Whitepaper

Low Latency – How low can you go?

Introduction

Low latency has always been an important consideration in telecoms networks for voice, video and data, but recent changes in applications within many industry sectors have brought low latency right to the forefront of the industry.

The finance industry and Algorithmic Trading, or Algo Trading as it is known, in particular is a commonly quoted example. Here latency is critical and to quote Information Week magazine "[A] 1-millisecond advantage in trading applications can be worth $100 million a year to a major brokerage firm". This drives a huge focus on all aspects of latency including the communications systems between the brokerage firm and the exchange.

Low latency is essential in the finance industry and especially within algorithmic trading.

However, while the finance industry is spending a lot of money on low latency services between key locations such as New York and Chicago or London and Frankfurt, this is actually only a small part of the wider telecoms industry.

Many other industries are also now driving lower and lower latency in their networks, such as cloud computing and video services.

Also as mobile operators start to rollout LTE services, then latency in the backhaul network becomes more and more important in order to reach the high quality required for applications like real-time gaming and streaming video.

This white paper will address the drivers behind the recent rush to low latency solutions and networks and will consider how network operators can remove as much latency as possible from their networks as they also race to zero latency.

Background and drivers

Latency has always been an important consideration in telecoms networks. In voice networks latency must be low enough that the delay in speech is not detectable and does not cause problems with conversation. Here the latency is generated by the voice switches, multiplexers and transmission systems, and the copper and fiber plant. Transmission systems (the main topic of this paper) add only a small proportion of the overall latency and therefore latency wasn't a large consideration with these networks as long as it was good enough.

Latency in data networks

In data networks low latency has been seen as an advantage, but until recently hasn't been a top priority in most cases, as long as the latency of a particular solution wasn't excessive. In most cases the latency must be low enough that the data protocol functions correctly.

A good example is Fibre Channel, where the throughput drops rapidly once the total latency reaches the point that handshaking between the two switches is not quick enough, a phenomenon known as droop. This is determined by the number of buffers credits within the switch and the latency of the link between them, which is largely generated by the fiber itself. So as long as the latency of the transmission system isn't going to push the performance of a link into the area where droop is a problem then it was normally deemed to be good enough.

Therefore there has always been the need within telecommunications systems to ensure that latency is low enough that it minimizes the impact on the voice or data traffic being carried but there hasn't specifically been the requirement to drive latency as low as absolutely possible, until now.

New applications requiring low latency - Algorithmic Trading and Cloud Computing

Latency is rapidly becoming much more important in data networks. New applications in many vertical markets are requiring lower and lower latency.

The most widely used example of recent changes in applications that is used to demonstrate this is the finance industry and the move to High Frequency Trading and Algorithmic Trading. In these applications latency is absolutely critical as there is no second place in the race for a trade. Latency in this application comes from many areas – servers, software and transmission, and those with an interest in low latency spend a huge amount of time and money driving as much latency as possible from every possible source.

Video distribution and content delivery are examples of applications where low latency is crucial.

Beyond the financial services industry, many other organizations are also now considering low latency as a much higher priority. For example services such as cloud computing are being mainstream and are considered by many to be the next big change in the way fixed telecoms networks will operate. Cloud computing includes business applications such as Salesforce.com and consolidated email services for organizations that are geographically widespread. Video distribution and Content Delivery are becoming big "cloud" industries. Some of these services require low latency and others such as email do not, but overall this shift in services requires operators who are connecting facilities such as data centers together to really look at the latency of the route and the systems used and if necessary to take corrective action. Most new installations in these applications consider low latency as essential in order to deliver good quality of service now and to ensure the solution is future-proof.

Latency in mobile networks

Finally we need to consider services over mobile infrastructure. Today latency is no doubt important in mobile network design but networks are designed with SDH/SONET backhaul which has a reasonably well understood and manageable latency. However, the move to LTE brings low latency to the forefront of mobile network planners' minds. This is because LTE offers a broad range of services, each with their own Service Level Agreement (SLA) which involves a requirement for a certain level of latency.

For example, real-time gaming and streaming video will require very low latency while services such as email and SMS messaging will require less stringent control of latency. One further consideration with the move to LTE and low latency is that we are now considering a Layer 2 based infrastructure due to the all IP nature of LTE, whereas the earlier examples were predominately Layer 1 in the transport domain.

This adds further Layer 2 processing into the backhaul network, either in two separate layers (Carrier Ethernet Switches over WDM layer) or via an integrated Layer 1 and 2 solution, with an associated increase in latency that must be managed and minimized. Of course, integrated Layer 1 and 2 solutions are not limited to mobile backhaul. They can also be found in fixed networks and in some cases, such as datacenter interconnect, also have a focus on low latency.

4G Dongles are putting low latency on the agenda for the design of mobile networks.

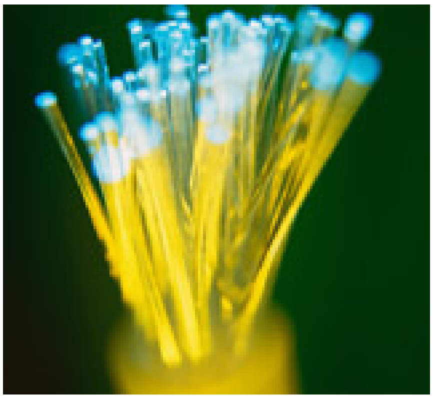
As you can see low latency is becoming increasingly important in Layer 1 and Layer 2 solutions, so let us now consider the sources of latency in a fiber optic network and what can be done to minimize this.

Sources of latency

Latency in Fiber optic networks comes from three main components; the fiber itself, optical components and opto-electrical components.

Latency in optical fiber

Light in a vacuum travels at 299,792,458 meters per second and this equates to a latency of 3.33 microseconds per kilometre of path length. Light travels slower in fiber due to the fiber's refractive index and this increases the latency to approximately 5 microseconds per kilometre. So, while we are using the current generation of optical fibers there is a limit to how low we can drive latency – take the shorted possible route and multiply this by 5 microseconds per kilometre. A 50km link would therefore have a fiber latency of 250 microseconds, a 200km link would have a latency of 1 millisecond and a 1000km link would have a fiber latency of 5 milliseconds.



The fiber itself introduces latency of approximately 5 microseconds per kilometer.

This is the practical lower limit of latency that is achievable if it were possible to remove all other sources of latency. However, fiber is not always routed along the most direct path between two locations and the cost of rerouting fiber can be very high. Some operators have built new low latency fiber routes between key financial centres and have also employed low latency systems to run over these links. This is expensive and is likely to only be feasible on the main financial services (algo-trading) routes where the willingness to pay is high enough to support the business case. In most other cases the fiber route and associated latency will be fixed due to complexity and cost.

Latency in optical components

The vast majority of the latency introduced by optical transmission systems is in the form of Dispersion Compensating Fiber (DCF). This is only used in long distance networks, so is not a consideration for example in an 80km datacenter interconnect project. DCF is used in long distance networks to compensate for dispersion of the optical signal. This is caused by the speed of light varying slightly for each wavelength and even though WDM wavelengths are very tightly spaced the pulse of light will spread out as it travels down the fiber as some components of the pulse will travel faster than others. Eventually this spreading reaches the point were the pulses start to get too close together and cause the receiver problems and ultimately bit errors in the system. To compensate for this dispersion, WDM systems use DCF in amplifier sites. DCF is essentially fiber with the opposite dispersion characteristics, so a spool of this added at the amplifier site can bring the pulse back together again. This extra fiber adds to the optical power calculations and requires more amplification in the network and of course adds more latency. A typical long distance network will require DCF which is approximately 20 to 25% of the overall fiber length and therefore this DCF adds 20 to 25% to the latency of the fiber, which could be a few milliseconds of long haul links.

Recently innovations in Fiber Bragg Grating (FBG) technology have enabled the development of the Dispersion Compensation Module (DCM). A DCM also compensates for the dispersion over a longer reach network but does not use a long spool of fiber and therefore effectively removes all the additional latency that DCF based networks impose. As both DCF and DCM units are directly connected to the optical path these should either be designed in for new low latency routes or swapped over during planned maintenance windows on existing routes where lower latency is now required.

The only other optical components that require discussion here are the optical amplifiers. These Erbium Doped Fiber Amplifier (EDFA) optical amplifiers enable WDM systems to work as they amplify the complete optical spectrum and remove the need to amplify each individual channel separately. They also remove the requirement of Optical-Electrical-Optical conversion which is highly beneficial from a low latency perspective. They operate by using a spool of a few 10s of meters of erbium-doped optical fiber and pump lasers. Due to the optical characteristics of this special fiber, optical power is transferred from the pump lasers to the optical signal as it passes through the fiber, leading to the amplification of the signal. But from a latency perspective, these amplifiers contain a small spool of optical fiber that we should consider if an operator is really looking to drive every possible source of latency out of a system. Of course, on a per amplifier basis then this latency is very small. But a long haul system will have many amplifiers, perhaps 10 to 15 in the link and assuming 30m per amplifier then this soon increases to 450m (with a latency of approximately 2.25 microseconds) in a 15 amplifier system which could be significant to some operators, especially those in the financial sector.

One approach to address this additional latency is to use Raman amplifiers instead. Raman amplifiers utilize a different optical characteristic to amplify the optical signal. High power pump lasers are used that use the outside plant fiber itself as the amplification medium and transfer power from the pump lasers to the optical signals to amplify the system. Here there are no additional spools of optical fiber and therefore no additional latency. These Raman amplifiers are more expensive than EDFAs so until now have mainly been used in addition to EDFAs to boost the amplification for systems with very long spans, such as in submarine networks. However, these do provide the operator who wishes to drive every possible source of latency out of their network with an additional option.

Latency in opto-electrical components

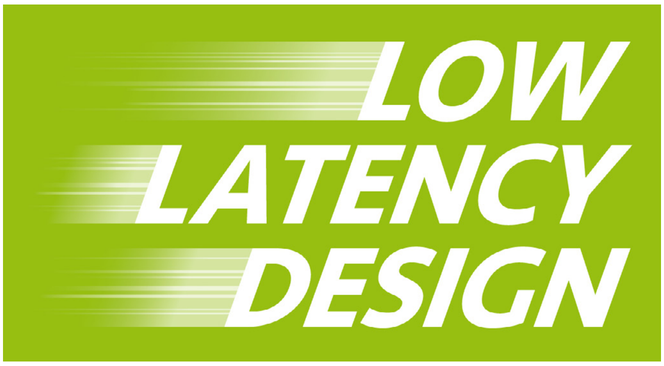
Firstly let us consider the Layer 1 examples mentioned earlier in this document. Operators have two approaches to transporting data over optical transmission systems – transponders or muxponders. Transponders take a single optical signal and convert this from optical to electrical and back to optical again, and in the process convert the wavelength from a short reach inter-office signal to a long distance WDM specific wavelength. Muxponders take multiple signals, multiplexes them together into a single higher speed signal and then convert that to the WDM specific wavelength. An operator will typically use transponders for high speed links such as 4G/8G Fibre Channel, 10G Ethernet etc, and muxponders for lower speed services such as Gigabit Ethernet.

The latency of both transponders and muxponders varies depending on design, formatting type etc. Muxponders typically operate in the 5-10 microseconds per unit. If Forward Error Correction (FEC) is used for long distance systems then this will increase the latency due to the extra processing. Transponders however can vary hugely in latency depending on design and functionality. The more complex transponders include functionality such as in-band management channels and this forces the unit design and latency to be very similar to a muxponder in the 5-10 micro second region, as the unit needs to combine the data and management channel signals in a similar way to a muxponder. Again if FEC is used then this can be even higher.

Some vendors also have options for simpler, and often lower cost, transponders that do not have FEC or in-band management channels and these can operate at much lower latencies. Transmode has set the industry benchmark with the lowest stated latency of any transponder at 4-10 nanoseconds for a pair of transponders (one per end of the link) and this equates to approximately 1-2 meters of fiber being added to the overall system link. The range from 4 to 10 nanoseconds is due to the varying latency over the operating range of the transponders. The higher the speed, the lower the latency, so 10G services benefit the most from this low latency.

A few other vendors also have low latency transponder options but none yet have been able to get as low as Transmode. Many others are stuck in the millisecond range, which is 1000x higher latency, due to the formatting structures they use.

Earlier we also mentioned that some networks now use integrated Layer 1 and 2 technologies. These are often referred to as Packet Optical Transport systems. A low latency Carrier Ethernet Switch will have latency in the order of 5+ microseconds. Transmode's family of Ethernet Muxponders (EMXP II) is optimized for aggregation and transport of Ethernet traffic, namely Transport Ethernet. A consequence of this is that the latency of the units is significantly better, at less than 2 microseconds. This might not sound that impressive when compared to the 1000x better claim with the Layer 1 transponders but there is an important network architecture angle to consider here too.



Transmode's Ethernet Muxponders are built with Low Latency Design.

In Layer 1 we consider point to point wavelengths with a transponder/muxponder at each end and optical components in between. In Layer 2 we have a network of Layer 2 capable devices where the traffic moves from one to the next until it reaches its destination. For a mobile backhaul network this could be 4 or 5 devices into the core and then 4 or 5 back again, or it could be much higher depending on the network architecture. If we assume 5 Layer 2 devices between a LTE enabled PC being used for real-time gaming and the core, then the data associated with a user action will hop through 5 devices on the way to the core and the response will hop back through the same number of devices, so 10 in this example. This means the 2 to 3 fold improvement in performance equates to a latency difference of 10x2 (20) microseconds compared with 10x5+ (50+) microseconds and thus a saving of 30 microseconds, or the equivalent of 6km of fiber.

Of course, Layer 2 based services are not limited to mobile backhaul. An operator wishing to offer a low latency Layer 2 based service should also consider using Transport Ethernet solutions with their associated lower latency.

An operator's options

So, with a toolkit of low latency solutions, what should an operator do when looking to provide a low latency service? From the discussion above it is clear that the fiber route has by far the biggest impact on latency and if the operator has two options then they should choose the shortest.

The next biggest impact an operator can make for long distance networks is to use DCM based dispersion compensation rather than DCF and this could reduce the latency by up to 20%. It is therefore equivalent to reducing the route length by the same amount but probably at a much lower cost than digging new trenches and pulling new fiber routes.

To drive latency lower in both short haul and long haul networks then the operator should use an optical transport solution that offers ultra-low latency transponders. These can reduce the latency associated with O-E-O conversion from milliseconds to nanoseconds. This has a similar effect to shaving off 1 or 2 km from the route distance.

Finally for those that really want to go as low as possible then they can also remove the small amount of remaining latency within the optical amplifiers by swapping them from EDFA to Raman amplifiers.

Below are two Low Latency examples; one over a short distance and another over a longer distance.

Example 1: Two datacenters 20 km apart

Fiber latency =	20 x 5 µs =	100 µs
Transponder latency =	2 x 5 µs =	10 µs
Total latency =		110 µs

Low latency options:
Replace transponders with ultra-low latency transponders with 4 ns latency per pair.

This effectively removes transponder latency for a 9% saving and a total reduction of 10 µs.

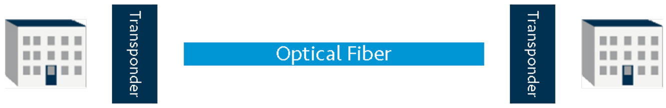


Figure 1.
Low Latency options in an example of two datacenters 20km apart.

Example 2: Two datacenters 400 km apart – 5 spans of 80km

Fiber latency =	400 x 5 µs =	2000 µs
DFC latency =	20% =	400 µs
Transponder latency =	2 x 5 µs =	10 µs
Amplifier latency =	6x 30m =	0.9 µs
Total latency =		2410.9 µs

Low latency options:
Replace DCF with DCM, transponders with ultra-low latency transponders and EDFA for Raman Amplifiers.

This effectively removes all DCF, transponder and amplifier latency for a 17% saving and a total reduction of 411 µs.

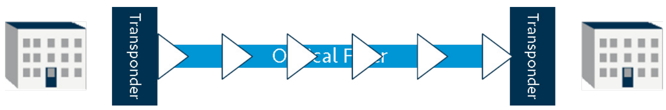


Figure 2.
Low Latency options in an example of two datacenters 400km apart

For operators deploying Layer 2 based transport networks who wish to consider low latency requirements, then an important option is low latency Layer 2 Transport Ethernet solutions. As these networks grow, the bigger the potential savings can be.

Conclusion

Low latency is a real concern in many network scenarios. Some such as telecoms services to the financial services industry can demand a substantial pricing premium if it can provide the end customer with a low latency advantage. Other industry sectors, such as data center interconnect, will require more of a focus on low latency as a basic feature to ensure the facility owner is strongly positioned to serve customers with low latency demands. There are limits to how low latency can go until we can change the laws of physics of light in fiber but there is a lot a network operator can do to ensure that the latency on any route is as low as physically possible with both Layer 1 and Layer 2 transport solutions.

Any operator looking to deploy low latency networks should ensure that they have a toolbox with all available low latency options. Optical fiber latency can only be reduced by taking a new route, which can be very expensive but could also be highly beneficial. Latency in optical components can be greatly reduced in long distance networks using DCM and Raman components. Finally, latency in opto-electrical components can further reduce latency and can offer the operator a competitive edge as this area varies from systems vendor to systems vendor and hence deployment to deployment.

Transmode offers operators the full tool box of low latency components and ultra-low latency Layer 1 transponders and Layer 2 Transport Ethernet solutions with the lowest latency available in the industry.

For further reading:
For more information on Transmode's Native Packet Optical architecture and the Transport Ethernet portfolio please visit our Native Packet Optical webpage for videos, video application notes and white papers:

- http://www.transmode.com/technologies/native-packet-optical
- **NPO white paper**
- **Ethernet Mobile Backhaul white paper**
- **Low latency press release announcing Transmode's as yet unbeaten low latency performance**

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