WDM Techniques in Broadband Optical Networks

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WDM techniques in broadband optical networks

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The penetration of optical-fibre technology into the local-access network may well occur by the economic provision of well-established services, such as basic telephony, over a shared-access optical architecture. The provision of new broadband services needs to be done without disruption to these basic (telephony) services.

Wavelength-division multiplexing techniques allow the possibility of broadband upgrade on a shared-access network architecture without disturbing existing services.

The nature of shared-access structures, although providing opportunities for the early economic provision of basic low-bit-rate services, gives rise to major implications for the requirements of the WDM technology used for upgrading to broadband operation.

In this paper example network structures are examined in terms of possible upgrade strategies and the associated technological implications.

Introduction

With many organizations worldwide working on the application of optical technology to the local-access network, penetration of fibre to all classes of customer can only be a matter of time. It is also becoming evident that the advantages offered by single-mode technology significantly outweigh any disadvantages and that this will become the 'standard' local-network technology. Single-mode fibre offers an optical window (figure 1) from about 1250 nm to 1600 nm depending on the fibre specification and the cable technology used. This potential optical window corresponds to over 50000 GHz of transmission capacity, the equivalent of 1.6×10^9 digital telephone channels or of the order one million digital television channels. A significant portion of this enormous capacity can be accessed by techniques that use multiple optical carriers.

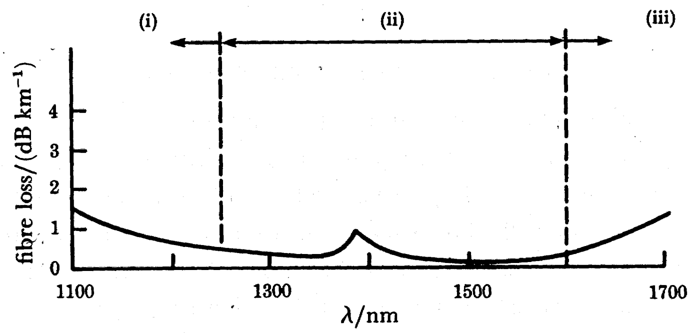

Figure 1. Single-mode fibre optical window. Multimode operation and high fibre loss prevent use in region (i). Possible operating window is region (ii), with a bandwidth of *ca.* 50000 GHz, which is equivalent to 1600 million digital telephone channels or $\frac{3}{4}$ million digital television channels. Infrared absorption edge and cabling losses prevent use in region (iii).

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MULTICARRIER OPTICAL SYSTEMS

Frequency-selective multiplexing in which different frequency carriers are modulated with independent message channels is an old idea in widespread use in modern communication systems. These techniques can also be applied with advantage to optical communication systems. For the purposes of this paper multicarrier optical systems will be divided into three categories.

1. Frequency-division multiplexing (FDM, sometimes termed subcarrier multiplexing). In this type of system the multiplexing and demultiplexing functions are carried out in the electrical domain and the preassembled multiplex of carrier frequencies is then used as the signal to modulate an optical source. In these systems the carrier frequency spacing is commensurate with the message channel bandwidth.

2. Coherent optical multiplexing. Here the multiplex may be assembled in either the electrical or optical domain but at the receiver homodyne or heterodyne techniques are implemented by means of mixing the incoming optical multiplex with an optical local oscillator. Channel selection can take place in the electrical domain by tuning an electrical intermediate frequency filter or in the optical domain by tuning the optical local oscillator. In this system the carrier spacing will be of the order of the message channel bandwidth.

3. Wavelength-division multiplexing (WDM). In these systems the multiplexing and demultiplexing/channel selection functions are carried out in the optical domain. The optical carrier spacing will be determined by factors other than the message channel bandwidth and in general will be much larger than the message bandwidths.

WDM can be considered to be the general case. With an adequately designed system, wavelength carriers in the wavelength multiplex could carry FDM or coherent multiplexed systems.

This paper will be mainly considering WDM as described in (3) above applied to the local access network.

LOCAL-NETWORK STRUCTURES

There is currently a major debate concerning the structure that a new optical local network should take. The major options are between single-star networks, multistar networks using active nodes, multistar networks with passive nodes and star-bus systems. These network structures are outlined in figure 2. The single-star topology is equivalent to that used for existing copper networks and requires one or two fibres from the switching centre to each customer termination. This network structure has the advantages of good security, very high capacity and low-technology optical terminal equipment. However, it also suffers from two serious disadvantages: one is that very high fibre count cables are required with the attendant installation and maintenance problems the other is the high capital cost of network provision.

In the current copper local network much of the capital cost of the network is associated with the line plant between the customer's terminal and the exchange, and the exchange's terminal equipment. Only a small proportion is reserved for the customer's termination. In an optical system some form of optical transmitting and receiving devices are required together with interface electronics and power supplies. This implies a significant increase in the capital equipment required at the customer termination. If it is assumed that no significant increase

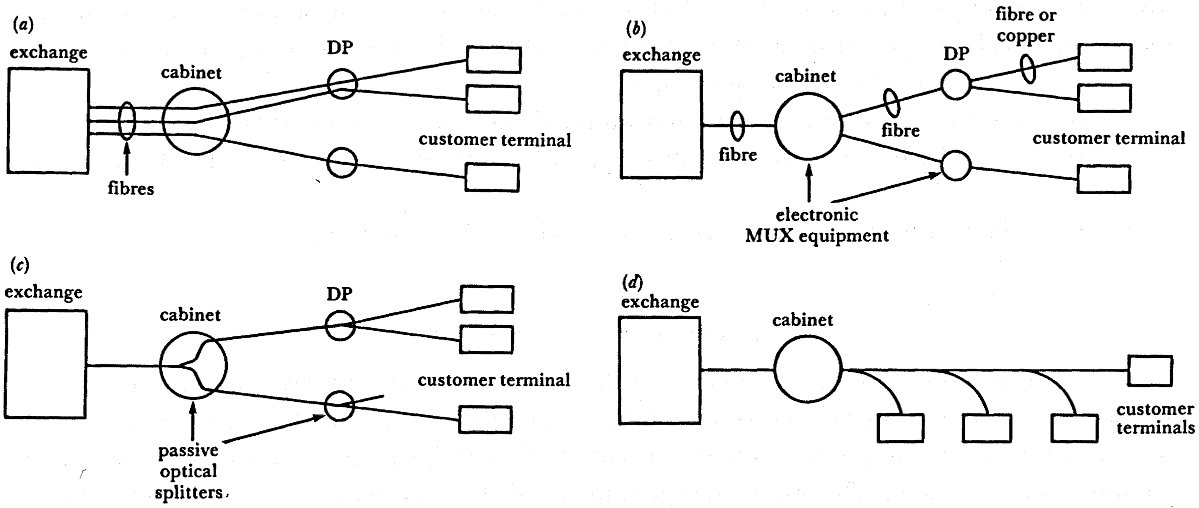

FIGURE 2. Optical local network options. (*a*) Single-star; (*b*) multistar with active nodes; (*c*) multistar with passive nodes; (*d*) star-bus.

in the capital base per customer is available for a new network, it becomes necessary to transfer capital cost from the network to the customer termination by resource-sharing techniques in the upper reaches of the local network. The multistar and star-bus topologies achieve this by traffic concentration as the exchange is approached.

The multistar active node system of which the Westminster cable system is a good example, has outstationed optical and electronic nodes to provide service selection and traffic concentration points. These active nodes are fed via feeder fibres from the exchange with further fibres (coaxial cable in the early systems) to the customer's equipment or further remote electronic nodes. This system has the advantage of offering a wide range of services with significant resource sharing in the upper reaches of the network and relatively simple optical technology. The disadvantages are the maintenance and power feeding issues associated with outstationed electronics and the reduced flexibility to add new services on a piecemeal basis. Also there is a need for significant up-front capital expenditure which requires good penetration and take up of new services to justify.

The passive optical multistar and star-bus systems are proposals that attempt to overcome the maintenance and power feeding issues of outstationed electronics by the introduction of totally passive optical nodes. They also try to minimize up-front capital costs such that the network is economic for existing telephony and data services while retaining the upgrade potential to new broadband services. The introduction of the passive nodes does, however, increase the complexity of the optoelectronic terminal equipment particularly when upgrade to new services is considered.

It is these passive network structures that lend themselves most readily to the advantages offered by WDM techniques and will be considered in more detail in this paper.

Wavelength multiplexing offers some unique advantages when used in the local network environment including

(1) very large potential bandwidth/wavelength channel;

(2) information and modulation format transparent, i.e. time-division multiplexing (TDM), asynchronous transfer mode (ATM) and FDM systems can be carried and analogue or digital modulation techniques can be used on different wavelengths independently of each other;

(3) mixed services that are easily carried;

(4) graceful growth of new services and minimal disturbance to existing services;

(5) network switching and routing possible within the wavelength domain (Payne *et al.* 1986*a*);

(6) crosstalk that is effectively independent of channel bandwidth.

WDM AND TDM: A COMPARISON

Although WDM offers many advantages for the local network it requires a significant increase in the amount and sophistication of the optical technology used. For this reason WDM should not be considered as a replacement for electrical multiplexing such as TDM, but as a complementary system. This raises the question of when or for what services should WDM be used rather than TDM? As an attempt to answer this question a model comparing the use of WDM and TDM techniques in shared-access optical networks was reported by Payne *et al.* (1986*b*). This model balances the power budget equation for the network schematic shown in figure 3 as a function of the number of terminals/customers served and the bit rate delivered to each terminal. The results of this model are summarized in figure 4 and are computed assuming 10 km between exchange and terminal with 0.7 dB km^{-1} cabled and spliced fibre loss, 0 dBm launched optical power, 5 dB system margin and receivers with sensitivities between 10 and 20 dB of the quantum limit for 1 in 10^9 bit error rate.

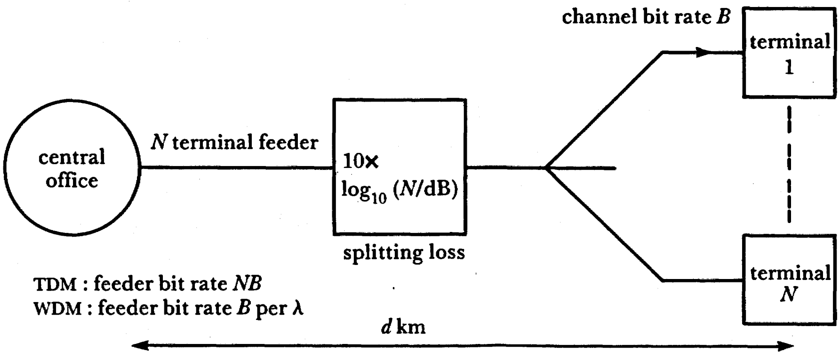

FIGURE 3. Model network schematic.

It can be seen from figure 4 that if power budget were the only criterion WDM would always be superior to TDM unless bit rates in excess of 10 Gb s^{-1} are delivered to each customer (TDM is only better than WDM at these very high bit rates because of a 6 dB loss assumed for the WDM technology in the model). To make the comparison more meaningful technological limits have been included for both WDM and TDM. For TDM arbitrary bit rate limits of 565 Mb s^{-1}, 2.4 Gb s^{-1} and 10 Gb s^{-1} are shown suggesting 565 Mb s^{-1} for a limit to 'low-cost' silicon electronics, 2.4 Gb s^{-1} for an upper limit for silicon and 10 Gb s^{-1} for an upper limit for new (GaAs?) electronic technologies. For WDM 20 channels is chosen for 'today's' technology with 300 channels for a limit to direct detection WDM systems. Beyond 300 channels coherent

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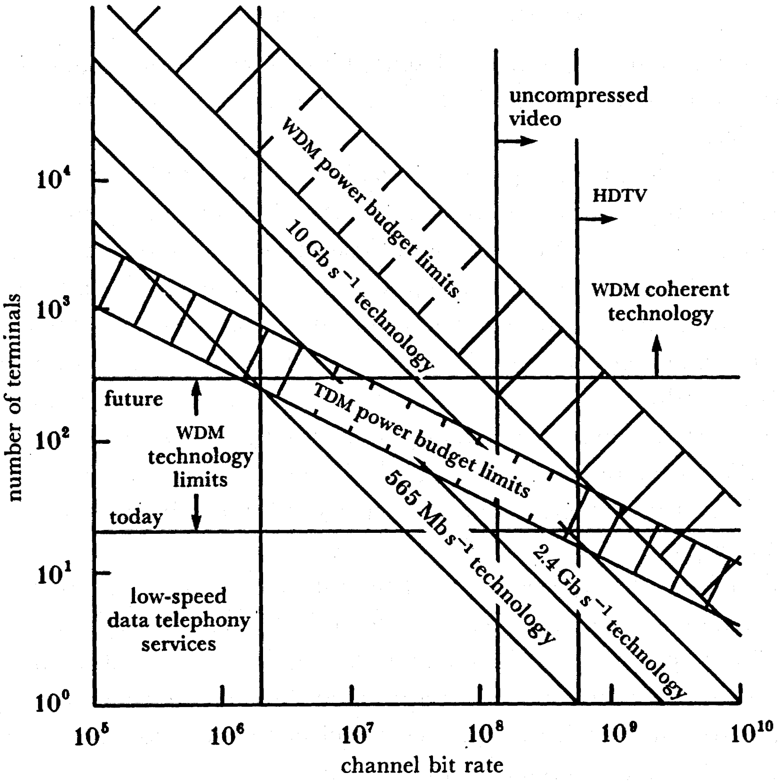

FIGURE 4. Comparison between TDM and WDM techniques.

technology is assumed to be necessary. It is stressed that all these limits are somewhat arbitrary and certainly debateable and are suggested for comparison purposes only.

When technological constraints are taken into account it can be seen that when delivering low-bit-rate services, e.g. telephony and low-speed data (less than 2 Mb s^{-1}), TDM is superior to WDM unless very advanced coherent multiplexing techniques are invoked for WDM. As bit rates per terminal increase beyond a few megabits per second WDM begins to challenge TDM particularly if 565 Mb s^{-1} transmission rates are a limit for 'low-cost' customer terminals. When high-bit-rate services such as uncompressed video and high-definition television (HDTV) are considered WDM technology becomes dominant.

It should also be noted that as these high-bit-rate systems become a major service to be carried, TDM will become limited by technology (bit rate) rather than by the optical power budget. This implies that improvements in optical technology that realize greater optical power budget cannot be used to increase the number of terminals served. At best it would be useful for increasing geographical range. However, for WDM systems any increase in optical power budget can be used to directly increase the number of customers served by a given size of feeder cable.

This simple model does not take into account the other networking advantages offered by WDM and in practice WDM and TDM (and possibly FDM or subcarrier techniques) will be used in combination with the initial role of WDM being to upgrade networks carrying TDM multiplexes of telephony and data services.

WDM AN UPGRADE STRATEGY

From the above discussion it is concluded that the first system on a shared-access passive optical network will be a single-wavelength TDM system delivering conventional telephony and low-speed data services.

This is the basis of the telephony on passive optical network (TPON), a possible entry strategy for telephony and low-speed data (Stern *et al.* 1987). The telephony and low-speed data services are transmitted as a TDM multiplex to the customers on a single wavelength. A ranging protocol is incorporated within the operating system to automatically adjust delays in the customer terminal equipment enabling synchronization of the customer's traffic at the exchange. New additional services can be added to the system on extra wavelengths via separate feeder fibres to the first splitting point. If the new services are significantly broader bandwidth than the first wavelength telephony-data system then a reduced path loss will be necessary to offset the reduction in available optical power budget. This can be achieved by bypassing some of the splitting stages in the first passive splitter reducing the splitting ratio for the broadband service path.

If only one additional wavelength is required then no wavelength multiplexing component is required at the exchange or head end of the system, in this case the splitting node performs the multiplexing function. If more than one wavelength is required then a single-mode wavelength multiplexing component will be required at the exchange end of the system. At the customer end of the system a device is required to select the additional wavelength(s) while continuing to receive the first (telephony) wavelength.

The use of additional feeder fibres to the first splitting point allows the addition of new services without any interruption to the existing telephony-data services on the first wavelength. In order that new services, added to the system by using extra wavelengths, do not perturb existing customers who do not require them, an optical band pass filter is incorporated within the receiver of the TPON customer terminal equipment. This filter is designed to pass only the first (telephony) wavelength and reject the remainder of the optical window that could be used for wavelength multiplexing at some future time.

THE TPON SINGLE-WAVELENGTH OPTICAL SYSTEM

The first-wavelength (TPON) system is shown schematically in figure 5. It consists of an optical source with a centre wavelength of 1300 nm, an optical path of loss L dB and an optical filter followed by an optical receiver. Although this is a single-wavelength system at some time in the future it will be an integral part of a wavelength multiplex and from the outset it must be designed as a wavelength multiplexed system.

This implies that the centre wavelength of the exchange optical sources will need to be well specified with a matching specification for the optical filter taking into account environmental and manufacturing tolerances of the components.

It is envisaged that early upgrades to new broadband services will be dominated by traffic in the exchange to customer direction, i.e. cable TV (CATV) type services rather than two-way video. This means that it is particularly important to conserve optical spectrum in the exchange to customer direction for the first-wavelength system. To reduce costs at the customer terminal the equipment will not be temperature controlled and the optical filter placed in the customer

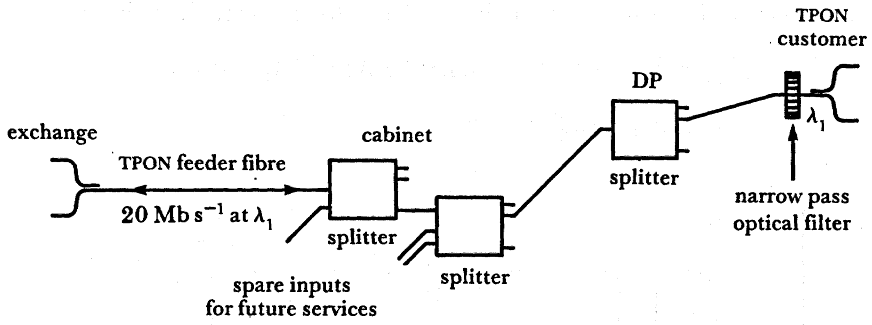

FIGURE 5. Single-wavelength TPON system.

receiver is therefore assumed to be subject to a temperature range of 0 to 50 °C. The current design for the filter is a four-cavity interference filter fabricated with thin film technology. The following simple analysis illustrates the relation between the centre wavelength tolerance of the exchange laser and the passband of the customer filter.

The required filter passband λ_B (see figure 6) at some minimum transmission value is given by

$$\lambda_B = 2(\Delta\lambda_c + \Delta\lambda_L + \tfrac{1}{2}\Delta\lambda_B),$$

where $\Delta\lambda_c$ is the centre wavelength tolerance of the filter and is a combination of production tolerances and temperature drift ($\Delta\lambda_T$); and $\Delta\lambda_L$ is the spread of laser source wavelength and includes production tolerances, residual temperature effects and chirp effects for directly modulated devices.

For thin film dielectric interference filters, the filter centre wavelength production tolerance and the bandwidth tolerance are related to the filter bandwidth:

$$\Delta\lambda_c = 0.1\lambda_B + \Delta\lambda_T \quad \text{and} \quad \Delta\lambda_B = 0.2\lambda_B.$$

The filter bandwidth becomes

$$\begin{aligned}\lambda_B &= 2(0.1\lambda_B + \Delta\lambda_T + \Delta\lambda_L + 0.1\lambda_B)\\ &= 3.33(\Delta\lambda_T + \Delta\lambda_L).\end{aligned}$$

Filter bandwidths are usually defined in terms of the full-width half-maximum (FWHM) bandwidth. The relation between λ_B and the FWHM bandwidth depends on the filter design and the minimum transmission level required, e.g. 85%. To minimize the adjacent channel spacing a multi-period filter is required to give a passband spectral shape as close as practicable to the ideal 'top hat' profile. In practice a four-period filter is the most complex filter that can probably be realized as a production item by using modern thin film coating techniques. Assuming a transmission efficiency in the passband of 85% the FWHM bandwidth for a four-period filter is approximately 1.25 times the 85% width.

The FWHM of the filter is therefore

$$\mathit{FWHM} = 4.2(\Delta\lambda_T + \Delta\lambda_L).$$

The adjacent channel spacing depends on the filter passband shape and the permitted optical crosstalk level. For example if the permitted crosstalk level corresponds to 1% transmission through the filter this occurs at a point 0.825 times FWHM away from the centre of the filter for a four-period filter. From figure 6 it can be seen that the adjacent channel spacing is given by

$$\begin{aligned}\lambda_{c2} &= \lambda_{c1} \pm (0.825 \times \text{FWHM} + \Delta\lambda_c + \tfrac{1}{2}\Delta\lambda_B + \Delta\lambda_L)\\ &= \lambda_{c1} \pm 1.23 \times \text{FWHM}.\end{aligned}$$

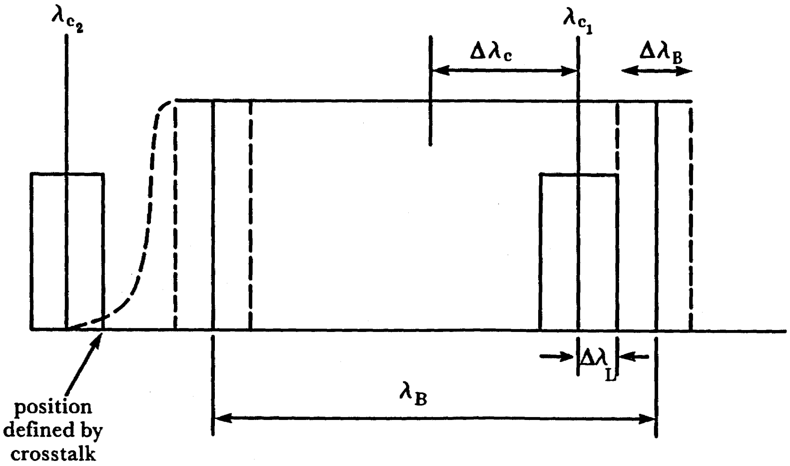

Figure 6. Tolerance effects in fixed optical filters.

The above shows that the combination of environmental effects and manufacturing tolerances give a significant multiplying factor between the spectral variation of the source laser and the bandwidth of the customer filter. To minimize the spectrum removed from the available optical window by the TPON system it is necessary to use a tightly specified distributed feedback (DFB) laser at the exchange end of the system. Such a laser will be too expensive to be used in the customer termination in the near term but a large splitting ratio allows economic use of such a device at the exchange end of the system because the cost is shared over a large number of customers.

In the return direction fairly conventional Fabry–Perot lasers will need to be used to keep customer equipment costs down. Also to further reduce costs the customer laser will not have a thermoelectric device to minimize temperature drift. Taking into account temperature, ageing effects and significantly varying drive conditions between different customer units on the same network a centre wavelength tolerance of as much as ±15 nm might need to be added to the manufacturing centre wavelength tolerance. To minimize problems that could occur at wavelength extremes and again to minimize upstream spectral usage, a significant tightening of manufacturing centre wavelength tolerance (e.g. ±5 nm) of the customer lasers will probably be required.

MULTIWAVELENGTH SYSTEMS

The first upgrade to broadband services on a TPON type system would be by the introduction of additional downstream wavelengths and then selection of one or more of these wavelengths at the customer terminal. A schematic of such a multiwavelength system is shown in figure 7. It consists of a wavelength multiplexing device at the exchange end of the system of loss L dB and a channel selection optical filter at the customer terminal. If the channel selection filter is of a fixed type using for example the same technology as that implementing the TPON band pass filter then the minimum channel spacing is dictated by the arguments above for the single

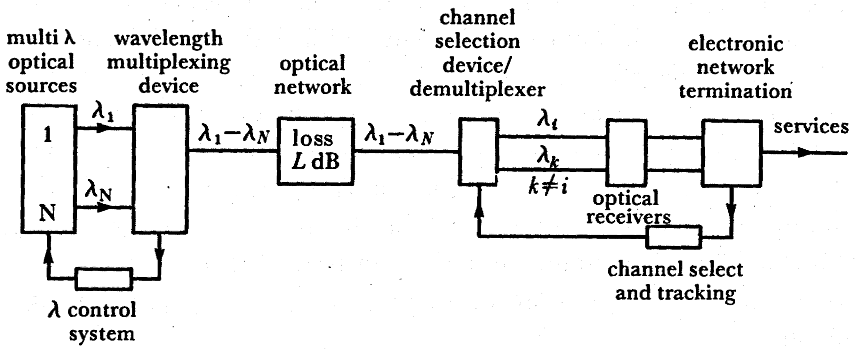

FIGURE 7. Schematic WDM system.

wavelength TPON system. If DFB lasers with centre wavelength controlled to approximately 1 nm are used, then a channel spacing of the order of 10–15 nm could be required depending in detail on the optical crosstalk levels that could be tolerated. Such a wide channel spacing is wasteful of the limited optical spectrum and would severely limit the number of available channels. To conserve spectrum and significantly increase channel density it will be necessary to enable the customer filter centre wavelength to track the laser source wavelength. In this way both production tolerances of the filter and environmental effects can be compensated with the result that channel spacing is determined by the filter spectral shape and the laser wavelength tolerance. If the tuning range of such a tracking filter is large, i.e. covering the optical window, then additional advantages of wavelength channel selection at the customer terminal can also be obtained. Whatever type of optical filter is used it must exhibit the optical characteristic of a band pass filter with adequate out of band rejection over the entire potential optical window which could be as wide as 1250–1600 nm for local loop applications.

Network spectral characteristics

With multiwavelength, single-feeder fibre, shared-access systems a wavelength multiplexing device must exist at the exchange or head end of the system. If the services offered over such a network include broadcast channels then it is advantageous to have the network splitting points wavelength independent such that common wavelengths carrying the broadcast channels can be accessed by all customer terminals connected to the network. With wavelength independent splitting points there is no wavelength matching problem of spectrally selective components mounted in the harsh field environment. There is the additional advantage in the longer term that wavelength routing can be used across the network when tunable sources are available. The disadvantage of spectrally flat splitting nodes is that a minimum loss of $10\log_{10}(N)$ dB must exist within the network and for large N this is the most significant loss in the power budget equation.

The use of a broadcast time-division multiple-access (TDMA) system for the telephony and data services and the possible use of TDM (Faulkner *et al.* 1988) or subcarrier multiplexing (Olshansky 1987) for broadcast television services dictates, for these networks, that optical power splitters must be used. At present the most promising technology for these power splitters are the wavelength flattened fibre biconical taper couplers built into splitting arrays (Mortimore 1986). These devices are now exhibiting low excess loss, fairly good spectral flatness, adequate splitting ratio characteristics and good environmental stability. They can also be essentially polarization independent, a parameter that may be important for future upgrade strategies using coherent techniques. Other technologies such as planar are also of interest. Although at present the optical performance of such devices falls short of the biconical taper device, they may offer a more cost-effective solution in the longer term.

If separate networks are used for upstream and downstream transmission directions rather than bidirectional working on one network (cost studies indicate no significant differance between the two strategies), then the option exists for wavelength selective splitters (a wavelength multiplexing device) to be used in the return path direction (customer to exchange). This could have advantages in the shorter term of reducing the return optical path loss and allowing the use of light emitting diodes (LEDS) in a spectral slicing mode at the customer terminal.

WAVELENGTH MULTIPLEXING TECHNOLOGY

In this section the technological implications of moderate to high-density wavelength multiplexing are considered.

Optical sources for WDM

Although lasers will be the usual optical source for multichannel wavelength multiplexing, it is possible to use LEDS for low-bit-rate systems that can tolerate a low launch power. In these systems the multiplexing component also acts as a filter selecting a small wavelength band of the broad LED spectrum. Such spectral slicing systems have been proposed for telephony and data services in order, in the short term, to exploit the relatively low-cost LED technology.

The spectral envelope of multilongitudinal mode Fabry–Perot (F.–P.) lasers will limit the channel spacing to about 10 nm. Also because of the unstable nature of the lasing modes any filtering of the laser spectrum by the multiplexing and channel section devices can give rise to mode partition noise. To avoid this problem careful consideration of the multiplexer and channel selection device spectral profile is required. The channel spacing of F.–P. lasers will limit the number of available channels to between 10 and 30 and although they are currently much lower-cost devices than single longitudinal mode lasers they are not a good choice for multichannel wavelength multiplexed systems.

Single-mode sources such as DFB lasers offer much closer channel spacing with 1–2 nm a realistic target (Hegarty *et al.* 1984). One limiting factor to channel spacing besides production tolerances and temperature effects is wavelength chirp when the devices are directly modulated (Koch *et al.* 1986). To reduce chirp effects the laser can be operated in continuous wave mode and external optical modulators used.

With channel spacings around 1–2 nm, 100 to 300 channels could be multiplexed within the optical windows of single-mode fibre. Each wavelength channel provides an independent optical path across the network and could carry many gigabits per second with the appropriate terminal equipment.

Tunable sources such as external cavity devices (Wyatt *et al.* 1985) could enable even higher channel densities because manufacturing tolerances and temperature effects could be eliminated. Tunable sources with a wide tuning range would also provide several networking advantages. For example, wavelengths could be assigned to services or customer channels on demand and the wavelength management problems of maintenance stocks and correct laser installation at the multiplexer, etc., would be considerably reduced.

Wavelength multiplexing devices

The ideal wavelength multiplexer should exhibit low insertion loss that is polarization independent, have a good optical channel bandwidth to channel spacing ratio and also exhibit good crosstalk performance if the device is also to be used as a demultiplexing component.

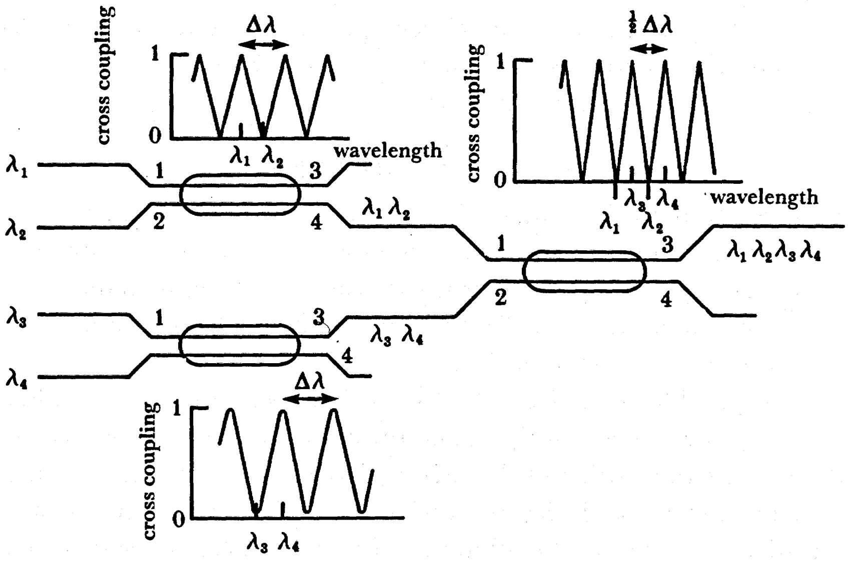

FIGURE 8. Fibre multiplexer example.

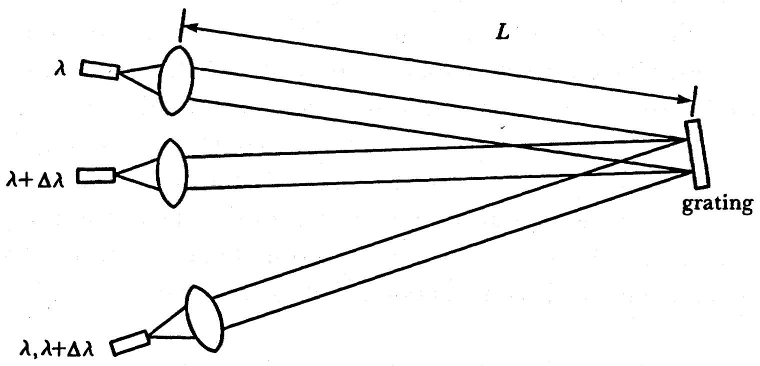

FIGURE 9. Multilens grating multiplexer.

For small numbers of channels interference filter devices have been proposed (Nosu *et al.* 1978) and small arrays of over coupled fused fibre biconical taper devices (see figure 8) are also a possibility. These technologies could provide devices with 10–20 nm channel spacing. As channel spacings decrease and channel numbers increase dispersive grating multiplexer designs are more suitable. A simple design for such a multiplexer consists of a single-mode fibre array of $N+1$ single-mode fibres (N input fibres and 1 output fibre) and a single lens which is used to collimate the light from the fibres on to a reflection mode diffraction grating such as a metal-coated blazed grating. Light from the input fibres is diffracted by the grating and reflected back through the lens to be imaged onto the core of the single-mode output fibre. Such devices are now available as commercial items. The major problem for this design as a single-mode multiplexer is the relatively poor channel bandwidth to channel spacing ratio that is determined by the single-mode spot diameter and the array fibre spacing, with etched fibre arrays (Hegarty *et al.* 1984) this is usually limited to $\frac{1}{4}$ or more typically $\frac{1}{6}$. One method of improving the channel bandwidth to spacing ratio is to use multilens designs (Chamberlain & Hill 1987); one possible configuration of such a multiplexer is shown in figure 9. With such designs it is possible to obtain ratios approaching unity.

To complete the multiplexing function for closely spaced WDM system a feedback control loop will need to be incorporated to keep the laser operating wavelength locked to the centre wavelength of the multiplexer optical channels.

Channel selection optical filters

In general WDM systems in the local network will have many more channels multiplexed onto feeder fibres than will need to be received by the customer terminal at any one time. A full demultiplexing function with an optical receiver for each wavelength channel is not therefore required. However, for small numbers of wavelengths this should be considered as a possible option if low-cost receivers are available.

The simplest conceptual form of channel selection filter is a series of fixed filters interposed between the incoming wavelength multiplex and the optical receiver. However, the arguments presented above for the bandwidth and channel spacing of the TPON customer filter would also apply to such a channel selection device and this would be a serious limit to channel numbers. However, the relative simplicity of the solution could make it viable for the early addition of only one or two extra wavelengths on a shared-access system. Beyond this number wastage of precious spectrum will severely detract from future upgrade potential.

Continuously tunable filters will be necessary to increase channel densities on the system. Several options exist including tunable Fabry–Perot devices (Mallinson 1987), variable pitch grating devices (McCartney *et al.* 1985), and dispersive grating devices.

The Fabry–Perot devices require high finesse cavities to achieve the required free spectral range combined with close channel spacing. Alternatively they could be combined with some other filter technology to give fine grain tuning over a restricted spectral range. One problem with single-cavity F.–P.s is the relatively poor spectral shape of the passband resulting in bandwidth to channel spacing ratios much poorer than those obtainable with multilens grating multiplexers.

Position tunable, variable pitch grating devices have been reported in both dichromated gelatine holographic technology and thin film dielectric filter technology. They offer tuning ranges across the entire optical window with better than 10 nm bandwidths. The difficulty of fabricating many-layer variable pitch gratings in thin film technology will probably limit this technology to bandwidths greater than 5 nm. Much thicker films are possible in holographic technology and limits are not yet known. However, material properties and processing problems may also limit these filters to bandwidths to not much less than 5 nm. One advantage offered by holographic technology in thick films is the potential for good passband spectral shape control enabling high channel packing densities, 5 nm filters could then realize up to 50-channel WDM systems.

Dispersive grating devices are based on the same principles as grating multiplexers and can exhibit similar channel densities. A schematic of one possible design is shown in figure 10. Light from the input fibre carrying the wavelength multiplexed is collimated by a lens onto a

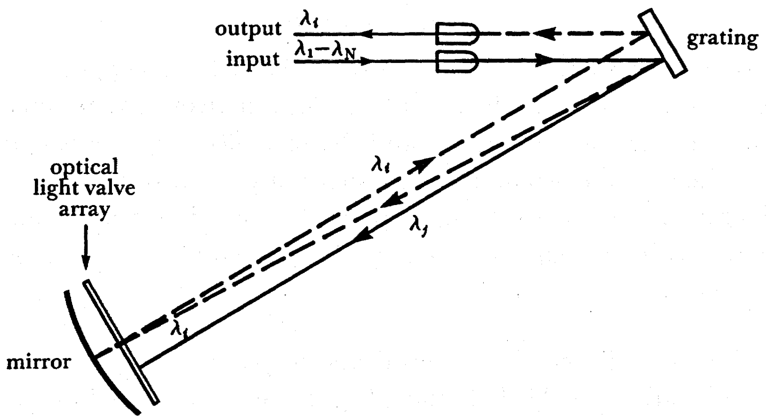

Figure 10. Dispersive grating tunable filter.

diffraction grating which diffracts the light onto a curved mirror via an optical light valve array. At the required wavelength an aperture is opened through the light valve and enables reflection off the mirror back to the grating where it is diffracted back through a further lens and onto the output fibre. In the simplest form the optical light valve could be a moving slit, but optoelectronic devices could in the longer term provide solid-state high-speed channel selection.

Optical receiver

In a general-purpose WDM system the individual wavelengths making up the multiplex could be carrying very different bit rates and even different modulation formats. An ideal optical receiver following a wavelength channel selection filter should be able to receive arbitrary bit rate source at widely different power levels and also to provide analogue output ports. The bandwidth and sensitivity of the receiver should be programmable and under the control of the local network termination unit.

Two-way WDM networks

The above discussion has centred on broadband transmission from the exchange to the customer with narrow band capability only in the return direction. When two-way broadband services are implemented, wavelength multiplexing in the return direction will require each customer to be able to transmit at different wavelengths. Individual DFB lasers sited at the terminal could be a solution if costs for devices with well-defined centre wavelengths can be significantly reduced by an order of magnitude or two. Technically this is a viable solution, but poses the operational problem of maintenance if a large number of different wavelength lasers are required to service the customer base. The longer-term solution would be to use tunable laser sources with a wide tuning range, the centre wavelength of which would be set up by the system operating protocol. Tunable sources would allow both greater channel densities and a significant reduction in the number of different wavelength devices required to be stocked by the operating companies for maintenance purposes.

Both solutions require an improvement in optical laser production technologies if costs are to be reduced to make these networks viable and it is this area that is now the key to the future for the extensive use of wavelength multiplexing techniques in the local network.

Conclusions

This paper has outlined some of the many issues involved in the application of wavelength division-multiplexing techniques to the broadband local network environment. Potential cost-effective solutions exist for the multiplexers and channel selection devices that will be required for such systems. The major shortfall of such systems at present is the non-availability of low-cost multiwavelength or tunable wavelength optical sources. However, technical solutions exist for these devices and with adequate development they should become available as cost-effective components in due course.

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