Agilent Lightwave Symposium 2003

Data over SONET/SDH - New Technology Standards and Test Challenges

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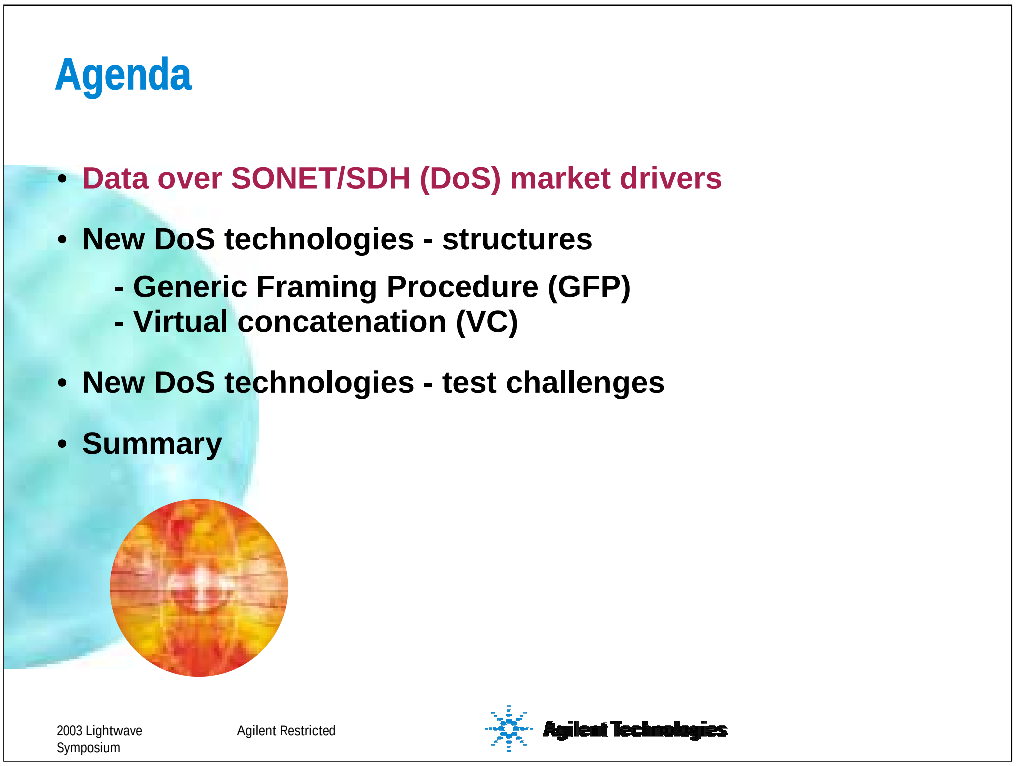
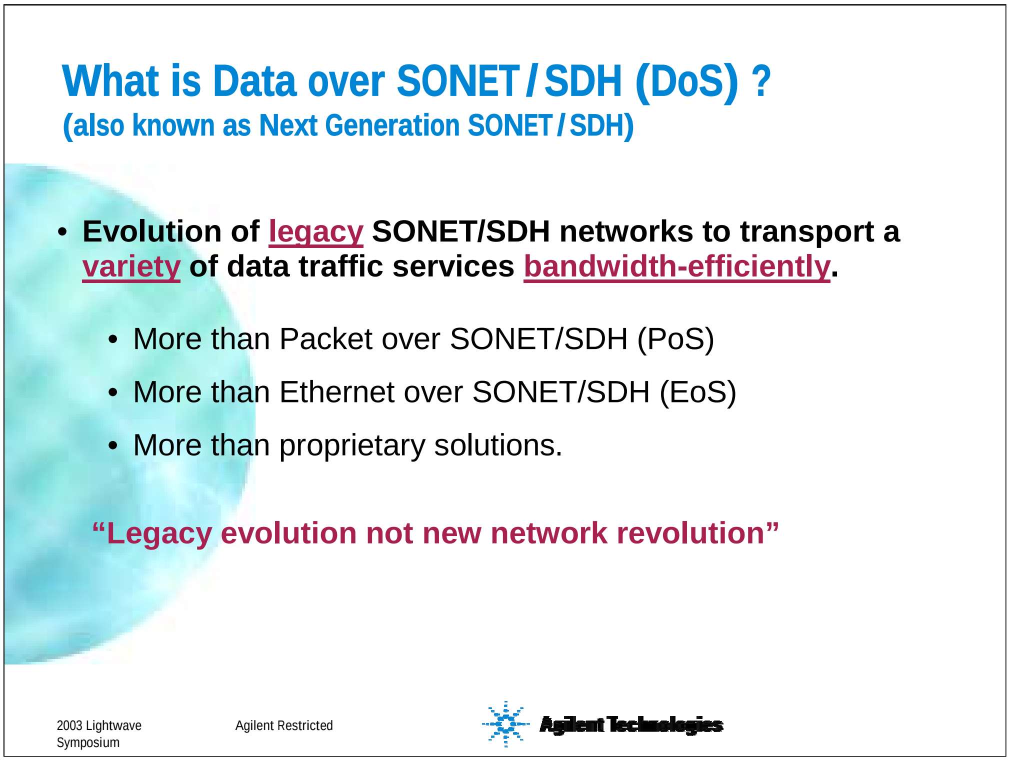


Let's take a look at the agenda.

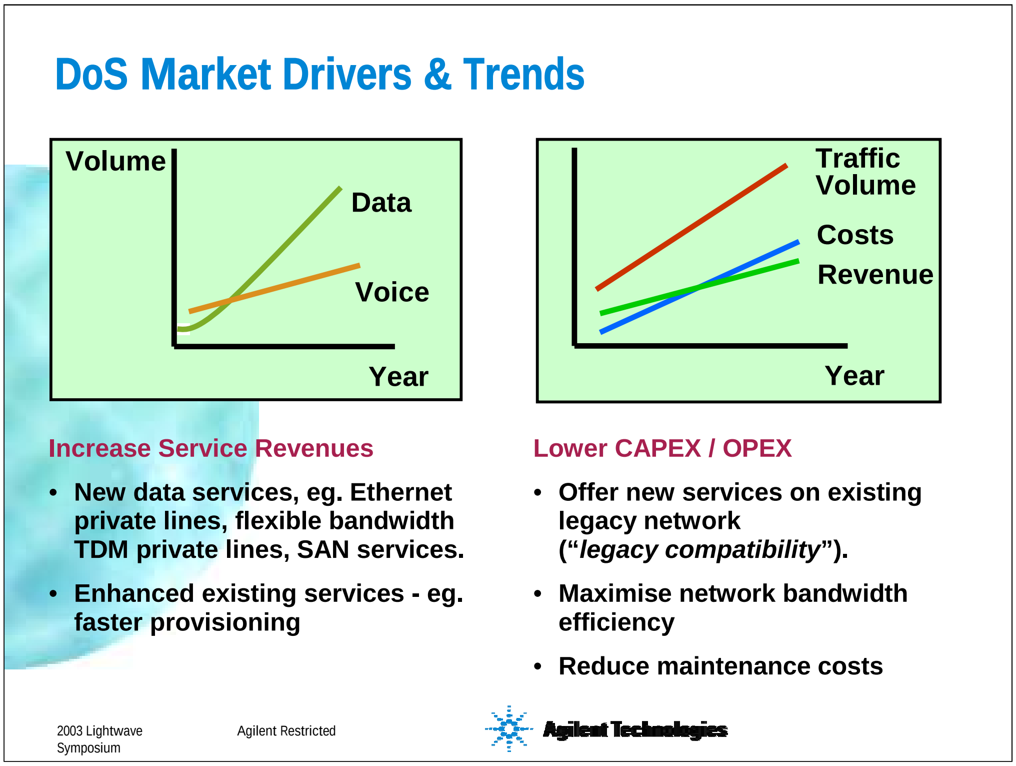
I'll start by briefly covering an introduction to data over SONET/SDH and the drivers for it's introduction. Thereafter, we will look in detail at the key new data over SONET/SDH technologies of GFP encapsulation and virtual concatenation. Finally, we will consider the test challenges posed by these new data over SONET/SDH technologies.



Let's start with a simple Agilent definition of data over SONET/SDH:

"Evolution of <u>legacy</u> SONET/SDH networks to transport a <u>variety</u> of data traffic services <u>bandwidth-efficiently</u> "

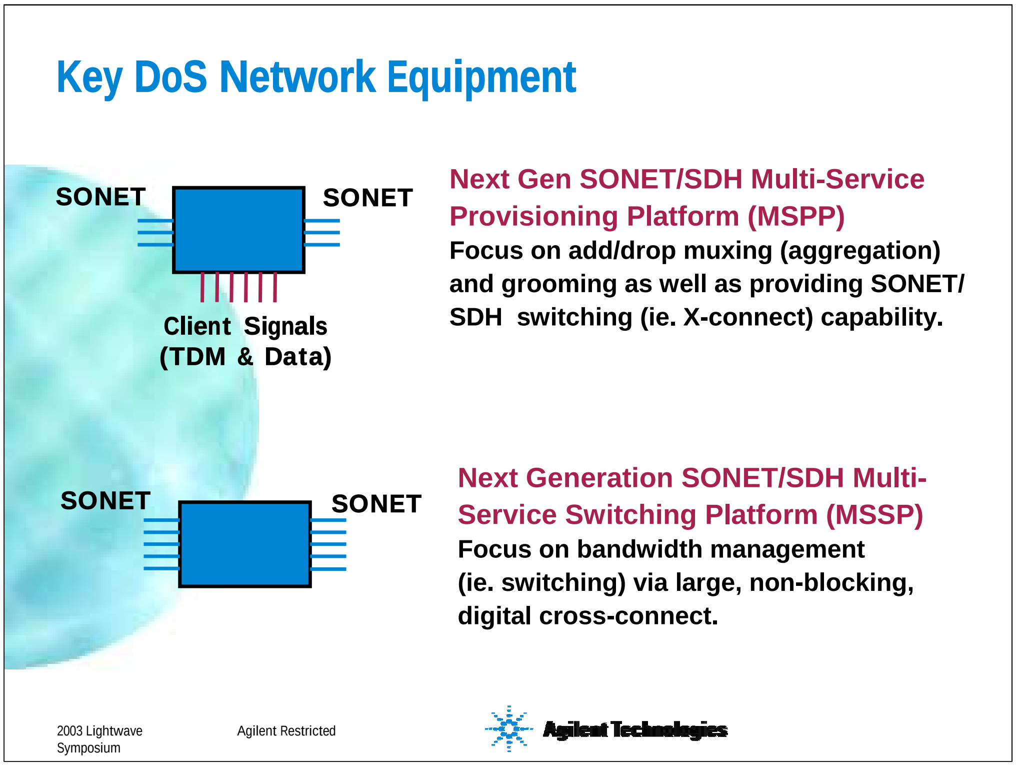
Variety is a key word here which establishes data over SONET/SDH as more than just Packet over SONET/SDH or Ethernet over SONET/SDH, which are limited in their client signal support. We are also talking here about industry-standards based solutions offering the inter-operability benefits which proprietary solutions cannot provide. And finally, we are following a path of network evolution, not network revolution, a very important consideration in today's bleak service provider economic climate.



This slide summarizes the 2 major drivers affecting the optical transport market today.

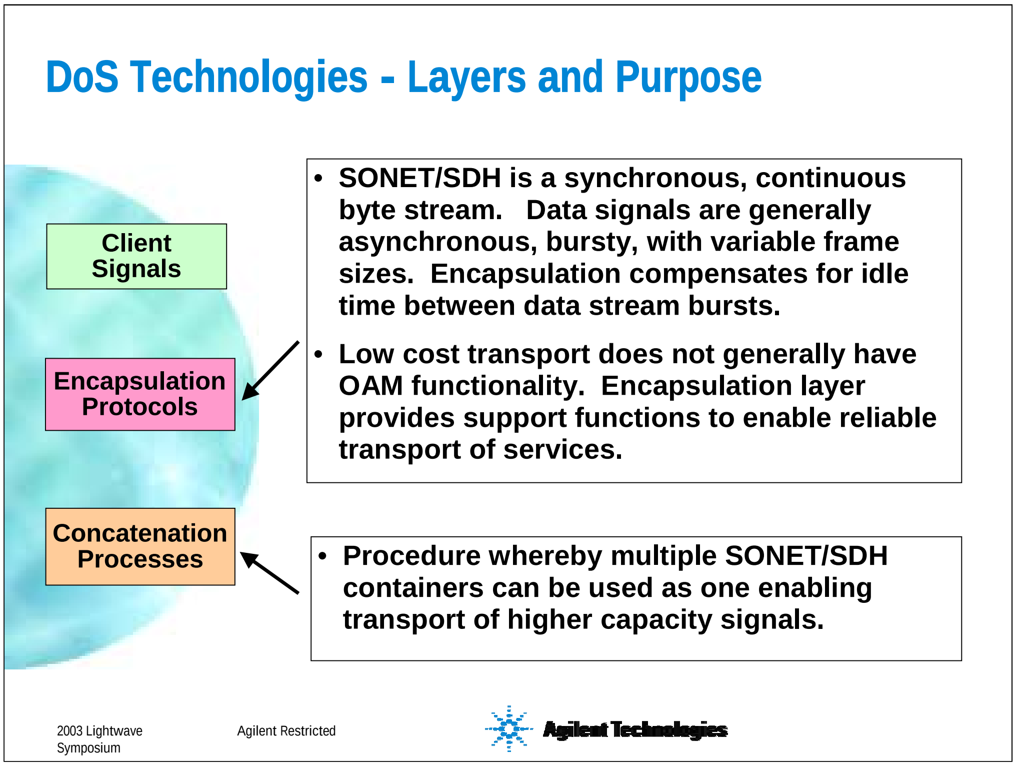
The 1st factor is the opportunity to grow revenues significantly on the back of new data services. As the chart on the left shows, data traffic volume is growing much faster than voice, so this is the obvious area to focus new service provider services, such as Ethernet Private Lines and Storage Area Networks (SAN) services.

However, the chart on the right highlights a financial gremlin associated with this rapid data traffic volume growth - revenue returns from data per unit volume are much less than those from voice, resulting in the situation where service provider costs have now been exceeding revenues. Service providers must therefore look to minimise their costs (both CAPEX and OPEX) while striving to deliver these new data services. One major cost saver in this regard is the ability to offer the new data services on the existing SP network, rather than have to build a second geographically parallel network.

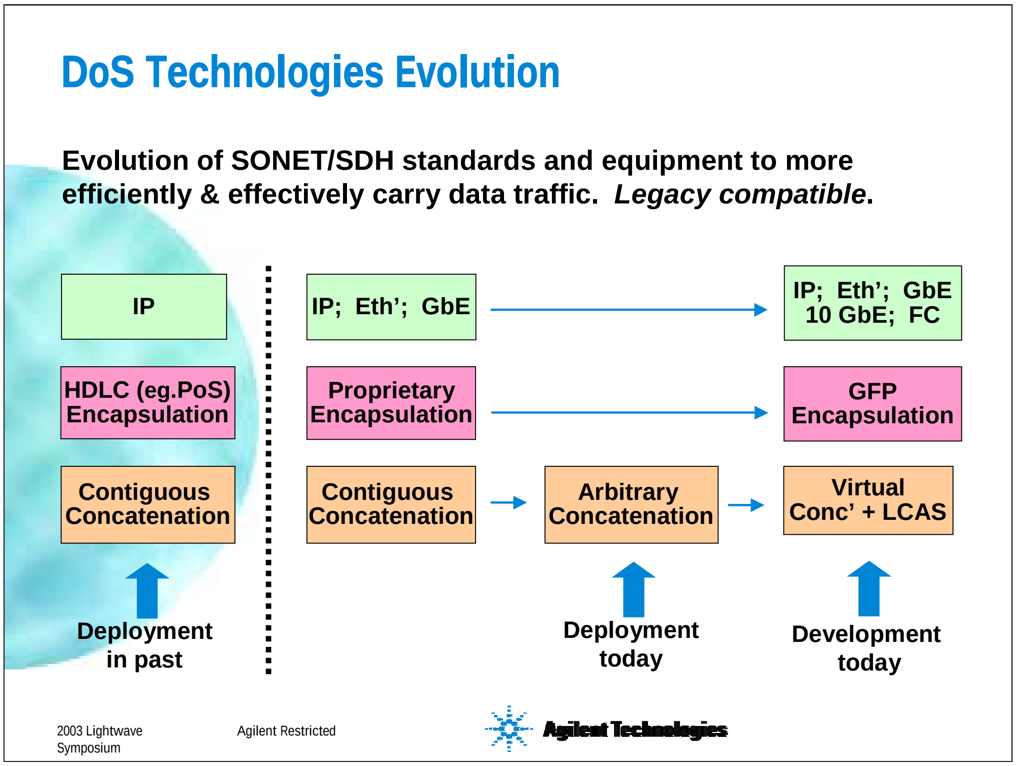


This slide outlines the two new equipment types dominating data over SONET/SDH networks. As their names imply, a key objective here is the support for multiple (ie varying) client service types. The MSPP sits at the edge of the network and is the ingress and egress point for the client signals onto the SONET/SDH network. An MSPP can typically aggregate and groom client signals of varying types, as well as digitally switching (ie X-connecting) SONET/SDH signals.

An MSSP, on the other hand, is a next generation switching platform, located more towards the core of the network, and only having SONET/SDH interfaces.



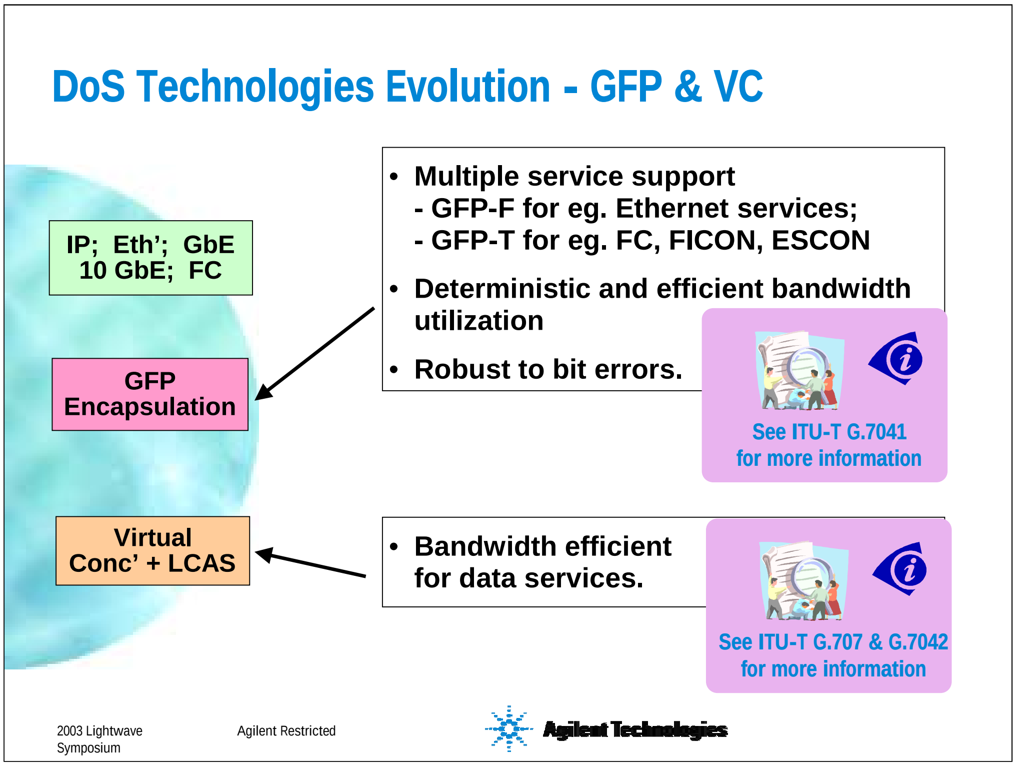
There are 2 technology layers involved in transporting data client signals over SONET/SDH networks - encapsulation and concatenation. Digitized voice, the traditional service carried on SONET/SDH equipment (and hence the service around which SONET/SDH was defined) is a continuous (at least for the duration of each call) and fixed 64 kb/s bandwidth service. Data services tend to exhibit neither of these characteristics. Hence the need for encapsulation processes which enable SONET/SDH to deal with non-continuous traffic clients and concatenation processes which allow SONET/SDH to carry signals requiring larger bandwidth than 64 kb/s.



Against the backdrop of the simple technology layer model introduced in the last slide, this slide summarizes the data over SONET/SDH technology evolution. And I stress again - this is a LEGACY COMPATIBLE network evolution, not a NEW network revolution. Remember that all important cost driver.

Shown on the left of this slide is that structure which has dominated data over SONET/SDH deployment in the past - IP packets encapsulated within HDLC (ie. High-level Data Link Control protocol) and carried by contiguous concatenated SONET/SDH containers.

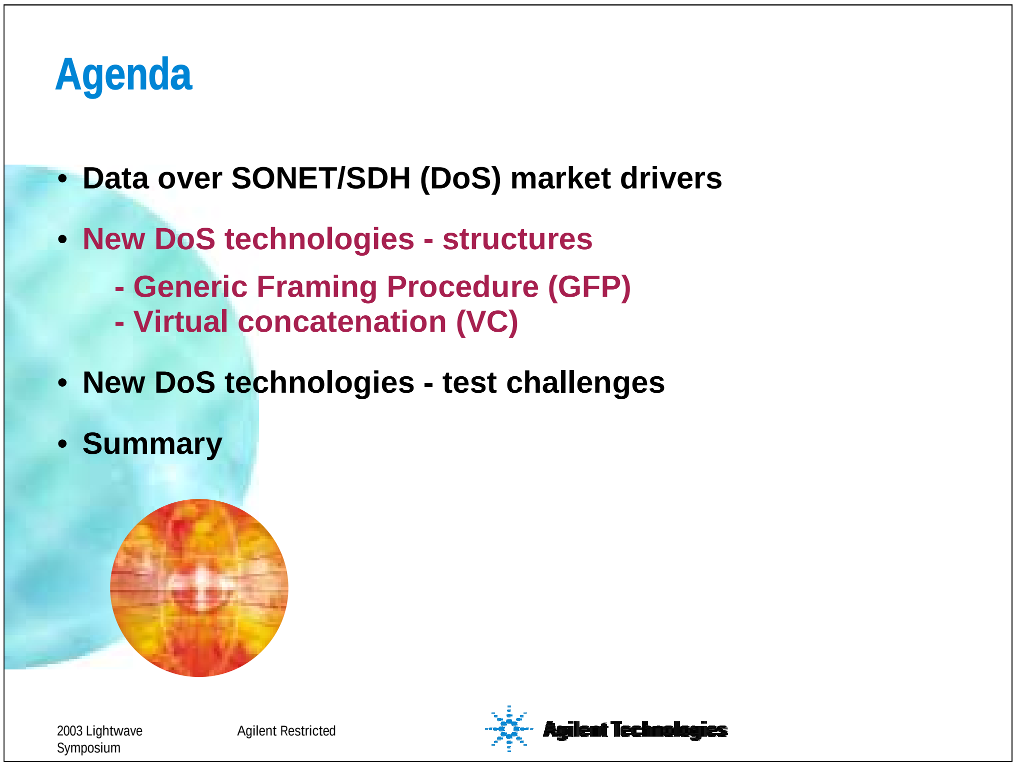
However, the focus has now changed, and the far right of this slide highlights the structure now being worked on within data over SONET/SDH related R&D projects around the world. Key technologies in this new data over SONET/SDH structure are the Generic Framing Procedure (GFP), Virtual Concatenation (VC) and Link Capacity Adjustment Scheme (LCAS).



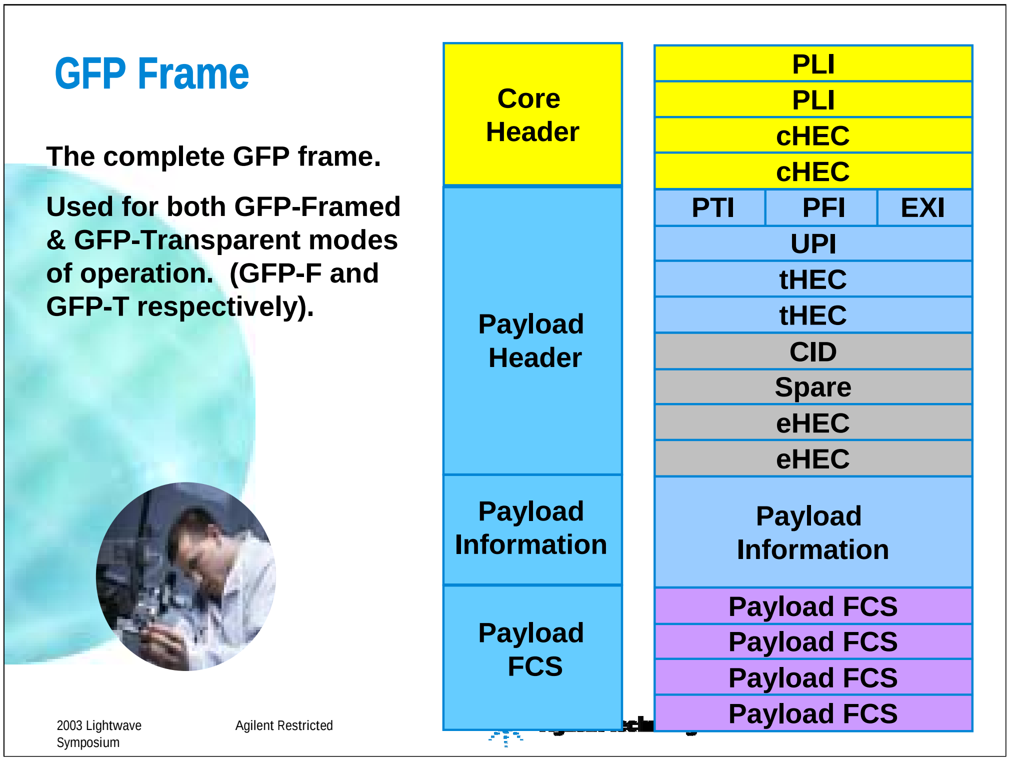
So what makes GFP the hot data over SONET/SDH encapsulation technology of today. Well, as this slide highlights, GFP suffers none of the drawbacks of the previously discussed encapsulation technique. In particular, GFP has been designed to support a variety of data service clients - a major benefit given that in the datacom world, one size certainly does not fit all! We will see how GFP achieves this flexibility later on in the seminar.

We will also review later how virtual concatenation offers greater bandwidth efficiency for carrying data services than the traditional contiguous concatenation technique.

I have also listed on this slide the key industry standards associated with GFP, virtual concatenation and LCAS. If you want detail, here is where you will find it, but bear in mind that some of the documents listed here are not the easiest of reads!



Well that's enough on the background to data over SONET/SDH.   Let's now review in detail the structures of the key technologies of GFP and virtual concatenation.

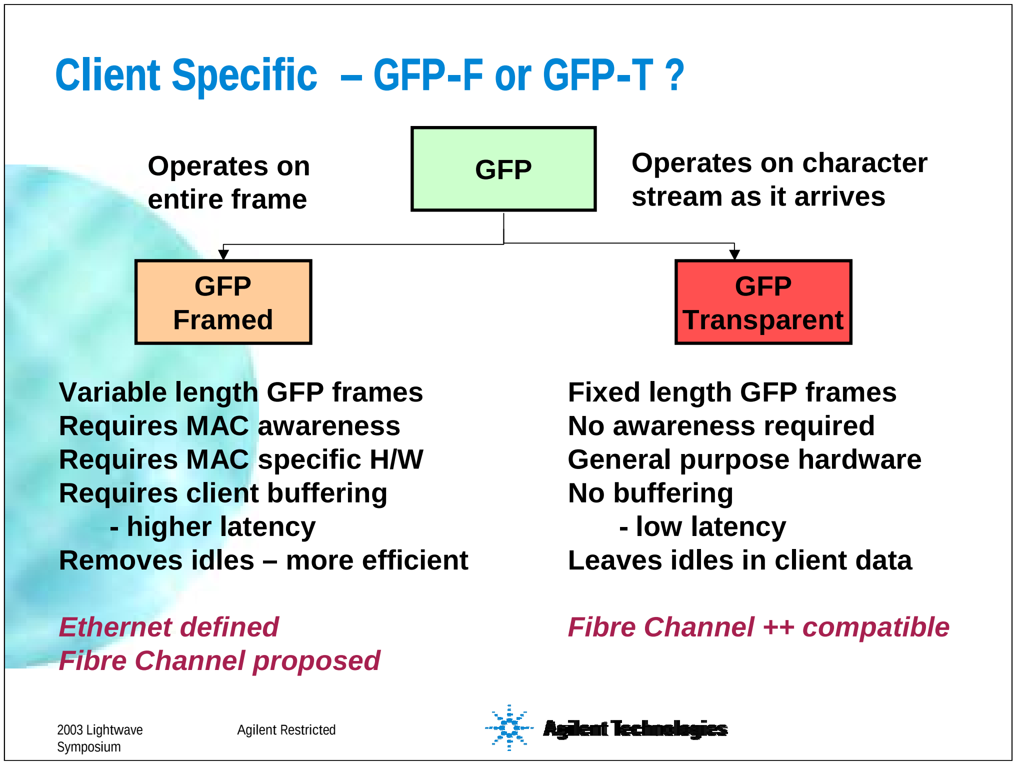


The basic structure of GFP frame comprises of a core header, followed by a payload header, payload information field and finally the payload FCS. The core header comprises of a **PLI or Payload Length Indicator field** which is guarded by a **Core Header Error Check or cHEC** which is a single bit error correction and multibit error detection techique.

The payload header can be broken down into the type header and the optional extension header. The type header comprises of the **Payload Type Identifier or PTI**, **Payload FCS Indicator or PFI**, **Extension Header Indicator or EXI** and **User Payload Identifier or UPI**. The PTI field identifies the type of payload whether its client data or client management. The PFI identifies the presence or absence of the payload FCS and the EXI identifies the frame application being Null, Linear or Ring. The UPI field identifies the framing type as framed or transparent. The type header is guarded by the **Type HEC or tHEC** which is once again a single bit error detection and multibit error correction.

Next is the optional extension header. Null applications do not have any associated extension header. The first field within the extension header is the **Channel IDentification or CID** which identifies which channel out of the 256 available will be used. The next field is Spare and its use has not currently been defined. These fields are guarded by the **Extension HEC or eHEC**.

The next field is the payload information field which contains the payload. The payload is followed by 4 bytes of optional payload FCS.



There are currently two modes of GFP encapsulation defined, which are:

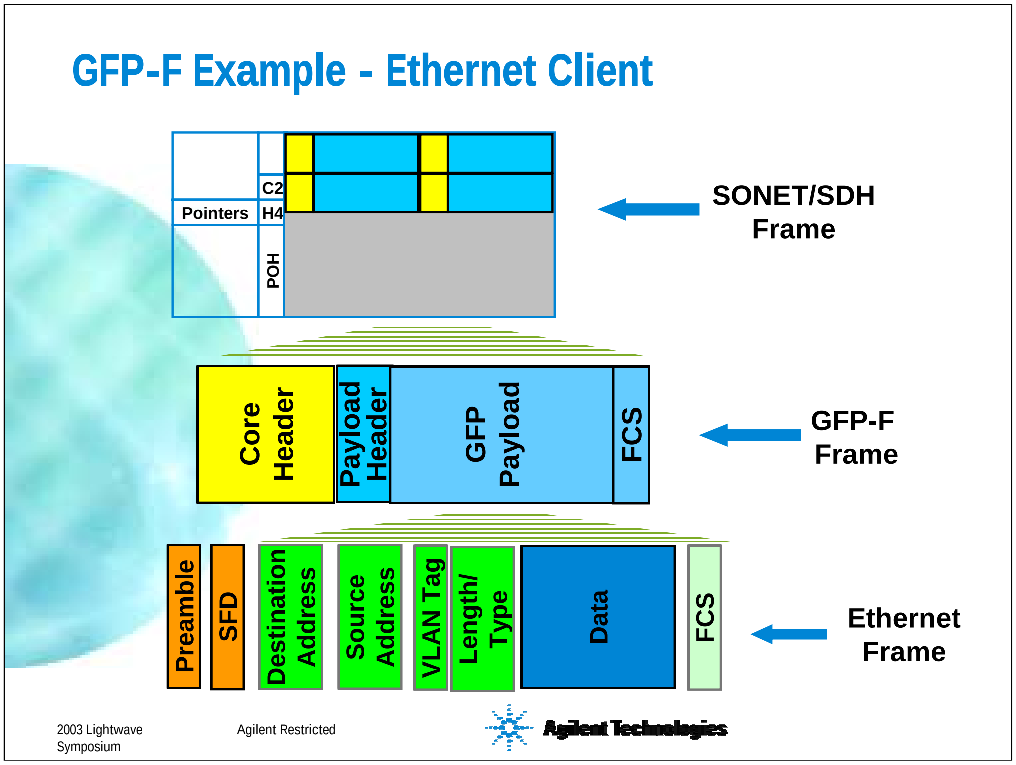
1. Framed mapped GFP, commonly referred to as GFP-F, and
2. Transparent mapped GFP, commonly referred as GFP-T

Both modes use the basic framing structure outlined on the previous page.

Frame-Mapped GFP maps a client frame in its entirety into one GFP frame. This implies that the GFP frame in Framed mode is variable length because the framing has to cater for any size of client frame that comes in. It also implies that the hardware needs MAC awareness. Further, appropriate buffers will be required to accommodate any size of the client frames.

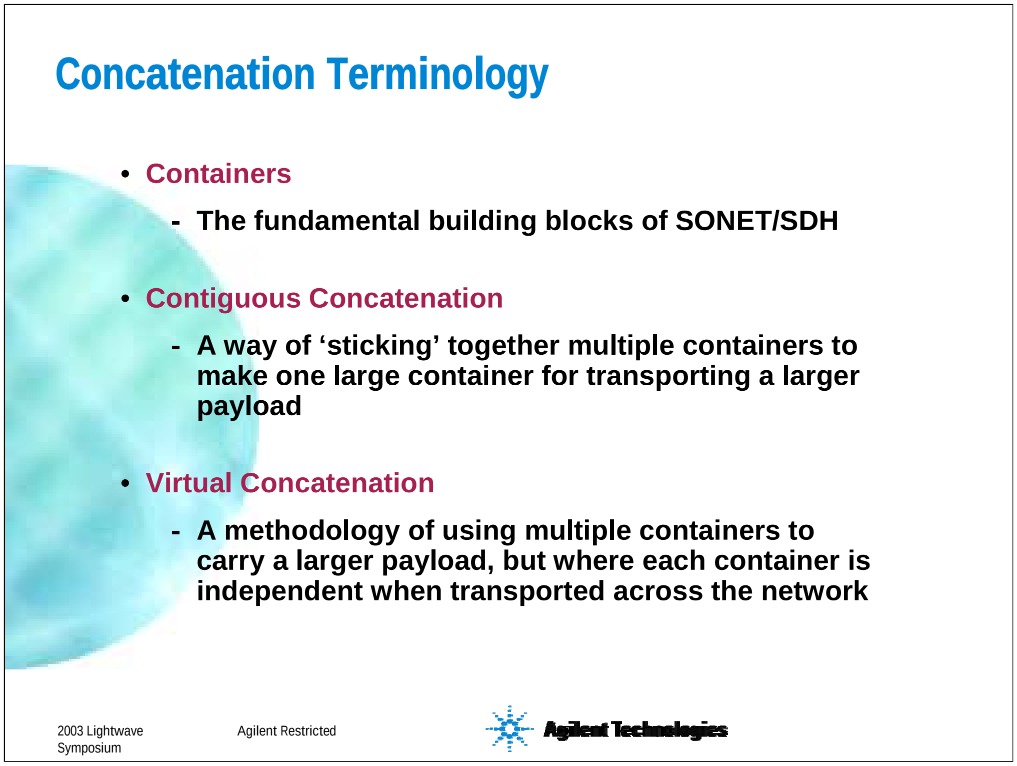
Transparent GFP operates on a data client stream as it arrives and requires fixed length GFP frames. Transparent GFP works independent of the client type and therefore requires only general purpose hardware Not needing MAC awareness). Also, in the case of transparent GFP, no buffering in involved.

Framed mapped GFP is more efficient than transparent mode. Ethernet is the only client type that has been currently defined for Frame mapped GFP and Fibre Channel is in process. However, transparent mapping caters for any type of client signal, be it Ethernet, Fibre Channel, ESCON or FICON.



This slide provides an overview of Ethernet's encapsulation process via frame mapped GFP. As the client signal is received, the preamble and SFD are taken off, and the rest of the frame is forwarded to the GFP layer for encapsulation. The Ethernet frame from destination address through to FCS is encapsulated into the GFP payload area and appropriate payload headers are then inserted. The Core header is constructed and the optional field of FCS is filled in if required. The GFP layer then forwards the GFP frame to SONET/SDH layer for further processing. The C2 byte is adjusted to reflect the correct encapsulation type and the GFP frames aligned in the SONET/SDH container for onward transport.

On the receive side the reverse processes happen to allow the extraction of the Ethernet frame from the SONET/SDH containers.



Enough on the new GFP encapsulation process. Let’s now turn our attention to the concatenation processes, and in particular, virtual concatenation.

The fundamental building block of SONET/SDH is a container. The efficiency of a SONET/SDH network in carrying data services depends upon the granularity of SONET/SDH container that it can support, and the way in which multiple containers can be combined to provide larger bandwidths. There are now two ways of concatenating containers in SONET/SDH, the traditional contiguous concatenation and the new virtual concatenation

In contiguous concatenation, side-by-side multiple containers are transported together in a way that they form one single large container. All SONET/SDH equipments forming a transmission path must recognise and process these contiguous containers. Only a few contiguous container sizes have been defined and implemented offering bandwidths such as 622 Mb/s and 2.4 Gb/s.

In virtual concatenation, the containers are formed together only virtually which enables them to be transported independently over the transport network. This also means that the containers used need not be side-by-side and that any number of containers can be grouped, enabling any required bandwidth to be accommodated very efficiently.

Virtual Concatenation

- **Uses groups of independent SONET/SDH containers.**
- **Containers take different routes to destination. Different routes have different delays**
- **Destination must remove delay, and re-align arriving containers**

	SDH	SONET
Low Order VC	**VC groups** **Tributary Units** **VC-1/2-Xv (e.g. VC-12-5v)**	**VC groups** **Virtual Tributaries** **VTn-Xv (e.g. VT-1.5-7v)**
High Order VC	**VC groups** **Virtual Containers** **VC-n-Xv (e.g. VC-4-7v)**	**VC groups** **SPEs** **STSn-Xv (e.g. STS-1-2v)**

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As stated before, virtual concatenation containers are treated independently. One consequence of this is that containers may take different routes during their network propagation. This means that receiving equipment must be able to compensate (ie. buffer) any delays and re-align the incoming data. This does not cause any problem for any network equipment in the transit path that does NOT support virtual concatenation, since the container is passed through transparently with no processing of the path overhead.

Virtual concatenation of two types has been defined - low order and high order. For SDH, the low order deals with container sizes of VC-11 or VC-12, and the higher order deals with VC-3/4 container sizes. For SONET, the equivalents are VT1.5 and STS-1/STS-3c respectively.

The significant point to be considered in the migration of any network to virtual concatenation is that only the path end points need to be VC ‘aware’. Another major benefit of allowing the containers to be treated independently and to follow different routes is that it is easier to utilize ‘stranded’ bandwidth. However, the downside of this is the need to buffer data at the receiver to re-align the incoming data.

Virtual Concatenation Bandwidth Efficiency

Service	Data Rate	Contiguous Concatenation		Effici-ency	Virtual Concatenation		Effici-ency
		SONET	SDH		SONET	SDH	
Ethernet	10Mb/s	STS-1	VC-3	20%	VT-1.5-7v	VC-12-5v	~90%
ATM	25Mb/s	STS-1	VC-3	50%	VT-1.5-16v	VC-12-12v	98%
Fast Ethernet	100Mb/s	STS-3c	VC-4	67%	STS-1-2v	VC-3-2v	100%
Fiber Channel	200Mb/s	STS-12c	VC-4-4c	33%	STS-1-4v	VC-3-4v	100%
Gbit Ethernet	1000Mb/s	STS-48c	VC-4-16c	42%	STS-1-21v	VC-4-7v	95%

67%

Efficiency Increase

100%

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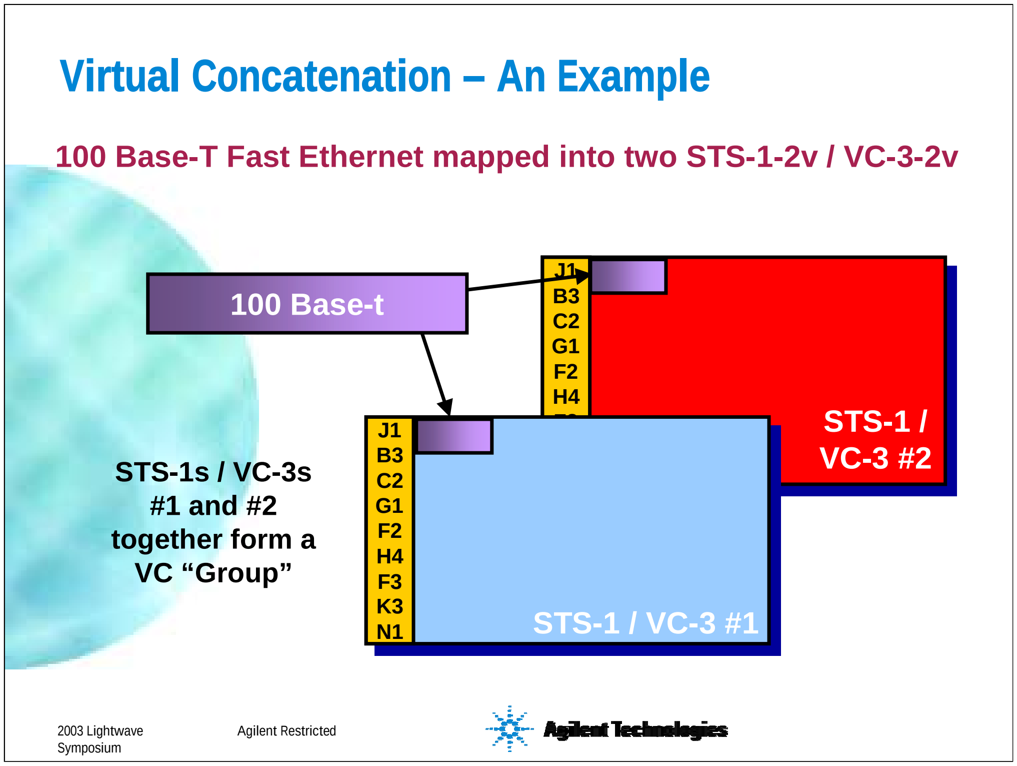
This table shows the improvements in bandwidth efficiency that can be made by using virtual concatenation instead of contiguous concatenation.

For example, traditionally with contiguous concatenation an STS-3c or VC-4 will be used to transport 100 Mb/s fast Ethernet service. This equates to a bandwidth efficiency of 67%. By using virtual concatenation, we can use 2 STS-1s or VC-3s to carry the same service and the bandwidth efficiency rockets to 100%!

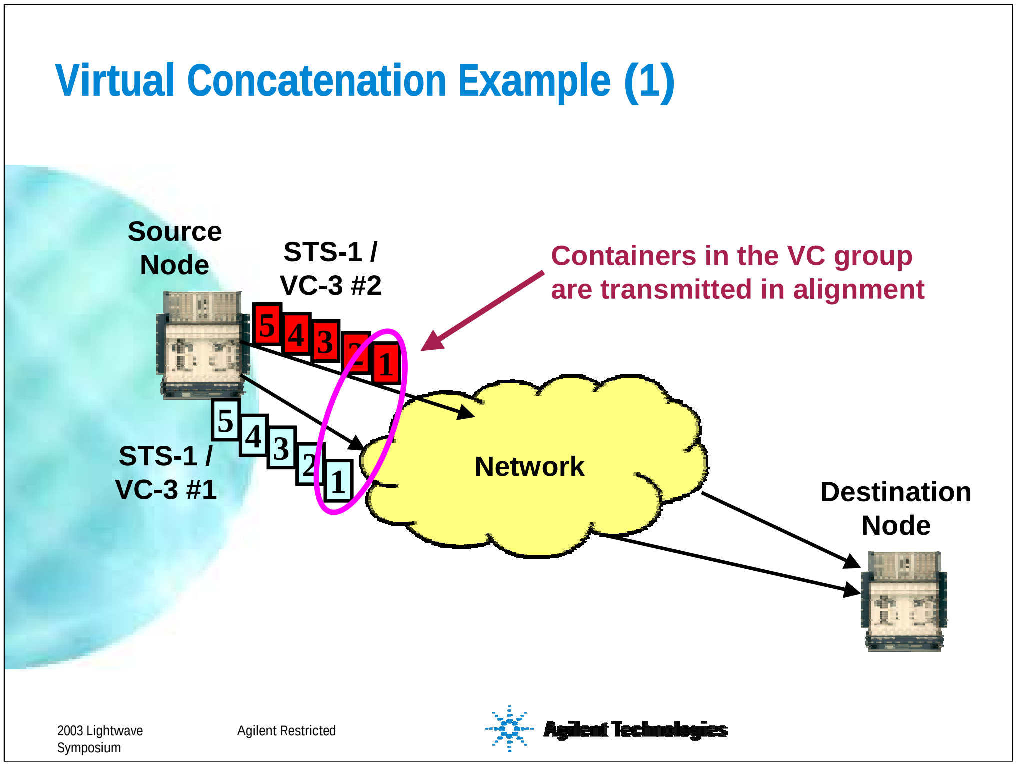
Even larger efficiency improvements can be made withsome other data services.



Let’s look at an example of transporting a 100 Base-t, fast Ethernet service using virtual concatenation.

Two STS-1s (or VC-3s) are generally sufficient to provide enough client bandwidth to carry a 100 Base-t data stream. This is a virtual container group of size 2, and the correct term for this is an STS-1-2v (or VC-3-2v).

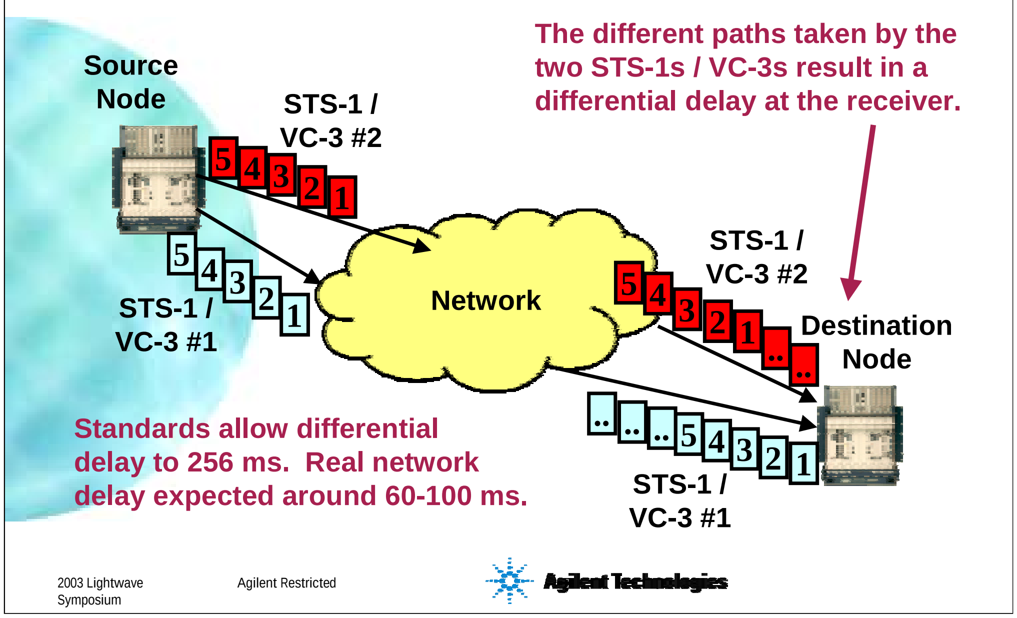
Each virtual container is filled a byte at a time, and the containers transmitted simultaneously on two different ports of a network element.



The pale blue boxes represent the SONET frames carrying the containers for STS-1 number 1 while the red boxes represent the SONET frames carrying the containers for STS-1 number 2.

Note that frames with the same number are transmitted on the different paths at the same time. So, frame 1 of STS-1 / VC-3 number 1 is transmitted at the same time as frame 1 of STS-1 / VC-3 number 2 and so on.

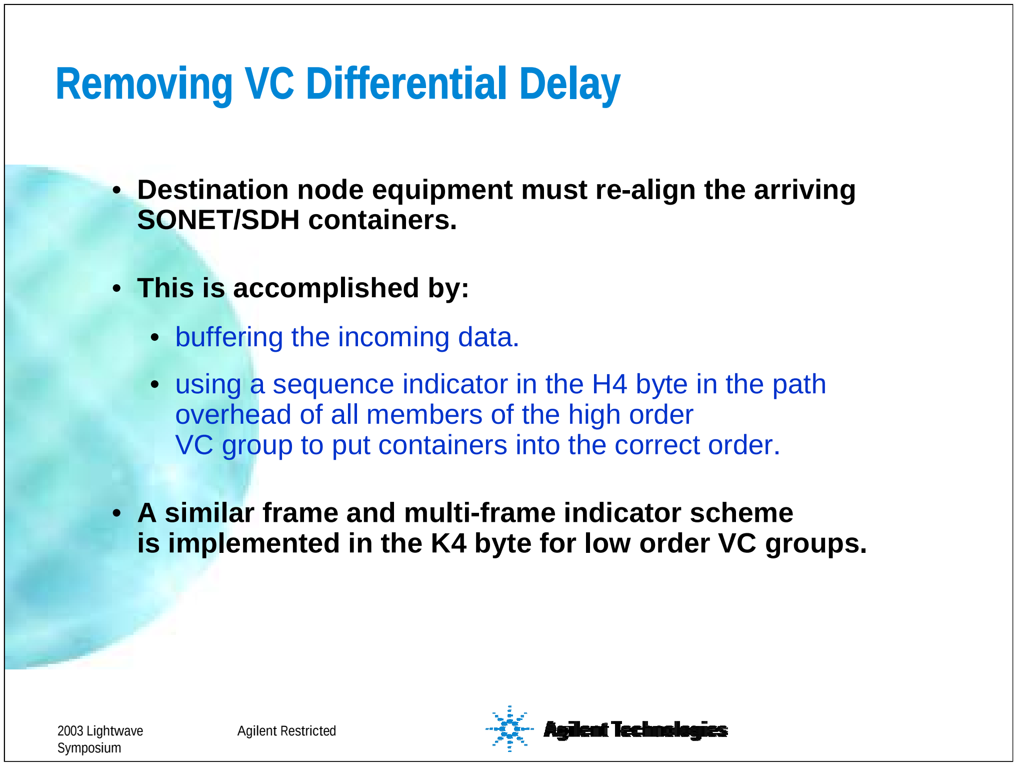
Virtual Concatenation Example (2)



The two STS-1s / VC-3s in our virtual concatenated signal have taken different routes through the network and you will see that, at the destination node, frame 1 of STS-1 / VC-3 number 1 arrives 2 frames sooner than frame 1 of STS-1 / VC-3 number 2.

In order for the network element to correctly re-create the original 100 Base-t data stream, it needs to buffer Frame 1 of STS-1 / VC-3 number 1 until frame 1 of STS-1 / VC-3 number 2 arrives.

It can also be seen that as the delay, or the number of members of the virtual concatenation group increases, more data needs to be stored. It is likely that the buffer memory size in real equipment will result in some trade-off between delay compensation and virtual concatenation group size.



In terms of correct realignment of containers, there are two requirements which must be met:

1. The receiving equipment needs some method of identifying the containers arriving on the different paths.

2. Some storage area, or buffer memory, is required to compensate for the differential delay between the two paths.

The identification is done with the help of sequence indicators within the H4 byte in higher order virtual concatenation and in lower order it is achieved via a similar scheme of frame and multi-frame indicators within the K4 byte.

Contiguous vs Virtual Concatenation Summary

Contiguous

- Poor granularity of container size
- Contiguous container travels along same path
- Requires all equipment forming path to understand concatenation indication
- Independent of network management system
- No differential delay

Virtual

- Flexible granularity (high order and low order)
- Individual containers can take separate paths
- Only the end equipment need understand the concatenation arrangement
- Requires control from the network management system
- Individual containers may experience differential delay

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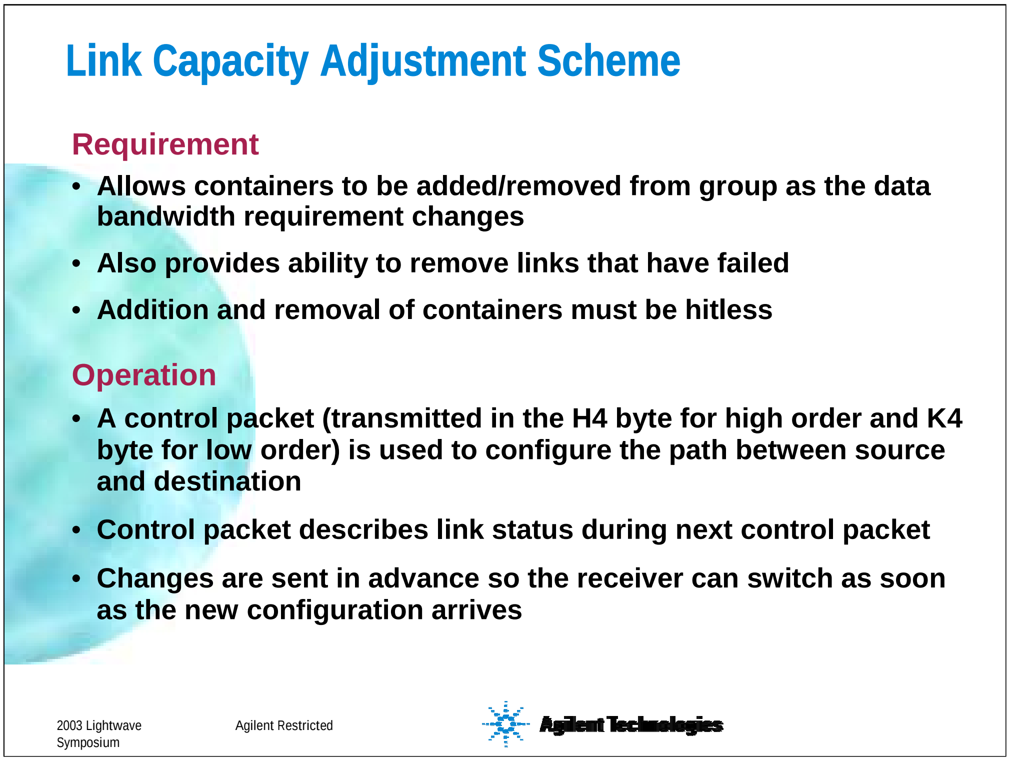
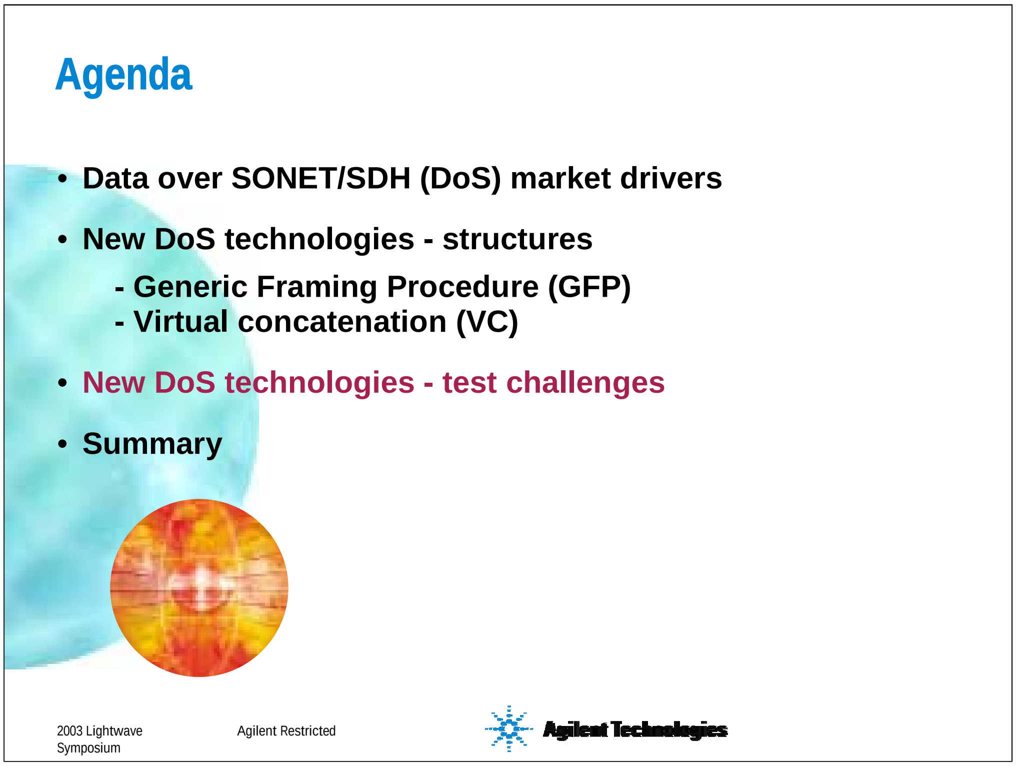
This slide summarizes the key differentiators between contiguous and virtual concatenation. As stated before, the key advantage, and major driver, of virtual concatenation is bandwidth efficiency.



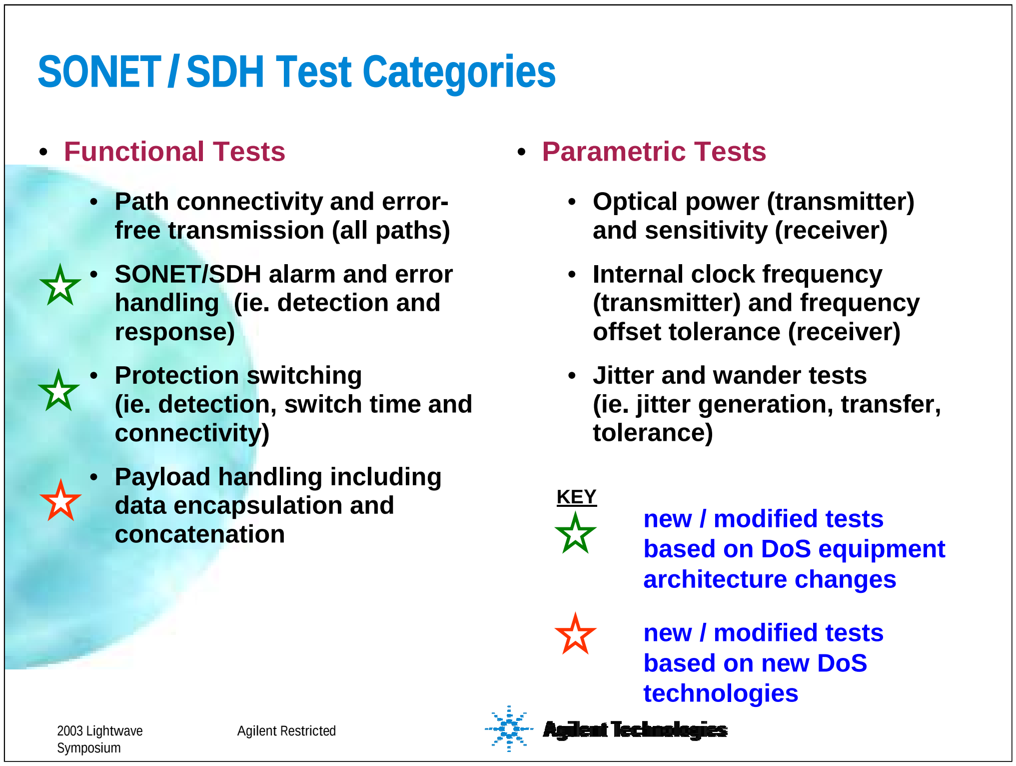
LCAS, or Link Capacity Adjustment Scheme, allows hitless addition and removal of containers (ie. bandwidth addition and removal) to virtual concatenation groups under control of a management system. Additionally LCAS can also temporarily remove any failed links.

LCAS operation is uni-directional and in order to achieve a bi-directional addition or removal the procedure needs to be repeated in the reverse direction.

LCAS uses control packets between source and destination points. The control packet transports information within the H4 byte for the higher order containers and in K4 byte for low order. The changes are transported in advance so that the receiver can respond accordingly and acquire the new configuration as soon as it arrives.

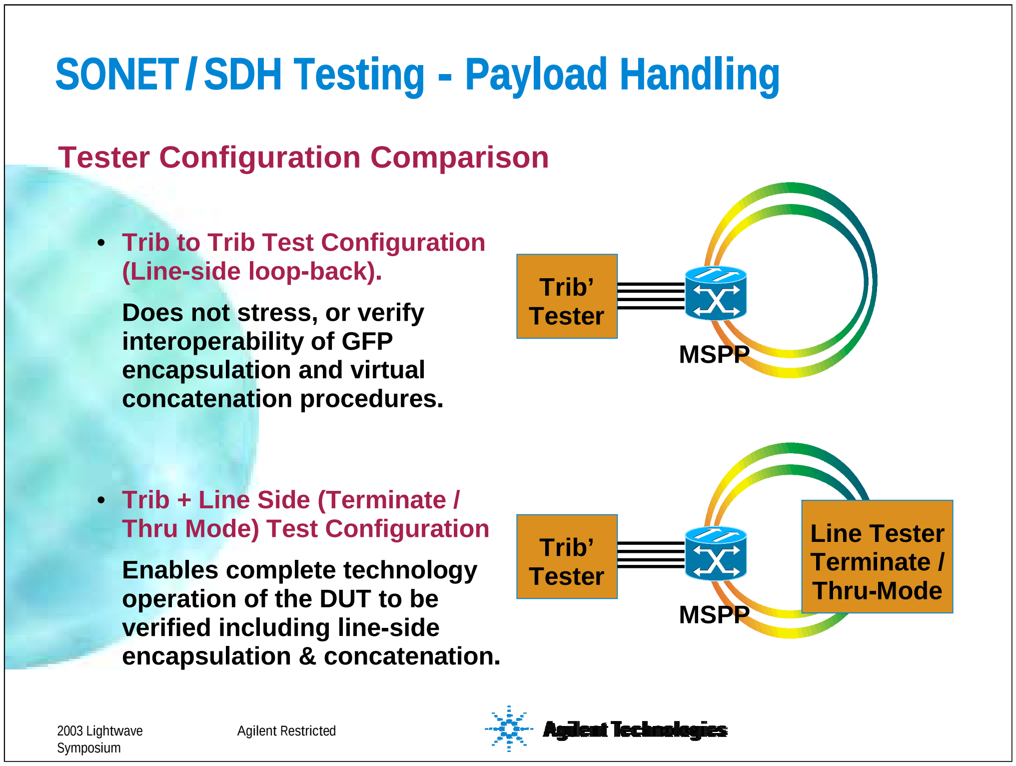


Having now reviewed the structures of the key data over SONET/SDH technologies, let us now look at the test challenges posed by these new technologies

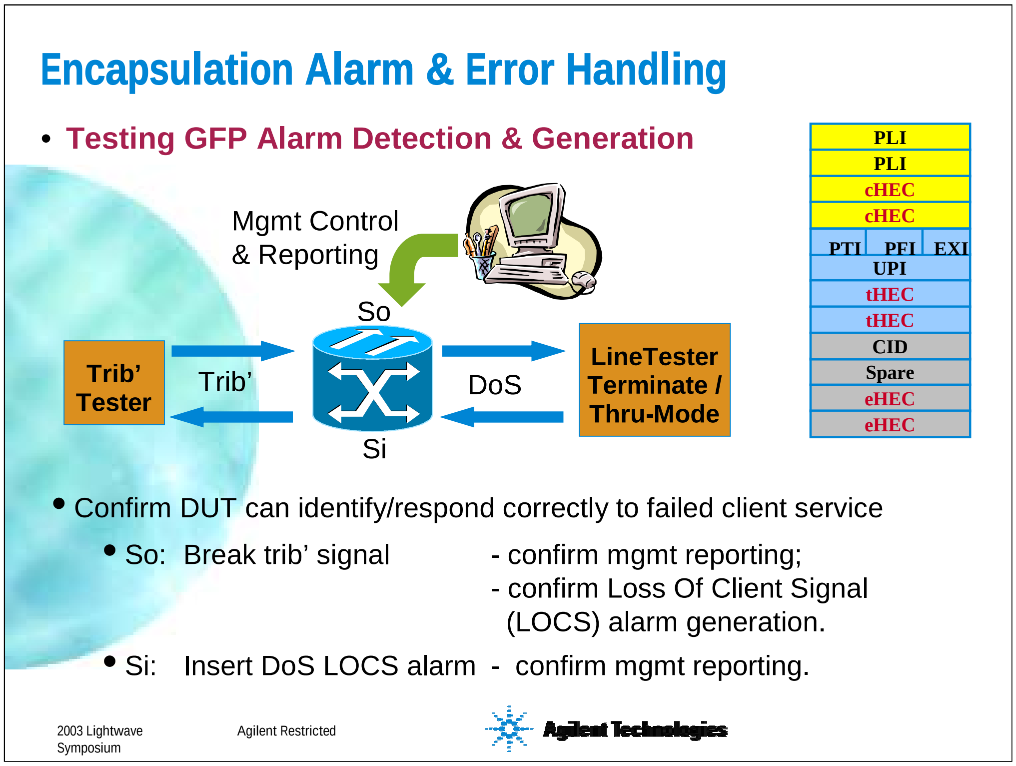


This slide summarises the major groupings of both functional and parametric tests required by SONET/SDH equipment. As indicated 3 of the functional test groups are impacted by the data over SONET/SDH evolution - two groups due to the architecture/topology changes and one group due to the new technologies.

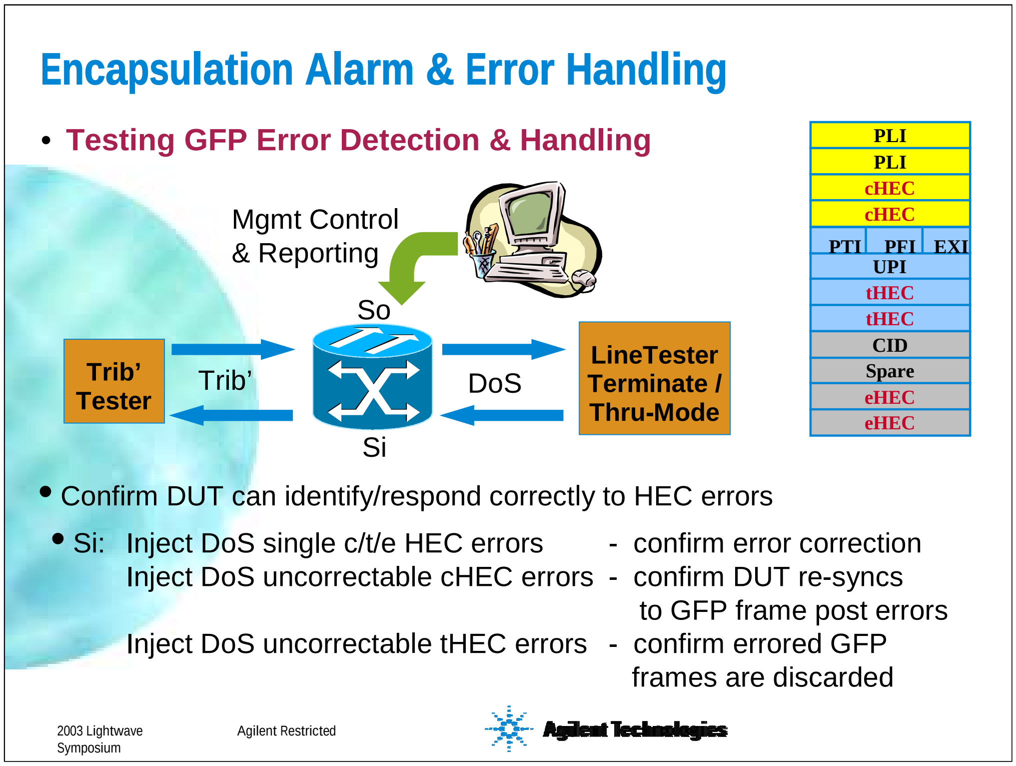
In the final section of this paper, we will review those tests impacted by the new technologies. Another Agilent paper reviews those test challenges impacted by the equipment architecture changes.



This first slide in this section highlights a simple, but important point. With regard to a dat over SONET/SDH MSPP equipment, GFP and virtual concatenation are line-side technologies. Therefore, to fully verify DUT compliance to the appropriate standards requires both tester stimulation and analysis of the line side. A test configuration involving only a client-side tester and line-side loopbacks will not achieve these required compliance checks.



Consider first the verification of the GFP data encapsulation. As explained earlier, one of the major advantages of GFP over previous encapsulation techniques is it's robustness. Accordingly there are a number of error and alarm features which require verification. In particular, this slide highlights the testing of the GFP Loss of Client Signal alarm, which is fairly straightforward.

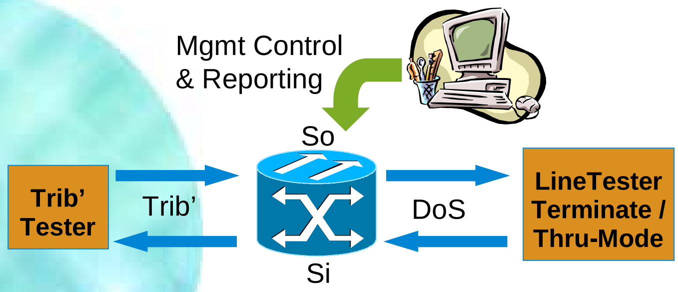


More complicated is the GFP error detection and correction test challenge shown on this slide. Again, as explained earlier, there are 3 categories of header error control - cHEC, tHEC and eHEC. This error control functionality can detect and correct single errors, but where there are more errors, the response of the DUT varies depending on the type of error.

With cHEC errors, the frame alignment is effectively lost as the DUT is unable to verify the start and finish of frames. With tHEC errors, frame alignment is maintained, but errored frames should be discarded.

Encapsulation Alarm & Error Handling

- **Testing GFP-T Specific Error Detection & Handling**



- Confirm DUT can identify/respond correctly to GFP-T specific errors
  - Si: Inject DoS 10B_ERR control char' - confirm DUT re-codes correctly at trib' egress
    Inject DoS superblock single error - confirm DUT corrects for de-scrambler errors

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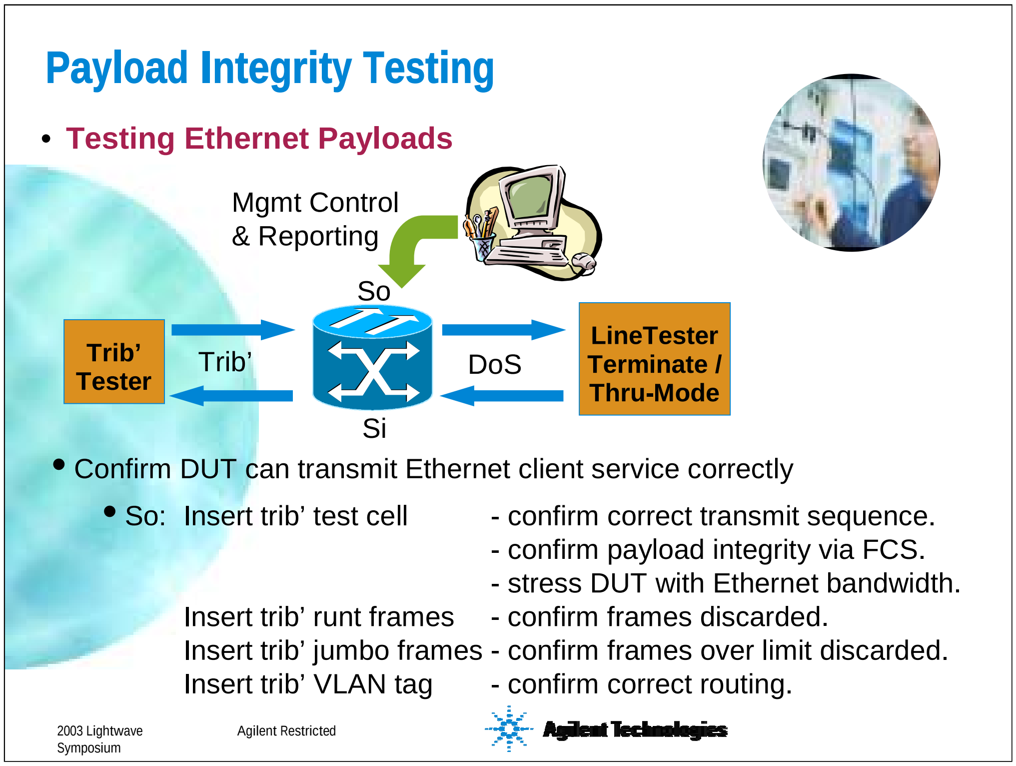
This slide highlights some test challenges specifically associated with the GFP-Transparent mode. GFP-T has some additional error conditions beyond the common conditions covered in the last slide. The specific examples shown here are:

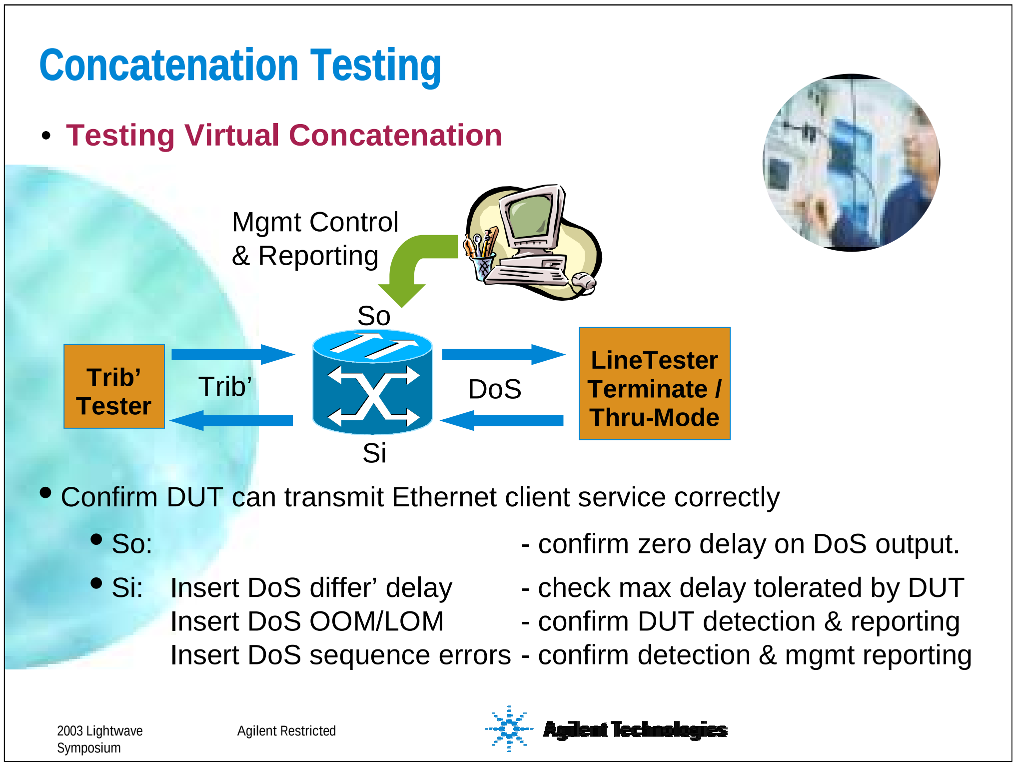
1) If an originating equipment receives a corrupt signal, GFT transmits a specific control character which should be recognised and processed accordingly at the receiving equipment.

2) A single error in the GFP-T superblock can lead to multiple errors in the descrambled signal. The DUT receiver should remove all these errors.



Associated with any encapsulation technique is the requirement to verify that client integrity is maintained through the process, and any corrupted signals are dealt with appropriately.

This slide highlights some of the common tests performed on Ethernet client signals processed within MSPP equipment. In particular, it is possible to define and implement an Ethernet test cell, the specific content of which can enable client payload measurements not possible on normal Ethernet frames. Agilent is currently in the process of patenting such a test cell, so it is not possible to go into this test aspect in detail.



Let's now look at the test challenges associated with SONET/SDH virtual concatenation.

In Agilent discussions with virtual concatenation development teams, one test challenge seems to stand out above all others in terms of causing concern - that challenge is to verify the DUT ability to cope with container differential delay on the receive side. Yes there are VC alarm and error scenarios to be verified, and some examples are listed on the slide. But differential delay is "the" key performance issue and, without the aid of an appropriately equipped tester, one of the most difficult test scenarios to simulate, even in a test network.

Agilent J7232A OmniBER OTN Analyzer

- **An example DoS line-side analyzer**

- **Simulate / analyze encapsulated Ethernet client signal payloads.**
- **Simulate / analyze GFP-F, GFP-T, LAPS and custom (eg. PoS, Cisco HDLC) encapsulation procedures.**
- **SONET/SDH virtual concatenation support (both simulation and analysis) to be confirmed.**

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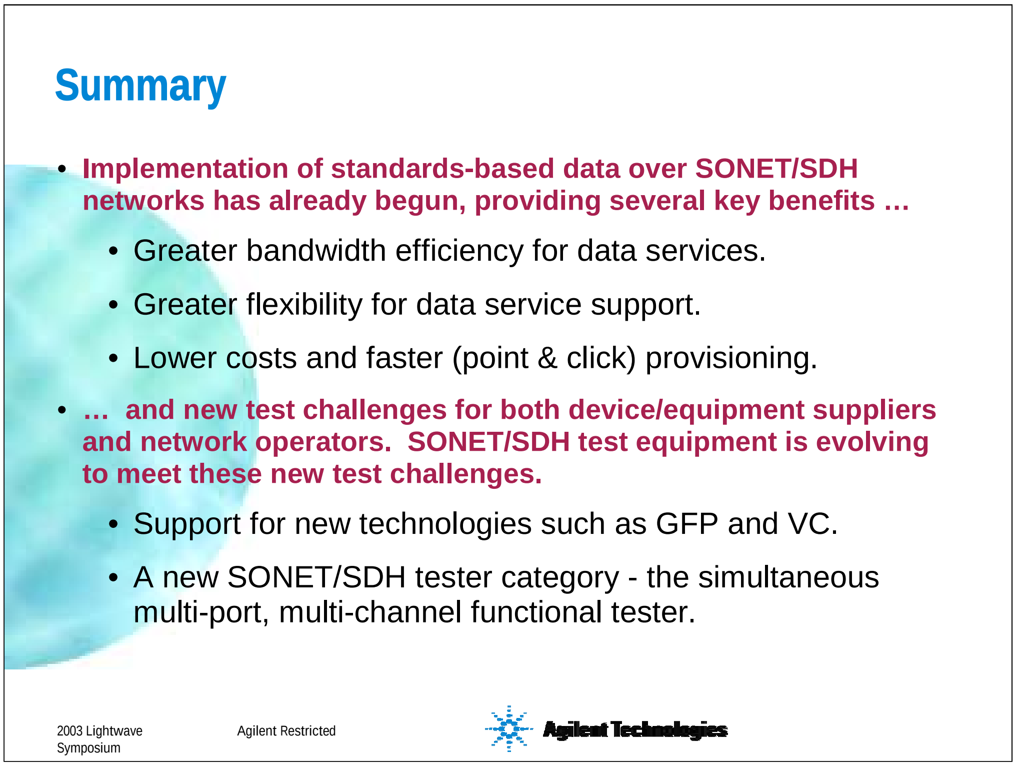
In line with the introduction of the new DoS technologies, existing SONET/SDH functional testers are evolving to include support for these new technologies.

As an example of such a tester, consider the Agilent OmniBER OTN, now offering support for GFP and other encapsulation schemes. Check with your local Agilent sales representative regarding virtual concatenation support within this product.



This paper has reviewed the new technologies associated with the data over SONET/ SDH evolution, and the test challenges associated with these new technologies.

Data over SONET/SDH equipment is one of the hottest segments within the overall optical transport market, offering significant benefits to service providers and their (data service) customers. Network equipment manufacturers are striving to bring their data over SONET/SDH solutions to market as soon as possible, and Agilent is committed to providing measurement solutions to support them in this goal.

Please note that there is a complementary paper to this one, reviewing data over SONET/SDH equipment architectures and the resulting new test challenges.


Questions
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