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**Operating Virtual Concatenation (VCAT) and the Link Capacity
Adjustment Scheme with Generalized Multi-Protocol Label Switching
(GMPLS)**
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Abstract

   This document describes the use of the Generalized Multi-Protocol
   Label Switching (GMPLS) control plane in conjunction with the Virtual

Concatenation (VCAT) layer 1 inverse multiplexing mechanism and its
companion Link Capacity Adjustment Scheme (LCAS) which can be used
for hitless dynamic resizing of the inverse multiplex group. These
techniques apply to the Optical Transport Network (OTN), Synchronous
Optical Network (SONET), Synchronous Digital Hierarchy (SDH) and
Plesiochronous Digital Hierarchy (PDH) signals.

Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",
"SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this
document are to be interpreted as described in RFC-2119 [RFC2119].

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1. Introduction

   This document describes the use of the Generalized Multi-Protocol
   Label Switching (GMPLS) control plane in conjunction with the Virtual
   Concatenation (VCAT) layer 1 inverse multiplexing mechanism and its
   companion Link Capacity Adjustment Scheme (LCAS) which can be used
   for hitless dynamic resizing of the inverse multiplex group. The
   reader is directed to appendix A that presents an overview of the
   capabilities of VCAT and LCAS in transport networks. Further,
   appendix B describes a carrier perspective on the application areas
   for these technologies. We develop a set of scenarios and specific
   requirements to support these scenarios in GMPLS-enabled networks.
   We then describe the RSVP-TE mechanisms needed to set up co-routed
   and diversely routed circuits that are members of the same VCAT group
   and to resize those using LCAS. We also identify some capabilities
   that would be nice to have through advertising OSPF-TE. The actual
   advertisement is currently TBD.

2. VCAT/LCAS Scenarios and Specific Requirements

   From the carrier application areas discussed in Appendix B, we can
   derive a number of specific requirements for the support of VCAT/LCAS
   in GMPLS. A number of requirements can additionally be derived from
   the flexible nature of VCAT/LCAS.

2.1. **Multiple VCAT Groups per GMPLS Endpoint**

   In general, an LSR can be ingress/egress of one or more VCAT groups.
   VCAT and LCAS are interface capabilities. An LSR may have for example
   VCAT-capable interfaces that are not LCAS-capable. It may at the same
   time have interfaces that are neither VCAT or LCAS-capable.

2.2. **Component Signal Configuration Requirements**

   We list in this section the different scenarios that SHOULD be
   supported. Here we use the term "VCG" to refer to the entire VCAT
   group and the terminology "set" and "subset" to refer to the
   collection of potential VCAT group member signals.

   o Fixed, co-routed: A fixed bandwidth VCG, transported over a co-
      routed set of member signals. This is the case where the intended
      bandwidth of the VCG does not change and all member signals follow
      the same route and minimize differential delay. The intent here is
      the capability to allocate an amount of bandwidth close to that
      required at the client layer.

   o Fixed, diversely routed: A fixed bandwidth VCG, transported over
      at least two diversely routed subsets of member signals. In this
      case, the subsets differ are link-disjoint over at least one link
      of the route. The intent here is additional resilience and
      graceful degradation in the case of failure (note that

      differential delay may be a limiting factor).

   o Dynamic, co-routed: A dynamic VCG (bandwidth can be increased or
      decreased via the addition or removal of member signals),
      transported over a co-routed set of members. Intent here is
      dynamic sizing of bandwidth.

   o Dynamic, diversely routed: A dynamic VCAT group, transported over
      at least two diversely routed subsets of member signals. The
      intent here is dynamic resizing and resilience (but differential
      delay is a limiting factor).

2.3. Discovery of Interface Capability

o Discovering VCAT: VCAT sources can only establish VCGs with VCAT
   capable sinks. Hence the VCAT capabilities of a PDH, SDH, or OTN
   path termination points may need to be known before the signaling
   of the individual member LSPs can start.

   Currently there is no support for the discovery of VCAT or LCAS a
   priori, i.e., via routing information. Instead, if a network
   operator tries to signal a co-routed VCAT group, if the interface
   does not support it, then RFC 3946 states that the receiver node
   MUST generate a PathErr message with a "Traffic Control Error/
   Service unsupported" indication. If the VCAT group is made up of
   diversely routed LSPs, each with carrying one element of the
   group, there is no specification of the error code to be used. TBD
   -- It may be useful to have a specific error code concerning "VCAT
   not supported".

o Discovering LCAS: LCAS offers additional functionality between
   VCAT capable sources and sinks. Hence the LCAS capabilities of
   VCAT enabled path termination points can be useful to know in
   advance of component signal setup.

   Currently there is no mechanism to check a priori that an ingress
   or egress is LCAS capable until after the VCG has been established
   and LCAS is invoked to dynamically resize the VCG. This may be a
   problem as this information may not be known until the VCG has
   been put in service. TBD -- It may be useful to have this
   information advertised and it may be good to have a specific error
   code "LCAS not supported" in the case LCAS is used on an interface
   that is not LCAS enabled.

2.4. VCAT Operation With or Without LCAS

VCAT capabilities may be present with or without the presence of
LCAS, hence GMPLS mechanisms for the establishment and removal of
VCAT groups SHALL be equally applicable in the presence or absence of
the LCAS.

2.5. Incremental Construction of a VCG

In some cases, it may not be possible to set up the VCG in one shot.
This may be the case for example when hardware cannot match the
individual members at sink and source in the inverse multiplexing
function. Therefore support for VCAT in GMPLS SHOULD allow
incremental setup of the individual members of the VCG.

3. **GMPLS Mechanisms for Signaling VCAT/LCAS**

We describe in this section the signaling mechanisms that already exist in GMPLS using RSVP-TE [RFC3473] and the extensions needed, mainly for diversely routed paths and in support of the LCAS procedure. We also discuss the advertising of bandwidth availability to the client layer using OSPF-TE [RFC3630], [RFC4202] and [RFC4203].

Section 3.1. is included for informational purposes only. It describes existing procedures and was included for completeness and for reference.

Section 3.2. describes new procedures proposed to support diversely routed VCAT groups. When possible it reuses any applicable existing procedures from section 3.1.

3.1. **Co-Routed Signals**

Note that this section is for informational purposes only.

The existing RFCs support co-routed signal setup using the NVC field as explained in section 2.1 of RFC 3946 [RFC3946bis]. In this case, one LSP will be set up in support of the VCAT group.

There are two options for setting up the VCAT group, depending on hardware capability, or management preferences. We'll outline the one-shot and incremental setup.

Let's explain the procedure based on an example of setting up an VC4-7v in SDH (corresponding to STS-3c-7v SONET) VCAT group.

3.1.1. **One-shot Setup of Co-Routed Signal**

An RSVP-TE Path message is used with the following parameters.

With regards to the traffic parameters, the elementary signal is chosen (6 for VC-4/STS-3c_SPE). The value of NVC is then set to 7.

A Multiplier Transform greater than 1 (say N>1) is used if the operator wants to set up N VCAT groups that will belong to and be assigned to one LSP.

SDH and SONET labels in turn have to be defined: an explicit ordered list of all labels (32-bit values of the Generalized Label object) in the concatenation is given. RFC 3946 requires that the order of the labels reflect the order of the payloads to concatenate and not the physical order of time-slots).

When the MT field is larger than 1, the list includes labels for the
components of each of the group.

Note that full Refresh messages (using Path) carry all the
information and parameters explained above whereas Summary Refresh
messages will only carry the Message IDs. Full Path Refresh messages
are NOT end-to-end signaling messages.

3.1.2. Incremental Setup of Co-Routed Signal

In some cases, it may be necessary to set up components individually.

One example of this requirement is when the hardware that supports
VCAT can only add VCAT elements one at a time or cannot match
automatically the elements at the ingress and egress for the purposes
of inverse multiplexing. The serial or incremental setup solves this
problem.

In order to accomplish incremental setup, and for each iteration, NVC
is incremented up to the final value required. The iteration
consists of the successful completion of a Path and Resv signaling.
At first, NVC = 1 and one label is included.

At each of the next iterations, NVC is set to (NVC +1), one more
label is added to the ordered list of labels (in the Path or Resv
message). A node that receives the message that contains changed
fields will process the full Path message and based on the new value
of NVC, it will add a component signal to the VCAT group, and switch
the new timeslot based on the new label information.

Note that if a new upstream label is required, this label must be
added to the PATH message. If only a downstream label is required,
then the upstream label is unchanged and a downstream label is
received in the RESV message.

Following the addition of the new label to the LSP, LCAS is used in-
band to add the new label into the existing VCAT group. LCAS
signaling for this is described in [ITU-T-G.7042].

3.1.3. Removing a Component Signal

The procedure is similar to 3.1.2. The LCAS step is taken first
though as follows. First, the label to be dropped is taken out of
the group using LCAS signaling (in-band). LCAS signaling is
described in [ITU-T-G.7042].

In this case, the NVC value is decremented by 1 and a label is
removed from the ordered list. This is not supported for VCAT-only
interfaces as removing one component of the VCG will result in errors
in the inverse-multiplexing procedure of VCAT and result in the
teardown of the whole group. So, this is a feature that only LCAS-
capable VCAT interfaces can support.

3.1.4. Removing Multiple Component Signals in One Shot

The procedure is similar to 3.1.3. In this case, the NVC value is
changed to the new value and all relevant labels for the components
to be torn down are removed from the ordered list. This is also not
supported for VCAT-only interfaces as removing one component of the
VCG will tear down the whole group.

3.1.5. Use of multiple LSPs for Co-Routed Circuits

It is possible to use as many LSPs to subtend the co-routed circuits.
If this is the case, the procedure outlined in the following section
can be applied directly here. The Association object as discussed in
this section is used to indicate the VCG association type.

3.1.6. Teardown of Whole VCG

LCAS signaling is used inband to remove the labels associated with
the LSP from the group. LCAS signaling is defined in [ITU-T-G.7042].

Following the removal of the LSP from the group, the LSP is deleted
by using deletion procedures of [RFC 3473] (e.g., the deleting
ingress LSR -egress LSR respectively- sends a Path -Resv message
respectively- with Admin_Status marked for the LSP being removed).

3.2. Diversely Routed Signals

The initial GMPLS specification did not support diversely routed
signals using the NVC construct. In fact, RFC 3946 says:

> [...] The standard definition for virtual concatenation allows
> each virtual concatenation components to travel over diverse
> paths. Within GMPLS, virtual concatenation components must
> travel over the same (component) link if they are part of the
> same LSP. This is due to the way that labels are bound to a
> (component) link. Note however, that the routing of components
> on different paths is indeed equivalent to establishing
> different LSPs, each one having its own route. Several LSPs can
> be initiated and terminated between the same nodes and their

corresponding components can then be associated together (i.e., virtually concatenated).

Diverse routing of signals can be a useful capability but requires the extensions identified in this document.

3.2.1. Association Object

The feature that needs to be added is the functionality to associate the corresponding components. For this purpose, we propose the use of the Association Object. The association object was defined in [E2E-RECOVERY] to associate working and recovery LSPs.

We expect a diversely routed VCG to use a number of routes R <= VCG size, as some routes may be the same for several components. We should then set up R LSPs. For a bin of c components using the same route, we set up the LSP with a value NVC = c as explained in 1.B and 1.C.

To be able to associate the LSPs, the SESSION object MUST be the same for all LSPs (also indicates that the same Tunnel ID is used for all the LSPs). The LSP ID, however, MUST be different to distinguish between the LSPs. The Association ID is a 16-bit value, so we can have for one SESSION up to 2^{16} associations, meaning up to 2^{16} diversely routed VCAT groups and any number of co-routed LSPs.

Since we are not using this Association ID to indicate protection, the value for the Association ID should be decided by an outside entity. This may be the management plane. The assignment of the Association ID is outside the scope of GMPLS but must be unique for the same Session.

This does not preclude the use of another Association ID to indicate the recovery, as the standard allows the use of multiple Association objects. We need to differentiate between the association objects used for the VCAT group and the association objects used for recovery.

In this draft, we define a new association type to indicate that this is a VCG association.

3.2.1.1. Format

Association Type: 16 bits

```
        Value       Type
        -----       ----
```

                           3   VCAT group

   See [E2E-RECOVERY] for the definition of other fields and values
   while noting again that the Association ID should be unique per
   session.

3.2.2. Recap of Setup Using Diversely Routed Components

   For every route R, use procedure outlined in 3.1.1. or 3.1.2.
   depending on the capability of the equipment or general preference.
   The Path message MUST include the Association object with type set to
   3.

   For example, we use two routes: one to carry 3 VC-4 circuits and the
   other to carry 4 VC-4 circuits. This results in two associated LSPs.

   Following the addition of the new LSP (i.e., RESV message is received
   by the endpoint adding bandwidth), LCAS signaling is used in-band to
   hitlessly add the new label into the existing group [ITU-T-G.7042].

3.2.3. Recap of Reduction/Teardown Using Diversely Routed Components

   For every route R, to remove component circuits on that route, first,
   LCAS signaling is used in-band to remove the labels associated with
   the LSP from the group. LCAS signaling is defined in [ITU-T-G.7042].

   Then, use procedures outlined in 3.1.3. or 3.1.4.

   This again can only be done on LCAS-capable interfaces. If the
   procedure is attempted on VCAT-only interfaces, then the whole VCG is
   torn down (this is not a graceful teardown so ingress/egress initiate
   a Path Tear/Resv Tear) on all routes R.

3.2.4. Update and Upgrade of Existing VCAT Groups

   For existing VCAT groups, in order to allow them to participate in
   diversely routed VCGs, we use the same method of changing the message
   ID for the Path message of an existing LSP and adding the Association
   object that will be interpreted at all intermediate and edge nodes
   and that Association object will be added to the LSP information.

3.2.5. One LSP per Circuit

   Similarly to in 3.2.4, one may wish to use as many LSPs as circuits.
   This is supported and each LSP will be used to set up one element of
   the VCG. The Association object is used to indicate the VCG
   association type.

4. IANA Considerations

   This document requests from IANA the assignment of a new Association
   Type within the Association object. This object was defined in [E2E-
   RECOVERY].

5. Security Considerations

   This document introduces a new use of the Association object for GMLS
   signaling [RFC3473] to associate diversely routed VCAT group members.
   It does not introduce any new signaling messages, nor change the
   relationship between LSRs that are adjacent in the control plane.
   This association information in the event of an interception may
   indicate that there members of the same VCAT group that take a
   different route and may indicate to an interceptor that the network
   may be more robust.

   Otherwise, this document does not introduce any additional security
   considerations.

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[7](). Acknowledgments

APPENDIX A: An Overview of VCAT and LCAS

   Virtual Concatenation (VCAT) is a standardized layer 1 inverse
   multiplexing technique that can be applied to OTN [ITU-T-G.709],
   SONET [ANSI-T1.105], SDH [ITU-T-G.707], and PDH [ITU-T-G.7043]
   component signals. By inverse multiplexing we mean a method that
   combines multiple links at a particular layer into an aggregate link
   to achieve a commensurate increase in available bandwidth on that
   aggregate link. More formally, VCAT essentially combines the payload
   bandwidth of multiple path layer network signals (or trails) to
   support a single client (e.g. Ethernet) layer link. For a more
   detailed introduction, see [BCR05], [BRS04] and [Hel05].

A.1. **VCAT Signals and Components**

   In the following we will use SDH terminology rather than both SONET
   and SDH terminology. In SDH Virtual Concatenation (VCAT) can be
   applied to the following component time division multiplex (TDM)
   signals referred to as Virtual Containers (VCs): VC-11, VC-12, VC-2,
   VC-3, and VC-4.

   Only like component signals can be aggregated into a VCAT group.
   These groups are respectively known as: VC-11-Xv, VC-12-Xv, VC-2-Xv
   (X= 1... 64), VC-3-Xv and VC-4-Xv (X=1... 256).

   VCAT can be applied to the following PDH signals as specified in
   reference [ITU-T-G.7043]: DS1, E1, E3, DS3. Similar to the SONET/SDH
   case these component signals can only be combined with like signals
   to produce aggregates. For some reason the virtual concatenation
   groups of the PDH signals were not given unique designations in [ITU-
   T-G.7043] so we shall adopt a similar notation to the SDH VCAT
   signals for the permitted PDH VCAT signals that follow: DS1-Xv, E1-Xv
   (X=1... 16), E3-Xv, DS3-Xv (X= 1... 8).

   Concatenation in the optical transport network (OTN) is realized by
   means of virtual concatenation of Optical Channel Payload Unit (OPU)
   signals. OPUk signals (k= 1, 2, 3) can be concatenated into OPUk-Xv
   aggregates (X= 1... 256). See reference [ITU-T-G.709] for details.

A.2. **VCAT Capabilities and Limitations**

   VCAT performs inverse multiplexing by octet/byte de-interleaving of
   the encapsulated client bit stream. The main limitation of any VCAT
   standard or implementation is the amount of differential delay that
   can be accommodated between the component signals when they are
   diversely routed. These are summarized for the different signal types

in reference [BCR05] and [Hel05] with details given in the respective
standards documents.

A.3. **The LCAS Protocol**

The Link Capacity Adjustment Scheme for VCAT signals is a protocol
for dynamically and hitlessly changing (i.e., increasing and
decreasing) the capacity of a VCAT group. LCAS also provides
survivability capabilities, automatically decreasing the capacity if
a member of the VCAT group experiences a failure in the network, and
increasing the capacity when the network fault is repaired. LCAS,
itself, provides a mechanism for interworking between LCAS and non-
LCAS VCAT end points. VCAT does not require LCAS for its operation.

LCAS functionality does not overlap or conflict with GMPLS' routing
or signaling functionality for the establishment of component links
or entire VCAT groups. LCAS instead is used to control whether a
particular component signal is actually put into service carrying
traffic for the VCAT group.

LCAS provides for graceful degradation of failed links by having the
sink end report back the receive status of all member components. In
the case of a reported member failure, the source end will stop using
the component and the source end will send an LCAS message to the
sink end that it is not transmitting data on that component. The
worst case notification times are summarized in [BCR05] and [Hel05].

APPENDIX B: Carrier Perspective on VCAT/LCAS Application Areas

   We present in this appendix a number of application areas of VCAT and
   LCAS that make them valuable in the transport network.

B.1. **VCAT Advantages**

   When used as a transport layer, SONET/SDH networks may require that
   containers be grouped together to offer services with higher
   bandwidth than the base elementary transport entities. While
   contiguous concatenation imposes stringent constraints on the
   placement of component signals and restricts sizing to specific
   combinations (X= 1, 4, 16 ...), virtual concatenation offers much
   more flexibility (X= 1, 2, 3 ...) in sizing and no placement
   restrictions.

B.1.1. **Right Sizing Bandwidth**

   Virtual concatenation allows the customization of the number of
   components in a group, thus offering a bandwidth closer to the client
   layer needs. A common example is the STS-3c-7v/VC-4-7v often used in
   data transport since well fit to 1 Gbit/s traffic, whereas an STS-
   48c/VC-4-16c (imposed by contiguous concatenation) would be too big
   and lead to wasting bandwidth.

B.1.2. **Bandwidth Efficiencies in a Mesh Network**

   Given an end-to-end bandwidth demand between a source and a sink and
   a mesh network topology, there may be enough total bandwidth across
   the network to meet the demand, but not along a single route. VCAT
   has the ability to transport components of a Virtually Concatenated
   Group (VCG) over different paths which can be diversely routed in the
   network. In this way, a carrier increases the efficiency of the
   transport network by making better use of the mesh topology of that
   network.

B.1.3. **Minimizing Restoration Impact**

   The diverse routing enabled by VCAT is a useful capability since, in
   case of single failure, only a subset of the members of the VCG needs
   to be recovered, which allows a higher availability than the single
   route case. This means that a failure does not require recovery for
   the whole VCG but only for the failed path, and a sub-part of the
   total bandwidth will be easier to restore than the full pipe. This
   becomes more beneficial when combined with LCAS (see below). As a
   matter of fact, this is a key driver for using VCAT in a carrier's
   network.

B.1.4. Modify Component Routing

   In order to migrate from singly-routed transport services and
   distribute circuits over multiple routes, it is also useful to
   segregate a single VCG into several LSPs. Indeed, while resources may
   be provisioned using a single LSP at day one, there should be a
   migration path to allow the members of the VCG to be carried over
   diverse routes as allowed by VCAT.

B.2. LCAS Advantages

   When VCAT is used in a carrier network, enabling LCAS brings a number
   of additional advantages to network operations.

B.2.1. Graceful Degradation

   When a member of an LCAS-enabled VCG is faulty, the other members
   keep carrying their portion (interleaved bytes) of traffic, i.e., the
   portion of the traffic on the faulty member does not reach the
   destination. Hence, the entire VCG is delivering errored data until
   the faulty member is removed from the VCG. With LCAS the process of
   removing the faulty member is automated and very fast. Note that
   removing the member from carrying traffic for the group is different
   from setting up or removing the member circuit. This functionality is
   particularly useful when the VCG is diversely routed because some
   bandwidth remains available during restoration and can be used by the
   client layer with no interruption to traffic, albeit at a decreased
   bit-rate.

B.2.2. Dynamic Adjustment

   LCAS allows for hitless resizing of VCGs between two endpoints.
   Without LCAS, the bandwidth associated with a transport service
   cannot be modified without traffic disruption: a VCG needs indeed to
   be re-provisioned with the necessary number of components to meet the
   new demand. LCAS brings the necessary mechanisms to modify a VCG by
   adding and removing some components while allowing the VCG to carry
   traffic uninterrupted.

B.2.3. Painless Re-Grooming

   When connections need to be rerouted due to maintenance or to make
   efficient use of network resources, the process, known as re-
   grooming, generally impacts user traffic. LCAS enables a hitless
   method for re-grooming by first adding to VCGs additional components
   that have been set up on the new desired path, then removing the old

components from the VCG and releasing the unused resources from the
network.

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