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**TITLE: Inference of Shared Risk Link Groups**

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**ABSTRACT: The Shared Risk Link Group (SRLG) concept introduced in [IPO-Frame] is considered as one of the most important criteria concerning the constrained-based path computation of optical channel routes. By applying the SRLG criteria to the constrained-based path computation, one can select a route taking into account physical resource and logical structure disjointness that implies a lower probability of simultaneous lightpath failure. This contribution describes the various physical and logical resource types considered in the SRLG concept. The proposed model focuses on the inference of SRLG information between the network physical layers as well as logical structures such as geographical locations. The main applications of the proposed model are the related Constraint-based Shortest Path First (CSPF) algorithm for optical channel path computation and the reduction of the SRLG information flooded through traffic engineering extensions of the IGP routing protocols (such as OSPF and IS-IS).**

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## 1. INTRODUCTION

Many proposals include the SRLG concept when considering the constraint-based path computation of optical channel routes. In optical domains this concept of SRLG is used for deriving a path, which is disjoint from the physical resource and logical topology point-of-view. However, the definition of SRLG in the current format as described in [GMPLS-OSPF] and [GMPLS-ISIS] does not provide:

- the relationship between logical structures or physical resources (for example, a fiber could be part of a sequence of fiber segments, which is included in a given geographical region),
- the risk assessment during path computation implying the allocation of a conditional failure probabilities with the SRLGs,
- the analysis of the specifications of constraint-based path computation and path re-optimization taking SRLG information into account.

The model proposed in this document proposes a technique to compute the SRLG with respect to a given risk type. This is achieved by identifying for a given physical layer the resources belonging to an SRLG. The proposed model also permits one to compute the dependencies of these resources into the resources belonging to lower physical layers. The result of the computation also enables one to determine the risk associated to each of the SRLGs.

In section 2, we present the hierarchical model of the resources and the corresponding SRLG encoding. In section 3, we discuss the use of such a model for the risk assessment for the path computation. Future work is proposed in section 4, which is followed by references in section 5. Appendix 1 provides an elaborate discussion on the inference of SRLGs.

## 2. REQUIREMENTS

The requirements concerning the SRLG have already been discussed in the IPO Carrier requirement documents [IPO-OLCP]. Within the scope of this document, these can be summarized as follows:

1. The SRLG encoding mechanism should reduce the path computation complexity.
2. The SRLG information flooding should be scoped to reduce the amount of information that is sent across domains.
3. The SRLG encoding should accommodate the physical and logical restrictions imposed on the diversity requirements as discussed in [IPO-OLCP].

## 3. HIERARCHICAL MODEL

The model defined in this proposal includes two hierarchies, as mentioned below:

- **Physical hierarchy**, which is related to the fiber topology (more generally the physical resources) of the optical network including the wavelengths built on top of this physical topology.
- **Logical hierarchy**, which is related to the geographical topology of the network

Between these two hierarchies, the nodes such as Optical Cross-Connect (OXC) and Photonic Cross-Connect (PXC) constitute the boundary layer. Each of these concepts is elaborated in the following sections.

The encoding of the SRLG could be either mapped on this hierarchical model or simply use a flat encoding scheme. Both methods seem feasible. Difference between both approaches relies on the extended usage of the SRLGs in the context of diverse route computation (i.e. path disjointness). Since a link can belong to more than one SRLG, an SRLG identifier list, as described in [IPO-BUNDLE] and [IPO-FRAME] is attached to the link identifier (Link ID). This results in a linear and non-structured information from which the underlying structure cannot be deduced.

Consequently, either a type field indicating the type of resource (or logical structure) to which this SRLG identifier refers extends the flat encoding scheme or the encoding itself translates the underlying hierarchical structure. Worth mentioning here that an hierarchical encoding (since depending on the physical layer which is by definition static) needs an additional mapping structure in order to keep the relationship with link identifiers. Nevertheless, the computational model developed in Appendix 1 does not depend on the encoding scheme.

### 3.1 Physical Hierarchy (or Network Resource Hierarchy)

The network (physical) resource model considered in the inference of the Shared Risk Link Groups (SRLGs) is based on concepts introduced in [IPO-FRAME] and detailed in [IPO-OLCP] and [OIF2000-019]. The concepts around network resource hierarchy developed within this document are based on the following definitions:

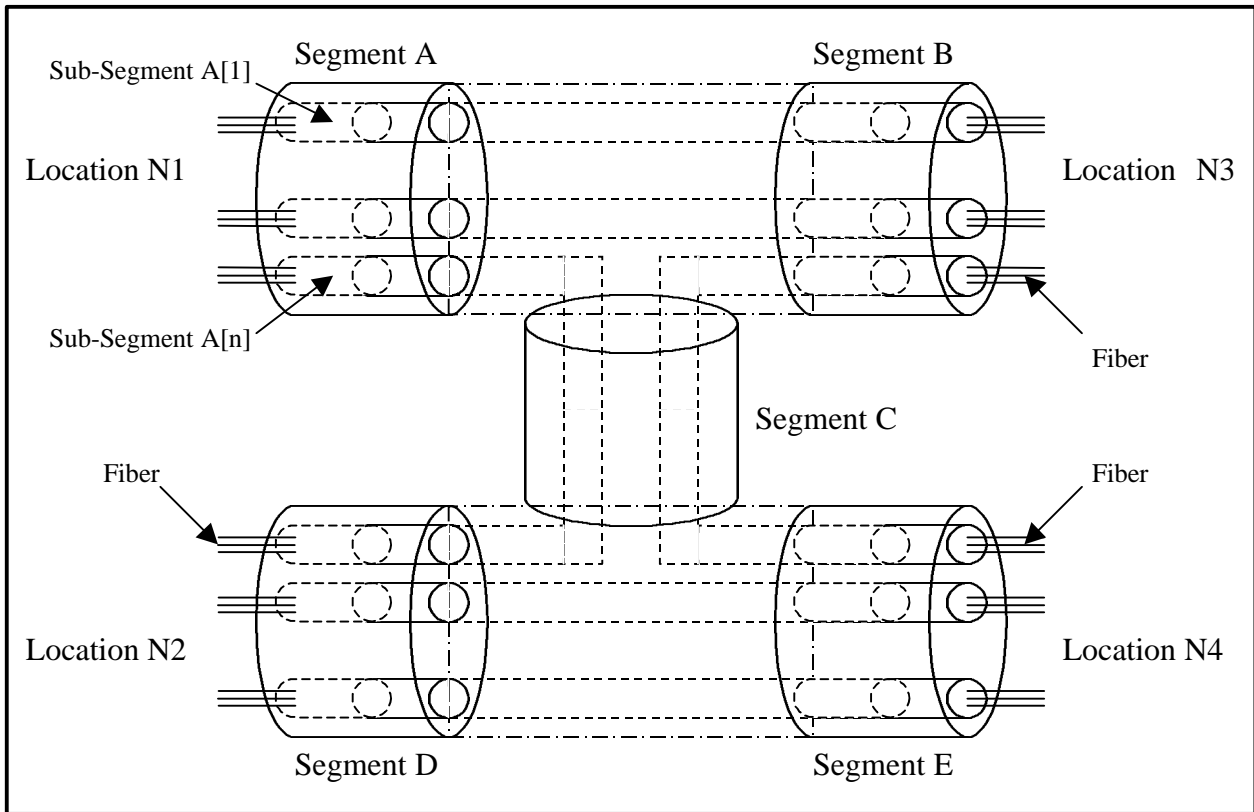
- **Sub-Channel:** a dedicated container included within a given channel uniquely identifies a sub-channel
- **Channel** (or wavelength): a channel is uniquely identified by a dedicated wavelength (i.e. lambda)
- **Fiber Link:** a fiber connects two Optical Network Element (ONE)<sup>1</sup> ports communicating through one optical channel or more than one optical channel if the ONE interfaces support Wavelength Division Multiplexing (WDM).
- **Fiber Sub-segment:** grouping of several fiber links forms a fiber sub-segment.
- **Fiber Segment:** a fiber segment includes a collection of fiber sub-segments.
- **Fiber Trunks:** a fiber trunk is a sequence of fiber segments, including one or more fiber segments starting and terminating at the same ONE.

The model developed extends the definition given within [OIF2000.019] by enabling ‘fiber topology’ non-limited to point-to-point ONE connections. Physical resources considered within this model are a common denominator of most Optical Transport Network (OTN) environments.

As represented in Figure 1, the fiber trunk from the location N1 to the location N3 is composed by the fiber segments A and B and the fiber trunk from the location N1 to the location N2 includes the fiber segment A, C and D.

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<sup>1</sup> ONE (Optical Network Element) terminology refers either to an OXC (Optical Cross-Connect) or to an PXC (Photonic Cross-Connect)



**Figure 1. An example for the network physical topology**

In this figure, the Segment A is composed by the fiber sub-segments A[1], A[2], ..., A[I], ..., A[n]. The same terminology applies for the segments B, C, D and E.

Consequently, the fiber trunk from location N2 to location N4 includes the sub-segments D[2] to D[n] and their corresponding sub-segments within the segment E: E[2] to E[n]. The fiber trunk from location N1 to location N2 includes the fiber sub-segments A[n], C[1] and D[1].

Note that if we introduce the new OIF terminology a lightpath refers to a link connection. The proposed hierarchy is suitable for diverse ‘fiber topologies’. We assume that all connections are unidirectional point-to-point unless otherwise specified.

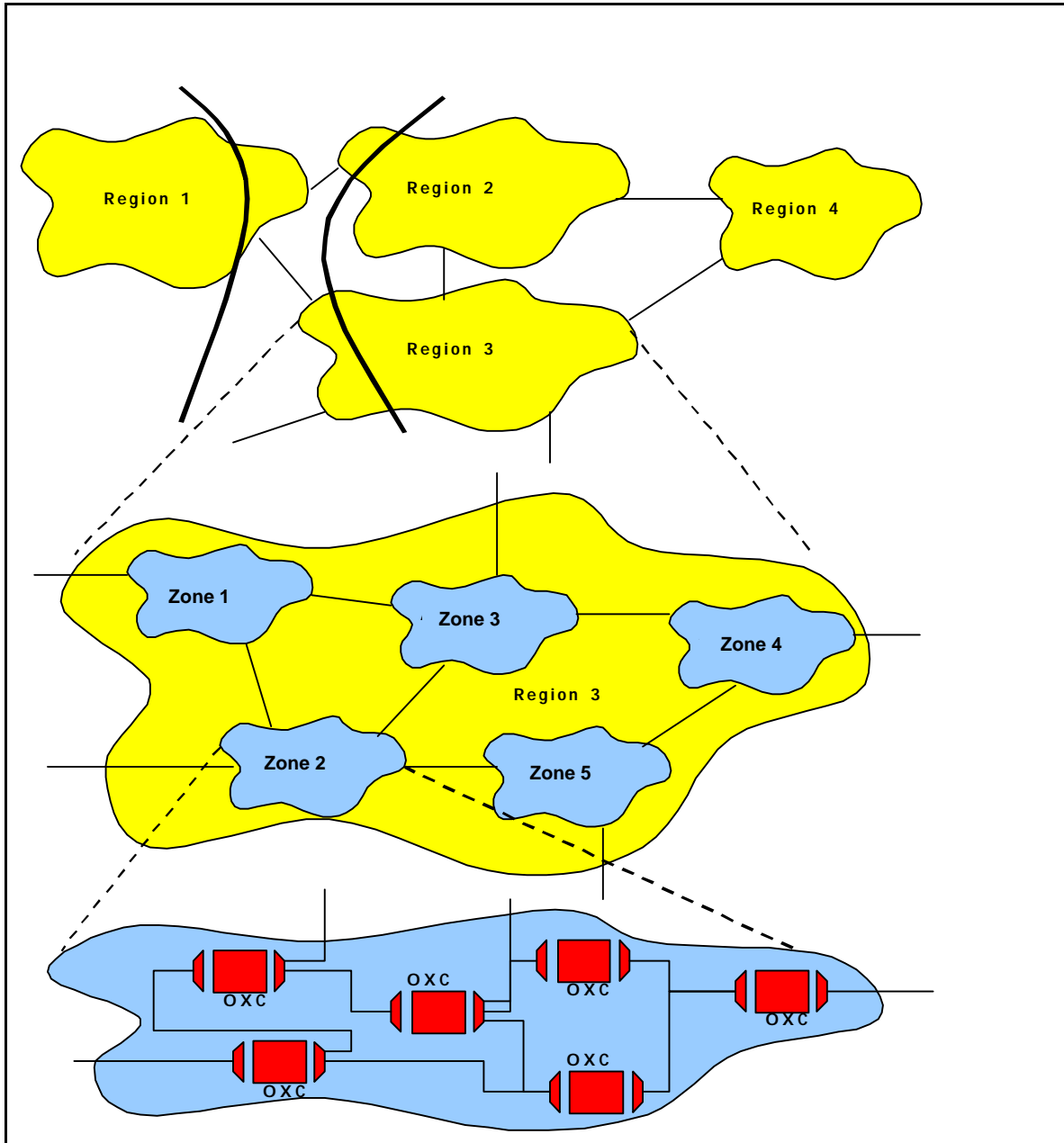
### 3.2 Geographical Hierarchy (or Logical Hierarchy)

Concerning the geographical hierarchy, the SRLG model developed in this document, includes the following definitions going from the less to the most extended logical structure partitioning of the area covered by the optical network (as shown in Figure 2.)

- **Node:** a node is a single device or active element included within the optical network; a node could be an Optical Cross-Connect (OXC) or a Photonic Cross-Connect (PXC). Exit points of a node are defined as the node ports.

- **Zone:** a zone includes one or more nodes whose location is limited to a confined area for the sake of maintainability. Zones have a fixed number of exit points and are non-overlapping meaning that a given node belongs to only one zone.
- **Region:** a region includes one or more zones whose location covers the individual locations of each of the area composing this region. Regions have a fixed number of exit points and are non-overlapping meaning that a given zone belongs to only one region.

Hence, a region could include one or more than one non-overlapping zone each of these zone could include one or generally more than one node.



**Figure 1. An example for the logical topology**

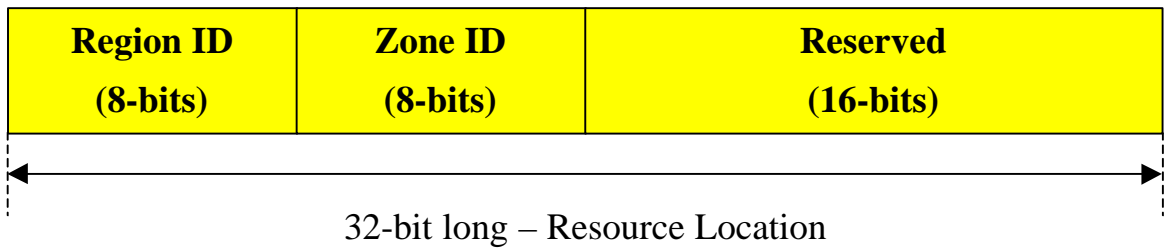
Note: A zone could correspond to an IGP area such as an OSPF are, and a region to an IGP Autonomous System (or BGP Autonomous System). However, the model does not exclude network topologies where the SRLG geographical hierarchy does not map the TE-routing hierarchical topology.

### 3.3 Hierarchical SRLG encoding

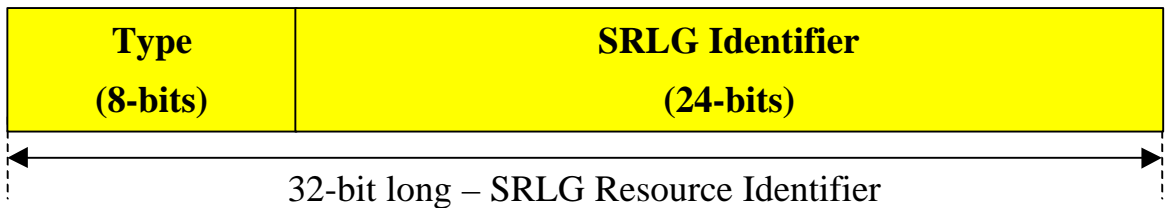
The objective of this hierarchical encoding is to achieve summarization of the SRLG identifiers at the boundary of geographical structures defined logically on the optical network. Here, we propose a linear encoding (with a type field) which seems more efficient, enables to abstract the physical layer structure and should facilitate the management of the identifiers.

Consequently, the detailed encoding of an SRLG identifier can include:

1. Resource Location (32-bit field)



2. SRLG Resource Identifier (32-bit field)



The resource location identifies the logical structure into which the SRLG Resource identifier is included.

Within the SRLG Resource Identifier, the Type field defines the resource type (i.e. the type of “link”) to which the SRLG identifier refers. The following resource types are currently defined:

- Fiber Link: 0x01
- Fiber Sub-segment: 0x02
- Fiber Segment: 0x03
- Fiber Trunk: 0x04

Since a given resource can belong to more than one SRLG, the SRLG Resource Identifier structure is defined in the most general case as a list of SRLG Resource Identifier structure (n x 32-bit):

Type (8-bits)	SRLG Identifier #1 (24-bits)
Type (8-bits)	SRLG Identifier #2 (24-bits)
// //	
Type (8-bits)	SRLG Identifier #N (24-bits)

Even if we propose a linear encoding, the summarization of the SRLG (at the logical structure boundaries) is still provided since the SRLG identifiers are structured as follows:

- A resource location frame (32-bit): Region (8-bit) + Zone (8-bit) + Unspecified (16-bit)
- And a physical Resource Identifier (32-bit) for each SRLG: Type (8-bit) + Resource Identifier (24-bit)

This encoding enables one to perform summarization at the boundaries of logical structures while overcoming the drawbacks of full hierarchical encoding scheme.

Note: the proposed encoding does not include the conditional failure probability as defined in section 4.2

#### 4. RISK ASSESSMENT

Risk assessment is defined as the quantification process of the potential risk associated to the inclusion of a given resource (this resource belongs to a given resource type located within a given logical structure such as a geographical location) in a given optical channel.

##### 4.1 Rationale for Risk Assessment

Consider the following example, where the client device makes the following requests to the optical network:

- Request for a persistent connection with 99.999 % (well known 5 9s) of availability or equally a down time less than X minutes per year.
- Request a high-protection for a portion of the traffic (at the expense of more charging) compared to other low-priority traffic.

Such requirements will be translated into path specific requirements. Such path specific requirements can be grouped into path selection requirements and path characterization requirements.

- Path selection requirements  
These typically dictate which physical path should be taken to achieve the availability requirements of the client. These requirements are typically the logical and physical diversity as mentioned in the hierarchical encoding section (see section 3).



- Path characterization requirements

Path characterization requirements typically dictate the protection mechanisms as requested by the client. This can be achieved in the form of optical rings, meshed protection mechanisms, etc. However, these are out of the scope of this document.

The components that need formalization in this example are:

- Step 1. Specification of the user requirements (such as the example above)
- Step 2. Configuring the network that helps in assessing the features such as the availability
- Step 3. Propagating the above-configured information.
- Step 4. Using the above-propagated information.

Step 1 of specifying the requirements is not in the scope of this document. Steps 2 – 4 are discussed in the remainder of this document.

As an example for this discussion we elaborate on the risk assessment for a selected path.

## 4.2 Quantifying the Risk Assessment

Risk (the complementary of availability) assessment is defined as the evaluation of the potential risk associated to the inclusion of a given resource (this resource belongs to a given resource type located within a given logical structure such as a geographical location) in a given path.

Given that an SRLG is used to encode the group of logical or physical resources, if a mechanism is devised to assign the risk associated with the resource, we can calculate the corresponding path with a high availability (as requested by the client).

A simple approach is to assign the conditional failure probability with each of the SRLG. This information can be encoded as an optional parameter along with the SRLG information. In addition, weights can be associated to each of the SRLG to either increase or decrease the usage of the resource.

In this approach the configurable parameters are:

- SRLG (Resource and Location Identifiers)
- Conditional failure probability per SRLG
- Weight for the selection of the SRLG

As mentioned above, the resource failure probability is defined as a conditional probability. For instance, we can associate a conditional failure probability 25% to any fiber sub-segment located within the same zone. It means that by selecting two (or more than two) different optical channels belonging to the same SRLG with respect to fiber sub-segment failure, if one of these lightpaths fails, then the probability that the other lightpath fails is 25%.

Moreover, the failure probability of a fiber can also depend on the zone and the length of the fiber. Moreover, a fiber can pass across different zones with different failure probabilities. In this case, we need to consider a summary failure probability per fiber.

For instance (if we refer to our previous example) and if we consider that:

1. a conditional failure probability of 50% is associated to any fiber link

2. a conditional failure probability of 1% to any fiber segment located within the same zone

Then by selecting two different optical channels included within the same SRLG with respect to fiber segment failure (S1, for instance), we obtain a simultaneous lightpath failure probability of 1%. Consequently, if the client asks for a protected path, by choosing fiber segment path disjointness, the simultaneous lightpath failure probability is also of 1%. However, choose two optical channels flowing through the same fiber (r1, for instance), then we have a probability of 50% that both optical channels fail simultaneously.

### **4.3 Risk Assessment Application**

Up to now we didn't define the association between the high availability of the path and SRLG conditional failure probability. A simple way to define the relationship is to consider the availability of the service requested by the client (i.e. a working and a protected path from the provider point of view) and conditional failure probability of the sequence of physical resource elements included within the corresponding paths. So if we consider,

1. a path whose source is located in zone 1 and whose destination is in zone 2 (same region)
2. a conditional failure probability of 1% if fiber links are selected within the same fiber trunk (and located within the zone 1)
3. a conditional failure probability of 1% if fiber links are selected within the same fiber trunk (and located within the zone 2)
4. the conditional failure probabilities are independent and weighted equally

Then, the availability of the service concerning the fiber link availability is of 98% since in this specific case conditional failure probabilities are additive.

Note that currently, the initial conditional failure probability value needs to be statically encoded; however, based on the "history" of the failures these values could be dynamically re-evaluated. The corresponding mechanism still needs to be specified.

## **5. FRAMEWORK for the SRLG INFORMATION and INFERENCE APPLICATION**

The SRLG Inference Model applications are related to the CSPF lightpath route computation and the SRLG identifier sets summarization in order to enable intra- and inter-area diverse routing.

### **5.1 Propagation SRLG Information**

The SRLG of each link is encoded as described in section 3.3, and this information is propagated between the various ONEs using the traffic engineering extensions to the IGP protocols such as OSPF [GMPLS-OSPF] and IS-IS [GMPLS-ISIS]. This propagation of SRLG information will be necessary whenever a new link is added or an existing link is removed. Initially the probability of failure of the various resources are assumed to be configured; it is envisioned that at some later time, the probability of failure of the SRLG will be propagated along with the SRLG itself (as described in Section 3.3).

## **5.2 Bottom-Up Computation of the SRR Relations**

Once the traffic-engineering topological information is received by the ONE, the Shared Risk Relationship (SRR) graph can be calculated on a regular basis, using the bottom up method described in Appendix 1.4. The fiber trunk SRR is used to compute the fiber segment SRR, which in turn is then used to compute the fiber sub-segment SRR until the fiber SRR computation is achieved. To the SRR which defines the membership of a resource belonging to the same SRLG set, we associate at each resource level (for instance, with this fiber SRR), the conditional failure probability between two elements belonging to this level (for instance, between two fibers).

## **5.3 Summarization in Topology and Resource Distribution**

By combining recursively several dependency graphs (of known structures) into a higher-level dependency graph, the number of SRLG sets and the number of element they include can be further reduced. Consequently, the applications of the extended model will also cover the reduction of the SRLG advertisements in the Topology and Resource Distribution [IPO-ONNI] running instance (i.e. the traffic engineering extensions to the link-state advertisements of the IGP protocol). In turn, this improvement will reduce the CSPF algorithm complexity for optical channel path calculation (i.e. engineered lightpath setup).

## **5.4 CSPF Route Computation**

Applications of this model are directly related to the Constraint-based Shortest Path First (CSPF) algorithm used for lightpath route computation (i.e. traffic-engineered lightpath creation) to maximize the lightpath disjointness and so decrease their common failure probability. Given an existing set of lightpaths across the network, the objective is thus to compute a route across the optical network topology for a newly requested lightpath such that this lightpath is diversely routed from a given set of existing lightpaths.

The diversity requirement is a routing constraint, and is expressed as the conditional failure probability of a requested lightpath with respect to the failure of an existing (set of) lightpath. Hence, in addition to the other traffic-engineering constraints, the diversity constraint requires that the conditional failure probability not exceed a given threshold. Therefore, the CSPF need to be updated to take the routing diversity constraint into account.

Moreover, the SRLG concept generates another dimension to the existing constraint-based path computation methods traditionally used in MPLS (or PNNI) based hierarchical networks. The SRLG constraints provide an additional dimension to the common traffic-engineering constraints such as bandwidth availability, link metrics and other parameters. The routing diversity constraint specificity requires the use of more appropriate path computation algorithms that provide not only complete multi-path disjointness but also partial multi-path disjointness with respect to various risk factors. In a similar way, appropriate mechanisms should also be used in order to perform path re-optimization following various restoration strategies.

### **5.5 Extension of the SRLG Concept**

The SRLG concept can be extended to logical-level structures by taking into account the following purposes:

1. Given the physical and geographical-level decomposition of the optical network topology, the SRLG encoding can be hierarchically structured. The hierarchical encoding helps in constructing the logical-level topological abstraction, which in turn can be used in the SRLG summarization and loose-path computation. The link semantics could be also extended to accommodate the inter-region and inter-zonal links.
2. Propagate these additional logical-level (region and zones) links using the IGP routing protocols for intra- and inter-area routing purposes.
3. To reduce the amount of the flooded information and hence lightpath route computation complexity, the flooding scope of the information propagation is extended to accommodate region-level and zone-level.

## **References**

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- 7. [OIF2000.197]** J.Heiles, ‘Alignment of the UNI with ITU-T Terminology’, OIF Contribution 197, September 2000.

## Appendix 1 : Inference of SRLGs - Model

### 1.1 Definition of the concept and Example

The present model is intended to be used to automate the discovery of the Shared Risk Link Groups (SRLGs) at a given layer for a given physical resource type. This resource type could be located within a given region and zone.

Note that a typical resource type is fiber, fiber sub-segment, fiber segment or fiber trunk and a typical resource location is: zone, region or node. For a given resource type, when the resource location is not specified, the resource location is limited to the nodes.

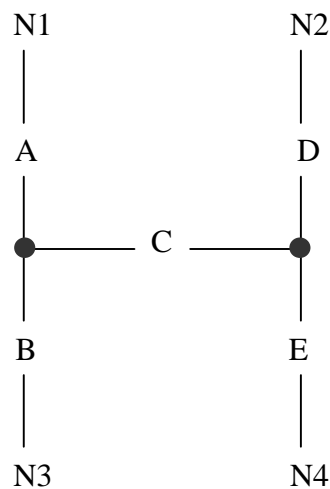
#### Definitions and assumptions:

- An SRLG is a set of links sharing a common physical resource i.e. a common risk.
- The set of links said to belong to the same SRLG, if they are established over fibers that go through the same fiber sub-segments (so through the same fiber trunk) and through the same fiber segment between two ONEs.
- A lightpath is defined to cover an SRLG iff (if and only if) it crosses one of the links belonging to that SRLG.
- Two lightpaths are defined as diverse with respect to a set of SRLGs iff the sets of SRLGs they cover are disjoint.

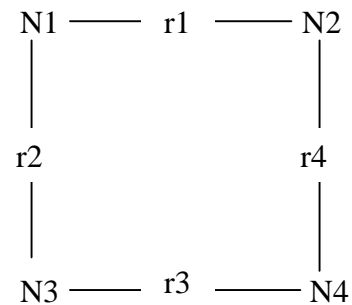
#### Example:

The following example referring to Figure 5 (for the physical network topology) offers some clarification. Let

- N1, N2, N3, and N4 represent locations that are linked by the fiber sub-segments,
- A, B, C, D and E be fiber segments, and
- r1 (ACD), r2 (AB), r3 (BCD) and r4 (DE) are fibers routed over the fiber segment topology.



Fiber segment topology



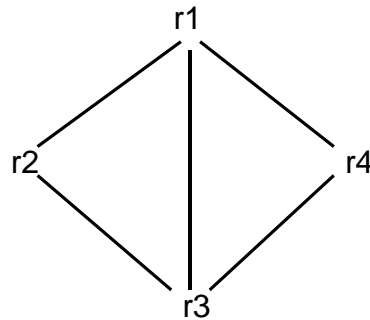
Fiber link topology

**Figure 2: A correlation between the fiber segment and fiber topologies**

In such a physical topology the obvious SRLGs are the following:

- {r1, r2} both going down when segment A breaks
- {r1, r3} both going down when segment C breaks
- {r1, r4} both going down when segment D breaks
- {r2, r3} both going down when segment B breaks
- {r3, r4} both going down when segment E breaks.

These five SRLGs can be replaced by two SRLGs,  $S1 = \{r1, r2, r3\}$  and  $S2 = \{r1, r3, r4\}$ , where  $S1$  and  $S2$  constitute the minimum edge covering with cliques<sup>2</sup> of the Shared Risk Relationship (SRR) graph that can be drawn between r1, r2, r3, r4 (see Figure 3). This decomposition is unique. If there was a dependency between r2 and r4, there would be a unique SRLG,  $S = \{r1, r2, r3, r4\}$ .



**Figure 3. SRR graph between fibers r1, r2, r3 and r4  
Shared Risk Relationships (SRR) wrt fiber segment failure**

Although  $R1 = r1-r2-r3$  and  $R2 = r4$  are diverse lightpaths between  $N2$  and  $N4$  in the fiber topology (link and node disjointness), they are not diverse with respect to the SRLGs, because both  $R1$  and  $R2$  cover SRLG  $S2$ , which contains r1, r3 (part of  $R1$ ) and r4 (part of  $R2$ ). SRLGs are thus a way of formalizing the propagation of link risk dependencies from server layers to client layers.

The rules guiding the definition of minimum set of SRLGs for more complex physical network topologies will be addressed in a future version of this study.

## 1.2 Rationale for the Model

We define the routing diversity requirement of a lightpath as the SRLG Inclusion Set (SIS) of all the lightpaths from which a given lightpath must be physically diverse<sup>3</sup>. The SRLG Inclusion Set (SIS) of a lightpath is defined as the set of SRLGs covered by this lightpath. As mentioned in before, routing diversity could be related to the following physical optical network resources:

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<sup>2</sup> A clique of a graph  $G$  is a sub-graph of  $G$  in which every two nodes are connected by an edge.

<sup>3</sup> Note: When client layers implement their own recovery mechanism, they may not want to request protected lightpaths (for instance, a client could only request unprotected lightpaths from the optical network). However, the client may request that some of these unprotected lightpaths be diverse throughout the optical network, such that the corresponding links in the client layer topology do not fail together or at least, are unlikely to fail together.

- Optical network element (not considered in this document)
- Fiber link
- Fiber sub-segment
- Fiber segment
- Fiber trunk

The resource identifiers (Resource ID) corresponding to the optical network resources can be defined by considering a hierarchical encoding:

- Optical device: ONE ID (or Node ID)
- Fiber link: Identified by a Fiber ID (and a Fiber ID – Port ID mapping table)
- Fiber sub-segment: Identified by a Fiber Sub-segment ID
- Fiber segment: List of fiber sub-segments included within the same segment; coded as Fiber Segment ID
- Fiber trunk: Sequence of fiber sub-segments connecting two ONE's

### 1.2.1 *Lightpath creation*

When a client CNE sends a lightpath create request to the boundary ONE<sup>4</sup>, it can only reference lightpath(s) from which the new lightpath j should be diverse. The purpose is to avoid the set of SRLGs contained in the SISs of lightpath 1, lightpath 2,..., lightpath N when routing lightpath j.

The ONE will process this request by considering the Shared Risk Link Groups (SRLGs) of the lightpath 1, lightpath 2, ..., lightpath N and find a physical route for the lightpath j whose SIS does not contain any of the SRLGs covered by the lightpath 1, lightpath 2, ..., lightpath N. Consequently, the SIS of the lightpath j could be represented as the union of the SIS of the lightpaths from which the lightpath j has to be diverse.

Each of the physical resources included within the optical network could be allocated to a lightpath. Consequently, there is a corresponding list of lightpaths sharing a common resource identified by a resource type and a resource ID that could be represented as a resource allocation array:

```

[ <<RT 1; RID 1>; <LPSet[1,1]>>
  <<RT 1; RID 2>; <LPSet[1,2]>>
  ...
  <<RT 1; RID N1>; <LPSet[1,n]>>
  ...
  <<RT 2; RID 1>; <LPSet[2,1]>>
  <<RT 2; RID 2>; <LPSet[2,2]>>
  ...
  <<RT 2; RID N2>; <LPSet[2,n]>>
  <<RT M; RID 1>; <LPSet[m,1]>>
  <<RT M; RID 2>; <LPSet[m,2]>>

```

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<sup>4</sup> Note: Here that the client CNE only knows about the lightpath he has already established.



$\dots$   
 $\langle\langle RT\ M; RID\ N_M\rangle; \langle LPSet[m,n]\rangle\rangle]$

where

- RT - Resource Type (such as - Fiber, Fiber sub-segment, Fiber segment, Trunk)
- RID - Resource Identifier for a given RT.
- LPSet[i,j] := Set of Lightpaths covering a RT i having a RID j

Since each of these lightpath sets shares a common resource each of these resources constitutes a shared risk. Hence, in the optical channel layer, the corresponding lightpath sets constitutes an SRLG for a given (RT, RID) pair.

If we consider the fiber set allocated to the optical network topology, then there is a corresponding list of fibers sharing a common resource and identified by a (RT, RID), as illustrated below:

$\langle\langle RT\ 1; RID\ 1\rangle; \langle FSet[1,1]\rangle\rangle$   
 $\langle\langle RT\ 1; RID\ 2\rangle; \langle FSet[1,2]\rangle\rangle$   
 $\dots$   
 $\langle\langle RT\ 1; RID\ N_1\rangle; \langle FSet[1,n]\rangle\rangle$   
 $\dots$   
 $\langle\langle RT\ 2; RID\ 1\rangle; \langle FSet[2,1]\rangle\rangle$   
 $\langle\langle RT\ 2; RID\ 2\rangle; \langle FSet[2,2]\rangle\rangle$   
 $\dots$   
 $\langle\langle RT\ 2; RID\ N_2\rangle; \langle FSet[2,n]\rangle\rangle$   
 $\langle\langle RT\ M; RID\ 1\rangle; \langle FSet[m,1]\rangle\rangle$   
 $\langle\langle RT\ M; RID\ 2\rangle; \langle FSet[m,2]\rangle\rangle$   
 $\dots$   
 $\langle\langle RT\ M; RID\ N_M\rangle; \langle FSet[m,n]\rangle\rangle]$

where<sup>5</sup>

- FS[i, j] := Set of Fibers covering a RT i having a RID j

In this case, each of these fiber sets shares a common resource meaning that each of these resources constitutes a shared risk Hence in the physical layer, the corresponding fiber sets constitutes an SRLG for a given (RT, RID) pair.

Consequently, the routing diversity of a lightpath X (so, extendedly the SRLG Inclusion Set of a lightpath X will be defined as the corresponding complement) can be represented as the list of all the resources covered by all the lightpaths from which this lightpath X has to be physically diverse from (i.e. the set of resources that must not be used the lightpath X):

$[\langle\langle RT\ 1\rangle; \langle RID\ 1, RID\ 2, \dots, RID\ K\rangle\rangle$   
 $\langle\langle RT\ 2\rangle; \langle RID\ 1, RID\ 2, \dots, RID\ L\rangle\rangle$   
 $\dots$   
 $\langle\langle RT\ N\rangle; \langle RID\ 1, RID\ 2, \dots, RID\ M\rangle\rangle]$

---

<sup>5</sup> This discussion including the one related to the LPSet does not include the logical structure to which a resource belongs.

- i.e., excluding lightpath X from
- RT 1 is identified by excluding <RID1,..., RID K>
  - RT 2 is identified by excluding <RID1,..., RID L>
  - ...
  - and RT N is identified by excluding <RID1,..., RID M>.

However, this interpretation does not permit to find the relationship between logical structures or physical resources: for instance a fiber is included in a fiber sub-segment, which is included in a fiber segment. Moreover, several lightpaths can be included within the same fiber (or link). As defined in [IPO-Frame] and [IPO-Bundle], the notable characteristic of SRLGs is that a given link could belong to more than one SRLG, and two links belonging to a given SRLG may individually belong to two other SRLGs. The algorithm described in the section 1.4, propose a method to dynamically discover these relationships.

### **1.2.2 Risk type**

As specified up to now, the SRLG model specification considers that each of the resource (as used in the lightpath computation) may experience one or more failure type(s). The same applies to geographical locations - a given location might be subjected to more than one failure type. Moreover, by applying the SRLG properties, a network resource failure could cover more than one geographical location. Consequently, some heuristics must be introduced to keep the SRLG computational complexity limited.

In order to limit the computational complexity, we define the following heuristics when considering the SRLG computation with respect to the type of risk:

- The set of risk types associated to network resources corresponds exactly to the set of resource type failure.
  - o So, for instance, the risk type associated to a fiber segment is a fiber segment failure. The same principle applies for other network resources such as fiber link, fiber sub-segment and fiber trunk. Consequently, we don't consider a finest granularity for the network resource failure than the one referred by their type.
- A risk type associated to a geographical structure covers exactly the region where it is defined. Moreover, a geographical failure is limited to a given location and does not impact the neighboring locations or generate another geographical failure type.
  - o For instance, we consider that an earthquake covers exactly one region or one area and that such a failure does not generate a hurricane impacting the neighboring locations. So, there is no correlation between geographical failures.
- Each of the network resources covers exactly one geographical logical structure (defined by a region ID or a zone ID).
  - o Consequently, when a geographical failure occurs, it generates a failure impacting the entire network resources included within the corresponding location. Hence, there is an ON/OFF relationship between geographical and network resource failures.

Consequently, when considering network resources, the risk type associated to an SRLG is defined as the potential failure of one (or more than one) instance of the resource belonging to a given resource type or the potential failure of one (or more than one) instance of the resource depending on one (or more than one) of the instance of this given resource.

In the previous section, we defined the concept of SRLG with respect to a given resource type (and by extension to the risk type to which this resource type refers) and a given resource identifier by means of the lightpath and fiber set concept. This definition can be extended to include the fiber sub-segment and fiber segment set concept. Since each instance of these sets corresponds to an SRLG class, we assign an identifier to each of the SRLG classes members and define this value as a SRLG identifier.

Moreover, by applying the defined heuristics above, the SRLG identifiers can be grouped together by taking into account their geographical location. The latter is encoded by identifying the region identifier (region ID) and the zone identifier (zone ID) including the resource identifiers to which the SRLG refers.

### 1.3 Calculation of Shared Risk Link Groups

In the calculation method, `shared_risk(RID i, RID j, RT)` is TRUE only if RID i and RID j belong to the same SRLG with respect to the type of risk (RT). The risk types considered here are related the fiber trunk, the fiber segment, the fiber sub-segment and the fiber link risk failure.

A recursive calculation of `shared_risk` proceeds as follows:

```
shared_risk(RID i, RID j, RT) =
    at_risk(RID i, RT)
    and at_risk(RID j, RT)
    and (RID i = RID j
         or (exists RID k, RID l
             such that
                 depends_on(RID i, RID k)
                 and depends_on(RID j, RID l)
                 and shared_risk(RID k, RID l, RT)))
```

In this calculation:

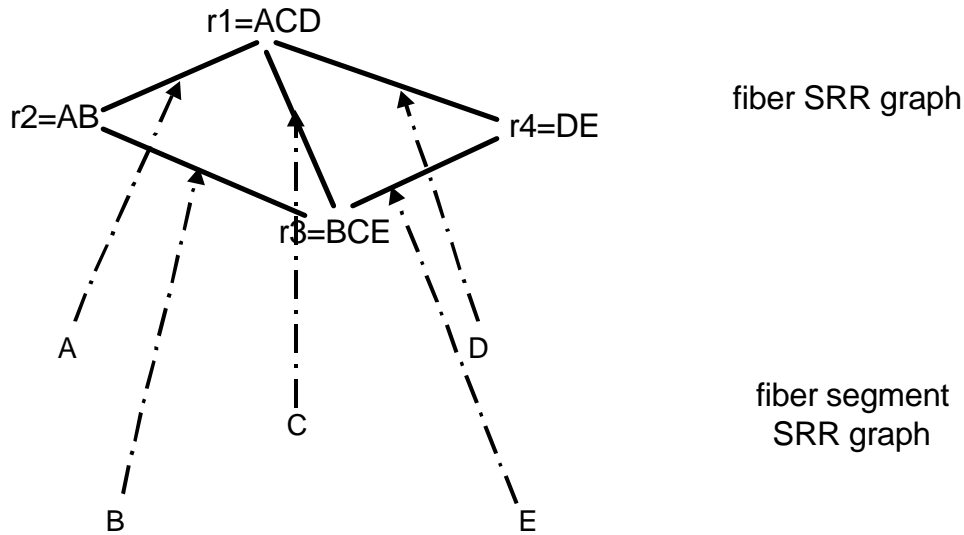
- `at_risk(RID, RT)` is TRUE only if RID is susceptible to a risk of type RT, either directly, or indirectly, through the failure of one of the elements it depends on.
- `depends_on(RID i, RID j)` is TRUE only if RID i fails as soon as RID j fails.

If we refer to the example detailed in the previous section, then `shared_risk(r1, r2, [fiber segment failure]) = TRUE` because `depends_on(r1, A) = TRUE`, `depends_on(r2, A) = TRUE` and `at_risk(A, [fiber segment failure]) = TRUE` (the latter simply because A is a fiber segment).

### 1.4 Practical Method for SRLG Calculation

The recursive formula presented in the previous section does not directly lead to an efficient algorithm. It's top-down nature illustrates nicely the recursive nature of the SRLG concept, but the calculation of the SRLGs in a top-down fashion would be totally inefficient, entailing the calculation of the same SRLGs in lower network layers over and over again.

A far more efficient algorithm can be obtained by a bottom-up calculation. **Error! Reference source not found.** Figure 4 illustrates this by using the example we introduced in the section 1.1 and in by introducing the concept of Shared Risk Relationship Graph (SRR) which defines the membership of a resource belonging to the same SRLG.



**Figure 4. Bottom-up calculation of Shared Risk Relationships**

For the calculation of a set of SRLGs, we need to calculate a Shared Risk Relationship (SRR) graph. The bottom-up calculation of the fiber SRR graph proceeds as follows:

- Step 1. For each fiber segment, there is an SRR between every two fibers contained in that segment (dot-dash lines in **Error! Reference source not found.**4).
- Step 2. For every SRR between two fiber segments, there is an SRR between every two fibers contained in either of the two fiber segments.

In the previous example, there are no SRRs between fiber segments, and the calculation stops after Step 1.

### 1.5 Application of the model

The model is intended to be used to automate the discovery of the SRLGs at a given layer for a given risk type (RT).

The dependencies may be confined to one layer, e.g. the dependency of an optical link on a ONE (for instance, a DWDM end-system) to which it is connected, when the RT = [ONE failure]. Dependencies may also extend over layer boundaries, e.g. the dependency of an TDM circuit in an SDH network established on an optical channel (or wavelength) through the optical network that is the server of the SDH network, when RT = [fiber failure].

Let two optical network resources  $RID_i$  and  $RID_j$  within the same layer share a common risk of type  $RT$ . Let this risk type be tied to a lower layer, which we will call the risk layer. To enable the layer to infer  $shared\_risk(RID_i, RID_j, RT)$ , its serving layer should advertise the following information:

`shared_risk(component_1, component_2, RT)`

where

- `component_1` are services of the serving layer on which  $RID_i$  rely and
- `component_2` are services of the serving layer on which  $RID_j$  rely.

If the serving layer is not the risk layer, the latter has to infer this knowledge itself from what its serving layer is advertising.

If shared risk relationships are not advertised, client layers should at least be able to query from their serving layer the shared risk relationships between the services they receive.

Some dependencies do not lend themselves easily to automatic discovery. For instance, it is hardly imaginable that the process of finding out through which fiber segments a fiber goes can be automated. This means that part of the image of `depends_on (RID_i, RID_j)` will have to be provided 'manually' by the operator or be at least statically configured into a centralized repository.

## 1.6 Generalized Inference Model

By referring to the example provided in the section 1.1, we can deduce the following statements:

- First, given a physical network, we must assign in the optical network the fibers to fiber sub-segments (this is usually trivial since a fiber sub-segment will correspond to a fiber bundle), and we must (less trivially) assign fiber sub-segments to fiber segments.
- Then, given a physical network, every fiber sub-segment that is connected to a location  $N_i$  must belong to a common fiber segment.

However one can argue that a location should be allowed to have multiple fiber segments connected to it. Consider for instance the example of a central office in a SDH/SONET network, which may be connected to a metro ring and a local access ring or a linear cascade of ADMs. Such a facility could be represented by a location vertex that is connected to four fiber segments in the two-ring case (two segments associated with each ring). A logistical issue is how the network will know that a particular section of a fiber bundle belongs to a particular fiber segment.

### 1.6.1 Connectivity Graph

So in the general case, any network at the fiber segment level can be represented as a graph  $G([N,X], S)$ , where  $N$  is the set of vertices that correspond to locations  $\{N_1, N_2, \dots, N_n\}$ ,  $X$  is the set of vertices that are not locations but are meeting points for fiber segments (call these vertices  $\{X_1, X_2, \dots, X_m\}$ ), and  $S$  is the set of fiber segments  $\{S_1, S_2, \dots, S_p\}$ .

Similarly, the network can be represented by a fiber connectivity graph  $C(N, F)$ , where the set  $N$  is equal to the set  $N$  in the fiber segment graph above, and the set  $F$  is the set of edges indicating fiber connectivity between the elements of the set  $N$ . Specifically, an edge  $F_i$  exists between two vertices  $N_k$  and  $N_l$  if and only if there exists at least one direct fiber link connection between the two locations corresponding to  $N_k$  and  $N_l$ . Furthermore, we can say that for every edge  $\{N_k, N_l\}$  in  $C(N, F)$ , there is a walk that can be represented as a path  $\{N_k, X_{a1}, X_{a2}, \dots, X_{an}, N_l\}$  or equivalently as a trail  $\{S_{a1}, S_{a2}, \dots, S_{a(n+1)}\}$  in  $G([N, X], S)$ , where  $\{S_{a1}, S_{a2}, \dots, S_{a(n+1)}\}$  is the trail of fiber segments (the fiber trunk) that connects  $N_k$  to  $N_l$ , and that every such walk corresponds to a fiber trunk that connects the two locations.

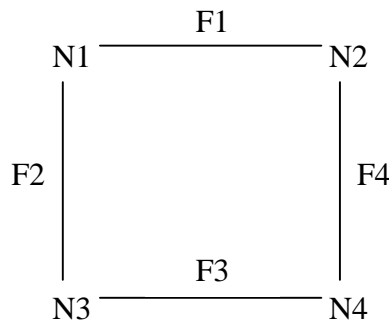
However, it is important to note that not every path in  $G([N, X], S)$  of the form  $\{N_k, X_{a1}, X_{a2}, \dots, X_{an}, N_l\}$  maps to an edge in  $C(N, F)$ . There must be a corresponding edge in  $C(N, F)$  to obtain such a mapping. In the example in the draft,  $\{N1, X1, X2, N4\}$  is a path from  $N1$  to  $N4$  whose only members that are elements of  $N$  are its endpoints, but there is no direct connection between  $N1$  and  $N4$ , as can be seen from  $C(N, F)$ .

### 1.6.2 Combined Connectivity Graph

In order to construct the SRR graph, we need to find a way to combine the information in  $C(N, F)$  and  $G([N, X], S)$  to form a new graph,  $H(F, S)$ . In this new graph, the members of the connectivity graph edge set become the vertices of the SRR graph, while the edges of the fiber segment graph become the edges in  $H$ .

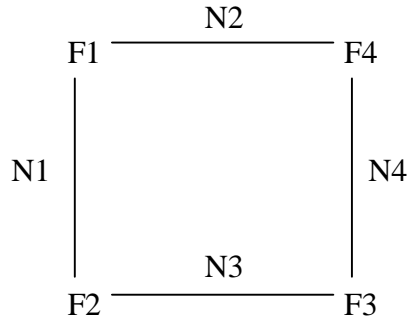
The graph  $H(F, S)$  can almost be created by taking  $C(N, F)$  and "switching" the vertices and edges, and then naming each edge with the fiber segment emanating from the location associated with the edge, rather than naming the edge with the location itself.

In the above example, the connectivity graph  $C(N, F)$  is



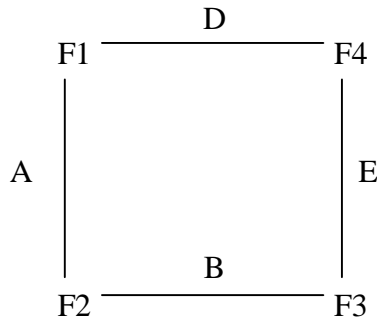
Connectivity graph  $C(N, F)$

By exchanging vertices into edges and edges into vertices one get:



Reverse Connectivity graph C(N, F)

Each location has its own fiber segment that comprises all the fiber sub-segments that emanate from that location. By replacing each location Ni with its own adjacent segment, the above graph becomes a combined graph:

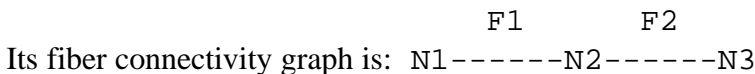
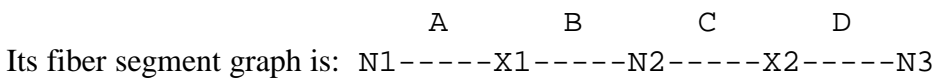
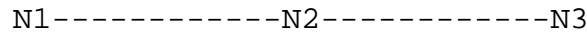


Combined Connectivity Graph H(F, S)

which is the SRR graph for the network minus the edge C connecting F1 and F3.

### 1.6.3 Basic Topologies

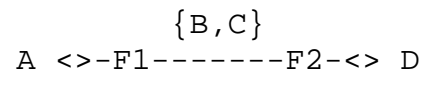
As first basic topology, take for instance the case of a network that is a linear cascade:



N1            N2            N3

The new graph is:  $\langle \rangle - F1 - \text{-----} - F2 - \langle \rangle$ , where  $- \langle \rangle$  and  $\langle \rangle -$  denote looped edges (so technically it's a multigraph).

By replacing locations with associated fiber segments, one get the following graph



In this graph, segments A and D affect only the fiber links (N1, N2) and (N2, N3) respectively, and affect no other fibers. The edge between F1 and F2 really shouldn't be a fully connected edge, since failure of the fiber segment B will not impact the (N2, N3) fiber connection. So, one should say that there can be an edge between Fi's if and only if they share a fiber segment connecting them to a location.