable co-

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unavailability of the working and protection paths in view of an unavailability of the working path.

8. Method according to any of claims 1 to 7, wherein said availability and/or
5 co-availability information is calculated based on measured data.

9. Method according to any of claims 1 to 8, wherein said availability and/or
co-availability information is retrieved from recorded MCS time series.

10. Method according to any of claims 1 to 9, wherein said availability and/or
co-availability information is managed by a control entity (1) that collects said
information either by means of communicating directly with the network equipment
via a southbound interface (7) and/or with the network management system (NMS)
(6).

15 11. Method according to any of claims 1 to 10, wherein said availability and/or
co-availability information is provided together with temporal information in order to
account for time variations of said availability and/or co-availability information.

20 12. Method according to any of claims 1 to 11, wherein the determined working
and protection paths are provisioned to the network equipment directly or via the
network management system (NMS) (6).

25 13. System for working and protection paths determination in a wireless
backhaul network (3), in particular for executing a method according to any of
claims 1 to 12,

wherein the modulation and coding schemes (MCS) used by a link of said
network are adaptable to the link quality,

30 c h a r a c t e r i z e d i n the system comprises a control entity (1) including
a database (5) that contains information about the availability of each link
on the granularity of the MCS level as well as co-availability information, which is
information about the correlation of availabilities among different links on the
granularity of the MCS level, and

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a working and protection paths computation engine (8) that is configured to determine said paths on the basis of information about both availability and co-availability on the granularity of the MCS level retrieved from said database (5).

- 5 14. System according to claim 13, wherein said control entity (1) is configured to obtain said availability and co-availability information by means of communicating directly with the network equipment via a southbound interface (7) and/or with the network management system (NMS) (6).

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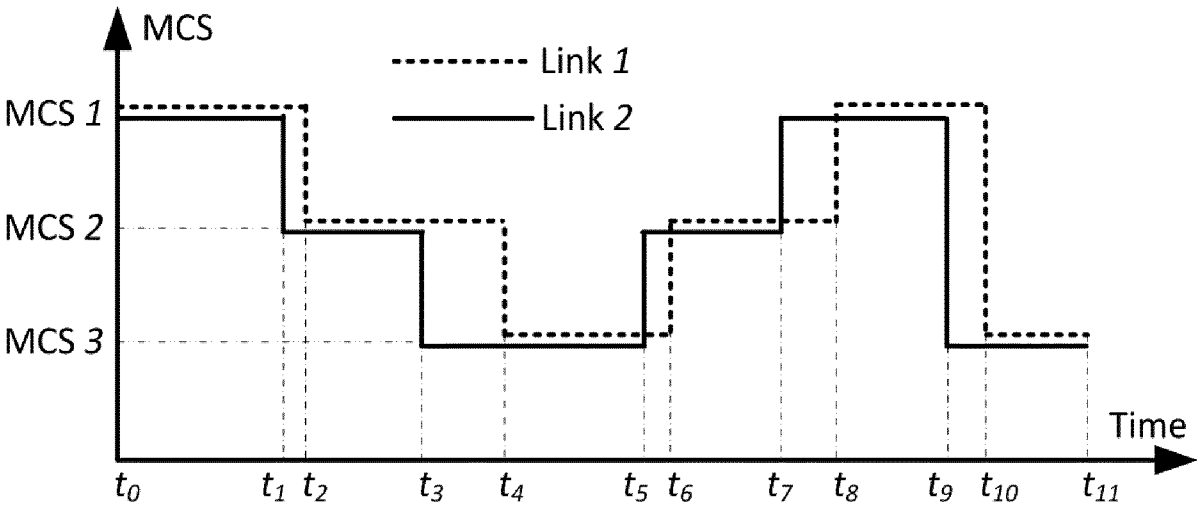


Fig. 1

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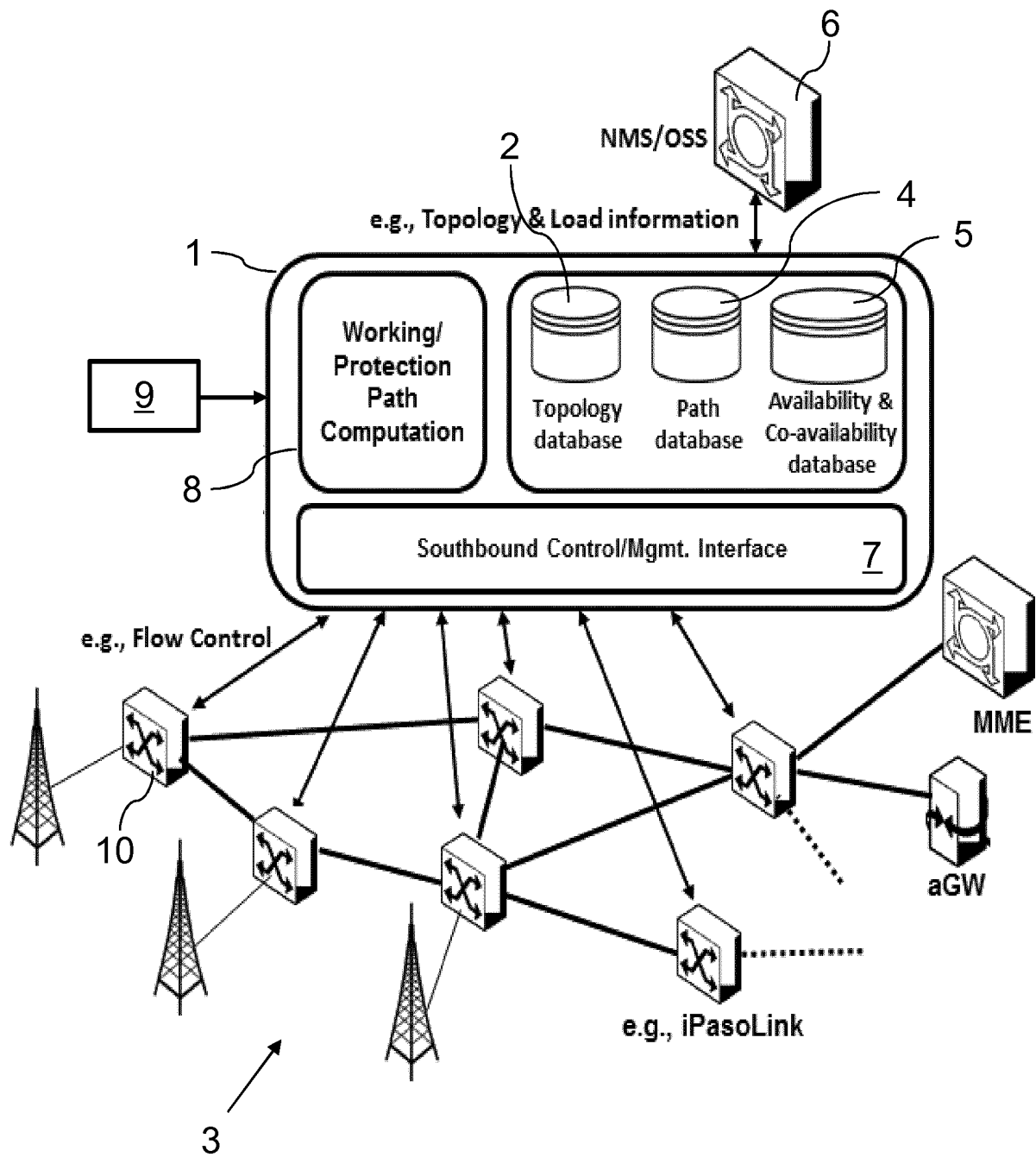


Fig. 2

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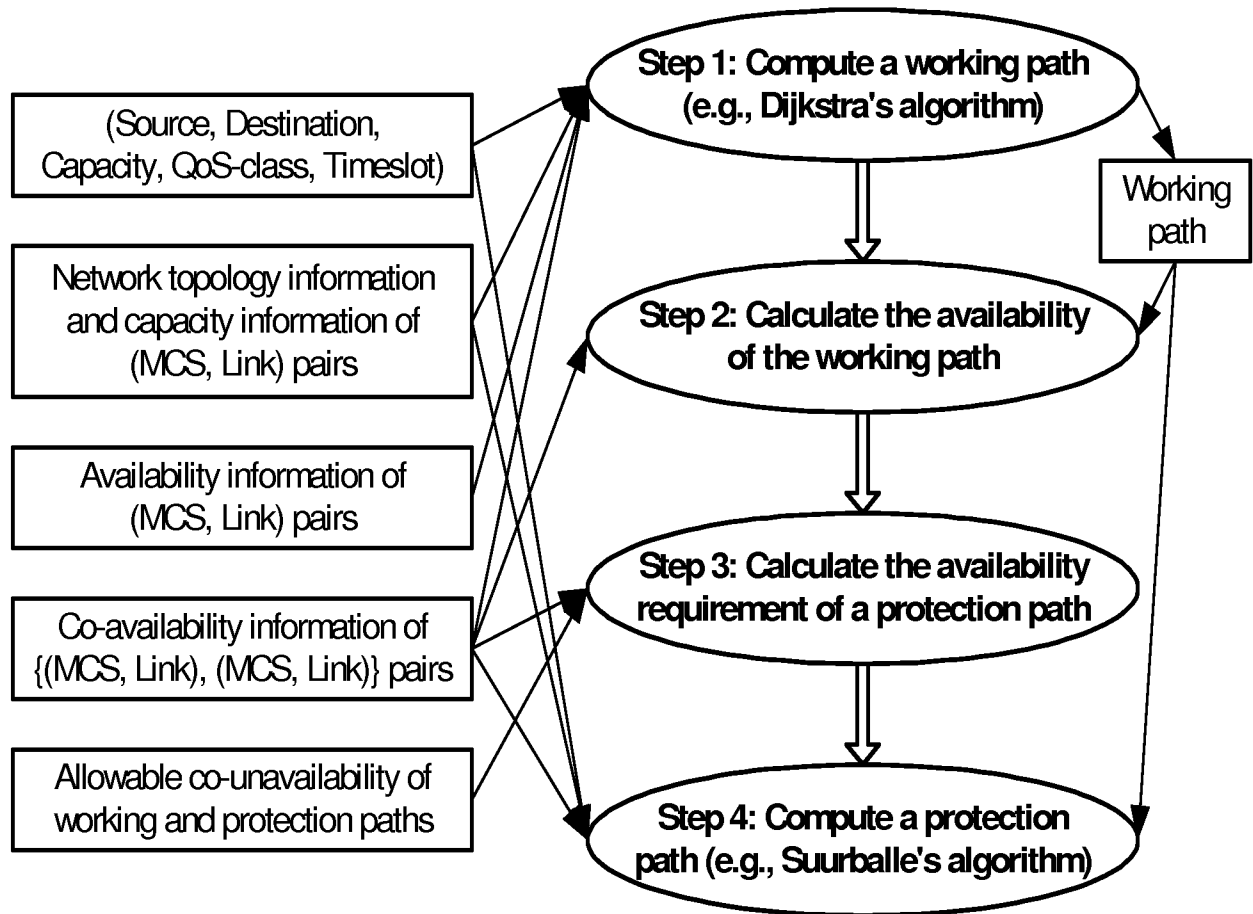


Fig. 3

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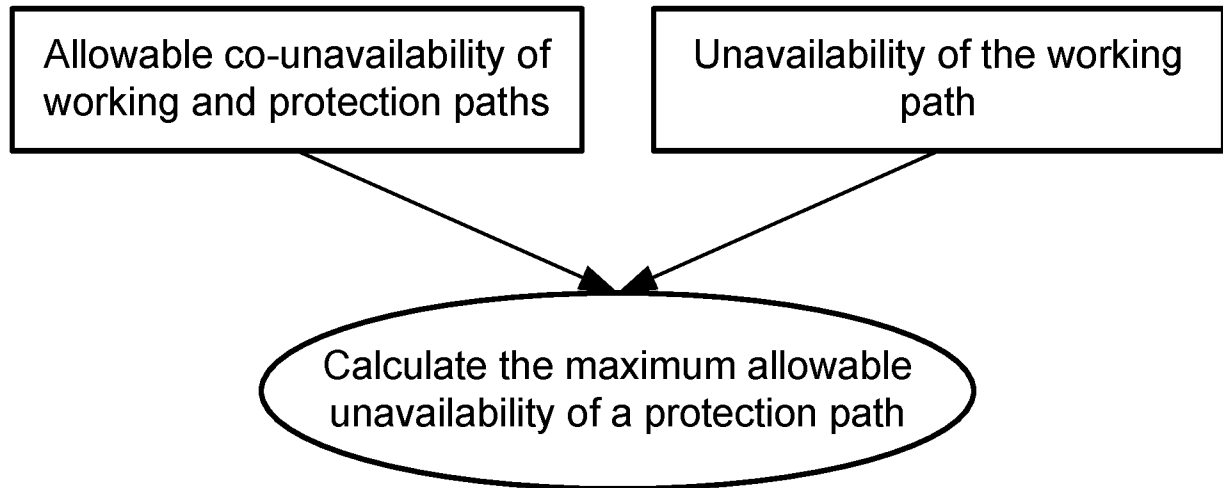


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/056966

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L1/00 H04L12/701
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)
H04L

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, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JUN NISHIOKA ET AL: "Availability Constrained Traffic Control for AMC-Enabled Wireless Mobile Backhaul Networks", WORLD TELECOMMUNICATIONS CONGRESS (WTC), 2012, IEICE, 5 March 2012 (2012-03-05), pages 1-6, XP032138270, ISBN: 978-1-4577-1459-7 the whole document	1-14
Y	WO 2014/044821 A1 (NEC EUROPE LTD [DE]) 27 March 2014 (2014-03-27) page 315 - page 4, line 3 page 10, lines 1-11 page 18, line 26 - page 19, line 24; figure 1 ----- -/--	1-14



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

3 July 2015

Date of mailing of the international search report

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Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/056966

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	GOODMAN J M: "Availability correlation distances for HF communications in a global network", HF RADIO SYSTEMS AND TECHNIQUES, SEVENTH INTERNATIONAL CONFERENCE ON (CONF. PUBL. NO. 441) NOTTINGHAM, UK 7-10 JULY 1997, LONDON, UK, IEE, UK, 7 July 1997 (1997-07-07), pages 140-144, XP006508133, DOI: 10.1049/CP:19970777 ISBN: 978-0-85296-688-4 the whole document	1-14
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Information on patent family members

International application No

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