The Photonics Future

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Unique developments by Marconi Communications deliver all the bandwidth-enhancing benefits of photonics technology to national and even metropolitan networks. This paper describes these developments – notably the world's first Reconfigurable Optical Add/Drop Multiplexer, providing ability to add and drop wavelengths in a fully-managed system. It illustrates how they augment existing wavelength division multiplexing (WDM) technology and assesses their overall market significance.

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Bandwidth Bottle-necks

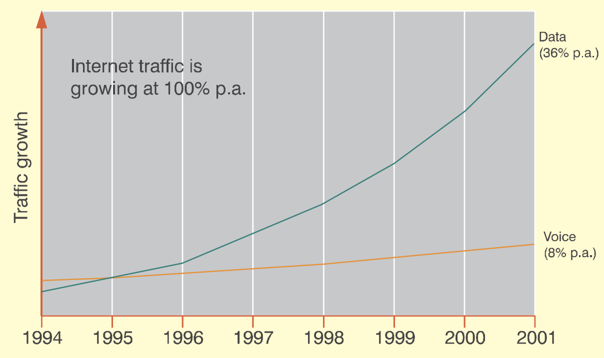
Demand for bandwidth is growing at a phenomenal rate – some commentators put data volumes expanding by as much as 36% per year (fig. 1). While attention tends to be focused on end-user connectivity, it is in the core or backbone – particularly in public networks – that congestion is the bigger threat and already becoming apparent.

To meet capacity demands, telecommunications carriers world-wide are investing heavily in upgrading their core networks, such as Cable & Wireless Communications' Network 2000 project and an £800 million investment by BT in core infrastructure.

They have three choices:

- Install more fibre, which is expensive for new entrants leasing fibres from third parties and even for existing PTOs (Public Telecommunication Operators) with established ducts. The cost of installing just 1km of fibre ranges from around £25000 to £75000; an operator with existing rights of way, such as waterways or electricity pylons, can expect to pay several thousand pounds per kilometre.
- Migrate to STM-64 (10Gbps) transmission capability in the core network which, in many cases, involves expensive upgrade of the cabling and deployment of new equipment.
- Adopt wavelength division multiplexing (WDM) technology, which delivers more capacity quickly and, by comparison with the other choices, more economically.

The use of optical fibre – developed for telecommunications transmission from the early 1980s – together with the science relating it to wavelength multiplexing, switching and amplification – which has become known as 'photonics' – hold the key to solving this capacity challenge.



1 *Data are driving future traffic growth (source: Frost & Sullivan)*

The maximum transmission speed has been revised upwards many times in recent years, as much as four-fold at each step, with the steps getting ever closer in time. Since the early 1990s, the established Plesiochronous Digital Hierarchy (PDH) transmission network is being rapidly replaced by the Synchronous Digital Hierarchy (SDH) and its US equivalent, the Synchronous Optical NETwork (SONET).

The International Telecommunications Union (ITU) defines basic transmission rates within SDH. The highest today is 10Gigabits per second (Gbps) per fibre, with further levels defined – though not fully specified. Some long-haul trunk players adopting WDM technology are examining up to 40 wavelengths, each capable of carrying 2.5Gbps, down a single fibre.

Today, most operators have only 2.5Gbps systems installed in their core network and, despite this seemingly enormous backbone network capacity, fibre congestion is already a significant problem for some carriers.

SDH and the ability to switch and route data around the world through SDH-based digital cross-connects have provided a solid foundation for carrier networks. However, it is rapidly reaching capacity limits using conventional electronic switching mechanisms. It is WDM and succeeding developments, such as those outlined below, that will provide the response to this challenge.

WDM and DWDM

WDM is not a new idea – it has been demonstrated in laboratories for years – but it is only now becoming economically feasible to implement WDM commercially. In essence, WDM splits the single laser-generated lightwave carried by an optical fibre into several wavelengths, each amounting, in effect, to an individual 'colour' of the spectrum and each carrying a high-capacity information channel – voice, data and video in digital form – each one equivalent to that of the original whole fibre.

Through a combination of filtering and multiplexing – dividing and concatenating the numerous signals as appropriate – the system transmits more channels, more efficiently over the same piece of fibre. WDM also sidesteps problems such as signal dispersion manifest in earlier technologies at high transmission speeds by providing higher capacity at lower speeds, without the need to increase the individual transmission speed.

A further development is the emergence of Dense WDM (DWDM), enabling many more optical signals per fibre. 'Dense' refers to the ability to support eight or more different wavelengths – up to 16 in systems commercially-available today with 32-channel density available shortly. The total bandwidth supported by a single fibre in traditional systems can now be multiplied by the number of channels or 'carriers'.

DWDM over long distances is made possible by amplifying the optical signal – a technique first used for submarine cables then applied to terrestrial networks where geographic barriers, such as swamps or mountains, prevented the network operator from installing conventional equipment to regenerate the signal. In DWDM the optical amplifiers amplify the multiple wavelengths; as the amplification is shared across all channels, far fewer amplifiers are needed.

It is no exaggeration to suggest that within the next few years, a single optical fibre enhanced by WDM will one day transport 25 terabits of data per second. Today, one day's entire data traffic carried in the US amounts to less than one terabit.

Not only is the transmission capacity of backbone networks increased but, by re-using existing infrastructure, telecommunications companies avoid the spiralling cost involved in laying new cable.

The first carrier to adopt DWDM for mass deployment was Sprint Long Distance in the US, heralding adoption of DWDM by many other long-distance operators in the US and, more recently, in Europe. Other examples of WDM and DWDM in action include the 30,000km-plus global undersea cabling project SEA–ME–WE 3 (South-East Asia–Middle East–Western Europe) and WorldCom's pan-European optical fibre network.

Since becoming available in 1996, DWDM equipment sales have sky-rocketed, with projections of over $3 billion annual sales in North America by the year 2000 and a further $1.5 billion across the rest of the world.

Moreover, WDM is the pre-cursor to all-optical networking, where the constraints of the traditional electronic domain no longer apply. An all-optical network has the potential to transport, route and deliver even greater amounts of bandwidth more cheaply than electro-optical solutions.

From Long- to Short-haul

Until now, commercially-available WDM systems, such as those from Marconi Communications, have been focused on point-to-point installations. Although optical amplifiers can extend the range and the signals can be regenerated, they have remained essentially systems carrying light waves from A to B, invariably in the long-haul backbone market for organizations such as WorldCom and Sprint and pioneered as operational systems in the US.

WDM is now mainstream technology in this market, fuelled by the tremendous benefits it delivers as an alternative to laying new fibre (see box on following page). And, importantly, the business drivers are accentuated the closer one gets to the points of access to the network. WDM is now being considered at the national, regional and even intra-city levels.

SDH provides a precedent: it began in long-distance networks. The turning point was the emergence of ADMs (Add/Drop Multiplexers), enabling fibres to be added or removed at particular nodes in the network as the capacity needs dictate. The regional layer or lower levels of a backbone network demands, moving gradually towards the access layer, demand this flexibility.

Marconi Communications is the first to develop the ability to add/drop at the optical layer, so enabling WDM systems to be introduced into the

The Advantages of WDM/DWDM

- Multiple services available independently on a single fibre, such as ATM and frame relay.
- Saving on the provision of fibre cables and ducts.
- Saving on transmission equipment, such as optical amplifiers and signal regenerators.
- Less capacity is needed in the SDH cross-connects.
- Shorter lead time to add new capacity compared with installing new fibre.
- Ability to provide network resilience by freeing up previously full cable routes.
- Greater flexibility in network planning.
- WDM is not constrained by a lack of standards – fibre is adopted as a global medium and carries simultaneous streams of information in their native format, such as ATM or IP, without the need to package or encapsulate them independently of each other,

network nearer the access points – in other words, closer geographically to the end users – with all the advantages of optical, rather than electromagnetic transmission.

The target for the new type of device is the inter- or perhaps intra-city hop up to about 100km span between nodes. WDM products have, to date, been too expensive to consider at this level of network granularity.

The primary focus is likely to be financial centres – notably London's Square Mile – in which numerous financial institutions need the highest 'Quality of Service' guarantees from their service providers, speed of installation, comprehensive management and unprecedented service flexibility. Of course, such areas are also the most expensive in which to lay new fibre.

All-optical Routeing

Marconi Communications' new PMA-8† is the world's first reconfigurable optical Add/Drop Multiplexer. Available commercially from early 1999, it enables services to be delivered at the optical level over a fully-managed and fully-resilient fibre ring. Rings with a PMA at each site linking, for example, numerous metropolitan locations such as a financial district, can be built on SDH principles but with the additional advantages of WDM, providing access from each node and elsewhere.

† PMA = Photonic Multiplexer Access

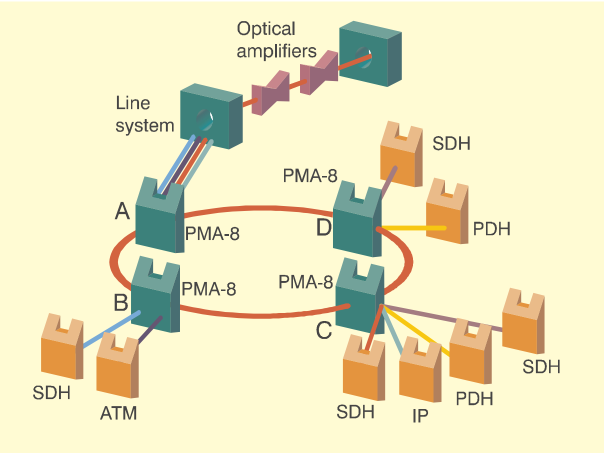
Traffic passes through a fibre as an optical signal between two points. To switch traffic through a conventional SDH ADM, it must be reconstituted as an electrical signal as it reaches the destination SDH node. To route A to B to C to D using conventional technology, information resides in the electrical domain at A. A laser is shone down the fibre, carrying the data in the optical domain to reach B where it is converted to electronic signals by the SDH ADM at B. A data stream intended for C must then be carried by another laser beam in the optical domain through to the ADM at C, where it is once again reconverted to electric impulses. The same conversion process is again necessary to reach D.

This is as complex and expensive as it sounds, whereas having a Marconi Communications PMA at each node enables the service provider to keep the data stream entirely within the optical domain on its journey around the ring.

Should C, for instance, move to a new location or wants to drop out of the network ring, no fibre re-routeing is necessary. Connection and configuration changes to the 'virtual' fibre connection can be implemented remotely at the WDM layer from a central management location, controlling an optical switch. This delivers unprecedented cost and flexibility benefits in a fast-moving and often uncertain market.

Service Flexibility

Fig. 2 presents an eight wavelength core passing by a metropolitan area fibre ring. Four wavelengths are to be dropped off and sent around the ring. Installing a PMA at each node, A, B, C, D in the example, enables each site to take off only those services it needs from the ring and add



2 *Service flexibility*

The Benefits of PMA

- Less investment in network equipment including switches and amplifiers.
- Fully-configurable, including remote configuration.
- Unprecedented network flexibility.
- Fully manageable via existing management systems.
- Enables information to be carried at the optical layer in its native form, rather than encapsulated in SDH containers.
- The network enjoys all the fault-tolerant features associated with SDH rings.

on, for onward transmission, whatever services it chooses. Only SDH equipment relating to those active services is necessary at each node.

Conventional technology demands that to extend the network from the core into the ring, all eight wavelengths – each with its own SDH ADM – would have to be installed. Using a PMA at the drop-off point in the trunk means that although one SDH ADM is still needed for each wavelength, only four SDH ADMs are needed as, in this example, only four wavelengths are going to be passed around the metropolitan ring.

This has several benefits: less investment in equipment is needed; there are fewer points of failure and far less fibre – often a rare commodity at this level of the network – is needed. Information remains in the optical domain as it passes from the trunk to node A in the ring and onwards. In the example, services and capacity on only two wavelengths may be needed at B, so a PMA carries the remaining two optical signals onwards around the ring towards C, amplifying them without having to regenerate them.

At C, in our example, two additional wavelengths are added to the two coming from B. This involves only enough active SDH equipment to receive the capacity needed at that particular site and to generate the new wavelengths from that point in the ring. The fibre has the capacity to carry up to eight wavelengths, giving tremendous flexibility to each node – the equivalent of one or more end-user organization sites – taking services from the telecommunications operator.

This can be contrasted with current technology: eight SDH ADMs would be needed at *each* node to deliver the equivalent service from the eight-wavelength trunk. Marconi Communications' Smartphotonix family of devices amplifies and passes any signals that are simply traversing a node, retaining that data entirely in the optical domain.

For customers with an existing ATM switch with optical capabilities – able to take a fibre directly into the back of the device – there is no need for investment in SDH equipment at the node, just in one PMA that is needed to manipulate the incoming and outgoing optical signals (fig. 3).

In addition, each wavelength carries a discrete service – in theory, up to eight services could enter a node and eight completely different ones could exit back into the ring.

A Fully-managed and Resilient System

Not only can a PMA installation be reconfigured remotely as the operator's customers' business needs dictate, Marconi Communications' photonic rings are fully manageable with the same look and feel as existing Marconi Communications' SDH management systems.

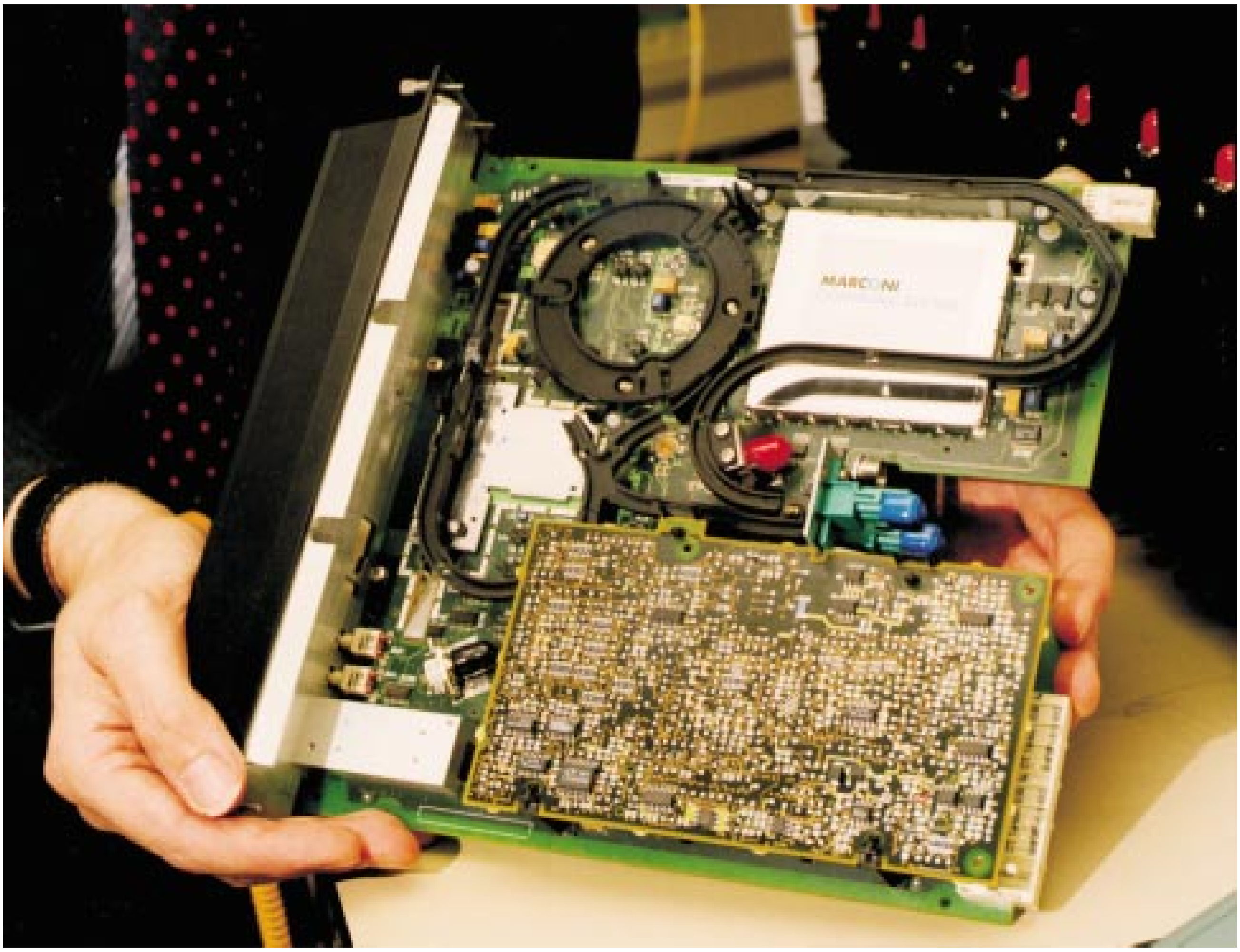
Until now, transmission technologies such as ATM and IP have always had to be packaged into SDH to ensure they have the benefit of SDH's inherent protection mechanisms. In their native form, such resilience – essential in the business-critical environments in which SDH thrives – does not exist.

With the advent of the PMA, these carrier-grade protection mechanisms become available for all types of transmission protocols, operating at the optical layer. Native IP or ATM information, for instance, can be sent in both directions around the ring, providing protection in the event of failure: information is immediately sent in the opposite direction to the problem link or node.

Future Direction

Future WDM implementations will scale upwards from 2.5Gbps per wavelength in an eight-wavelength system to, most likely, 10Gbps in the first instance. Whereas, in our example, each node has in theory a data-handling capacity of up to 40Gbps data (8 × 2.5Gbps incoming and the same outgoing), in future this could exceed 80Gbps.

Not only will the world market for this far more flexible form of WDM, based around PMAs, be huge, it is also likely to exceed estimates, rather as bandwidth volume predictions have been outstripped by demand.



3 ***The SmartPhotonix multiplexer***

These innovations in carrier-grade information transport have been developed by Marconi Communications' world-leading engineering group based in Beeston, near Nottingham. In the past, Beeston has produced the world's largest ASIC (Application-Specific Integrated Circuit), for example, for an SDH switch.

Work continues in order to develop fibre components and methods of using fibre to new levels of efficiency and flexibility, such as reducing the amount of fibre – and expensive and time-consuming fibre terminations – needed within, and to connect, network devices. More devices than ever can be placed on a single silicon substrate. Marconi Communications engineers have also enhanced the design of its switches to make the PMA as near plug 'n' play as possible – far in advance of anything else commercially available. For example, the use of an optical backplane reduces the 'spaghetti' of fibres associated with WDM terminations. It also protects the fibre connections by separating them from the electrical backplane and provides a standard card for a range of devices, including switches and line interfaces.

Much of the new WDM technology has been developed from work on fighter aircraft, where performance, fault-tolerance, size and ease of maintenance are critical. It heralds an era in which information is processed increasingly in the optical domain and light can be 'processed' as easily as electrical signals. Through developments in transmission and physical component design, much of the complexity can be isolated, so that the telecommunications operator can concentrate on operational and revenue-generating issues rather than the underlying delivery mechanisms.

Marconi Communications staff at the Beeston laboratories continue to push back the boundaries of what is possible and commercially feasible with photonics technology for the world's service providers.