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Study of model requirements in local area networks [LAN]

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Abstract
This paper introduces the use of multimode fibre in Local Area Networks and describes how, in order to compete with copper technology, operating bandwidths are continually being pushed upwards. Standards are now becoming available to support 10Gbit/s performance on multimode fibre in both the 850nm and 1300nm transmission windows.
Specification, and control, of the launched mode distribution have become quintessential requirements for the operation of these systems.

Keywords: local area networks

Introductions
A Local Area Network (LAN) is a system for communication between computer terminals and related equipment within the same general area. A network might encompass a commercial building complex, or a small residential area, where link lengths between terminals are generally up to a few hundred metres.

A typical network consists of a main backbone cable, which could be fibre or copper based, entering a building complex in the basement area and terminated at a main *cross-connect* enclosure. The enclosure has the function of providing switching to internal *riser* cables, which pass up through the building in special cabling ducts. These are terminated at smaller cross-connect enclosures on each floor of the building, from where *horizontal* cabling connects them to wall-mounted outlet points in the various work areas of each floor of the building. In a large complex, the riser cables are described as *vertical* backbones. The work areas contain equipment such as personal computers (PCs), shared printers, scanners and telephones, which are fitted with Network Interface Cards (NICs) for connection to the outlet points, via short cable runs of a few metres or so [1].

Traditional copper-based networks offering 10Mbit/s data-rates are becoming unable to cope with the growing demands on bandwidth resulting from the ever increasing power of PCs and the demand for network connection. Ethernet standards for higher bandwidths, such as for 100Mbit/s and 1000Mbit/s, have been developed and are now becoming widely used, but even these are not sufficient for the main network backbones where many operators are shifting to the new 10Gbit/s standards being offered by optical fibre.

Since the 1980s the trend has been to install single-mode fibre for *telecommunication* systems, connecting main exchanges, and switching centres, where gigabit bandwidths are required over long distances, and to employ multimode fibre for LAN backbones and main riser cables. Horizontal connection, however, from the risers to the workstation areas continues to be copper twistedpair due to the higher cost of fibre connectors and devices, and it is unlikely that *Fibre to the Desk* (FTTD) will become widespread for some time, except for specific applications requiring extremely high data-rates. As speed requirements increase, and the price of optical fibre components continues to fall, then FTTD may start to become a reality.

Multimode fibre in the local area network
The growing use of fibre in the LAN backbone is due to the advantage of the *bandwidth-times-distance* product of fibre over copper, enabling higher data-rates over longer link lengths. For example, the new Category 6/Class E copper cabling standard supports 10Gbit/s transmission, known as 10GBASE-T, but is limited to distances of up to 55m, whereas fibre is able to achieve tens times this reach at the same data-rate.

This length benefit manifests itself in the need for less repeaters than copper and the ability to operate star-type topologies where each user group may be connected directly to a centralised hub. This topology has the advantage of requiring less cross-connect enclosures, which are expensive, and is considerably easier to operate and maintain than ring-based networks.

There are also other advantages of fibre over copper, such as its immunity to electrical noise, lighter weight, increased data security, low spark risk hazard and upgradeability to higher bandwidths.

The main industry standard for Ethernet LAN systems is IEEE802.3 [2], which covers 1, 10, 100 and 1000Mbit/s systems. For each of these categories, the use of both copper and fibre is specified. Regarding 1000Mbit/s, the specifications for fibre are known as 1000BASE-SX and 1000BASE-LX, for 850nm and 1300nm respectively. For the former, both 50um and 62.5um core diameter fibres are specified, with respective bandwidth-distance products of 500MHz.km and 200MHz.km at 850nm and maximum operating distances of 550m and 275m respectively. For 1000BASE-LX, 50um and 62.5um fibres are again specified, both with 500MHz.km bandwidth at 1300nm and a maximum operating distance of 550m.

In order to achieve 1000Mbit/s over the maximum operating distance, IEEE802.3 specifies a range of transmitter and receiver characteristics, such as launched optical power level, return loss, detector sensitivity and eye closure. Of particular interest to this thesis is the interplay of the optical characteristics of the transmitter with the fibre link itself in terms of its bandwidth and loss performance. Regarding bandwidth, 1000BASE-SX specifies the launch characteristics of the 850nm laser source in terms of the mode distribution it launches into the fibre, using a parameter known as Coupled Power Ratio (CPR). The CPR is required to be above a certain value to ensure that the bandwidth performance of the fibre is not dominated by a few individual modes. A draft addendum to the standard, IEEE802.3z, specifies the modal distribution of the source in terms of an *Encircled Flux* distribution [3]. The purpose of this is to ensure that neither the lowest order, nor the highest order, modes dominate.

Differential mode dispersion

Measurement of fibre bandwidth has traditionally been carried out with an *Overfilled Launch* (OFL) [4], as this type of launch has been found to give reproducible results with different types of test equipment. The development of the 850nm VCSEL laser source in the 1990's, however, found immediate application in LAN systems due to its high power, low threshold current, high modulation speed and circular optical symmetry. Installers soon found that they could achieve system bandwidths far in excess of the values associated with an OFL and so it was clear that some other performance standard was required that would be a better predictor of system performance.

The Telecommunications Industries Association (TIA) responded with a two–pronged approach. Firstly, the fibre bandwidth would be measured using a Restricted Mode Launch (RML) and, secondly, the output from the source VCSEL would have to satisfy some sort of modal template. For the RML, the TIA chose to use a launch fibre with a core diameter of 23.5 mm and a numerical aperture of 0.208 [5]. For the VCSEL, its output when measured via a patch cord would have to satisfy an Encircled Flux template. So, if the fibre bandwidth with the RML launch exceeded 385MHz.km and the VCSEL source passed the template then the fibre link should operate at 1Gbit/s over distances up to 500m [6].

For 10Gbit/s the situation was a little more complex, as the requirement on fibre bandwidth was 2000MHz.km and it was found that the RML launch was not adequate to guarantee this performance. The TIA preferred a direct measurement of Differential Mode Delay. The technique [7] consists of scanning a singlemode launch fibre across the input end of the fibre under test and measuring the relative time delay of pulses launched into the fibre as a function of radial position. The overall DMD of the fibre is then given as the time delay between the leading edge of the pulse with the least delay through the fibre and the trailing edge of the slowest pulse. In order to meet the bandwidth requirements for 10Gbit/s, a series of six alternative DMD templates were introduced [8]. As an example, the measured DMD must be less than 0.25ps/m in the radial range 5um to 10um and less than 5ps/m in the range from zero to 23um.

In tandem with the DMD template, which characterises the fibre itself, there is also the Encircled Flux template that the transmitter source must also satisfy. So, if both fibre and source meet their respective specifications then the fibre link should operate at 10Gbit/s over distances up to 300m [9].

In contrast to systems operating at 850nm, long wavelength systems generally use 1300nm singlemode lasers, although this situation may change as 1300nm VCSELs will soon become available. Coupling a singlemode fibre to a multimode system clearly only excites a few low-order modes and it might be expected that the DMD envelope would be much narrower. This is generally the case but it has been reported [10] that modal dispersion for a laser launch on the axis can be much worse than launching a full range of modes from a larger source. This is due to imperfections around the centre of the index profile of the fibre, such as ripples or a dip. It was found that by introducing a small lateral offset between the single mode and multimode fibres, the bandwidth could be maximised. This is due to the offset causing a range of mid-order modes to be launched [11] where the index profile is more uniform, thus avoiding the central dip.

This type of launch has been included in the IEEE802.3 standard for 1Gbit/s and 10Gbit/s systems, where the specified offset is 20um for 62.5um fibre and 13um for 50um fibre. The actual modal distribution resulting from this type of launch has hitherto not been specified in the literature due to lack of mode profiling test equipment at 1300nm.

Channel loss is the total optical loss between the transmitter and the receiver including the fibre and any connectors and splices. The short-wave 1Gbit/s standard, 1000BASE-SX, specifies a maximum channel loss of 3.56dB for 50um fibre and 2.60dB for 62.5um fibre. At 1300nm, 1000BASE-LX specifies 2.35dB for both fibre types. For 10GBASE-S the maximum channel insertion loss is 2.6dB.

The measured channel loss is known to be dependent on the launched mode distribution, particularly if slight offsets between connector interfaces are present, due to differential mode attenuation (DMA).

In order to ensure the required channel loss performance is met, it is important to verify this parameter prior to commissioning the system. The measurement of channel loss is normally carried out using an Optical Time Domain Reflectometer (OTDR), or a Light Source and Power Meter (LSPM). It has been found, however, that loss measurements made with OTDRs are usually more optimistic than those made with the LSPM method, due to the difference in mode distribution launched by the laser source in an OTDR compared to that launched by a typical LED source in the LSPM method. In fact, there would seem to be some merit in testing an installed system using a source that is modally similar to the actual transmitter source to be fitted to the system. There is, therefore, a clear need for standards to define the mode distribution for testing such that reproducible results may be obtained with differing types of test equipment. A link-testing standard published in 2006, ISO/IEC14763-3 [12], has now addressed this issue by specification of a mode distribution template to verify the conformance of test equipment.

A situation can be envisaged where a combination of mode-coupling and DMA causes power to be continuously transferred to higher-order modes and these modes being preferentially attenuated, leading to an *equilibrium mode distribution* (EMD). In fact, in Figure 1 there is a tendency of the launched mode distributions to move towards the mid-launch curve (green). This distribution is largely unaffected by propagation through the fibre and represents a approximation to the EMD of the fibre. Several efforts have been made in the literature to simulate an EMD launch, such as (a) restricting both the launch spotsize and the NA to 70% of the values of the test fibre, (b) employing a long fibre length situated between the source and the fibre under test, and (c) inducing a large amount of mode-coupling using controlled microbending in tandem or a mandrel-wrap mode filter.

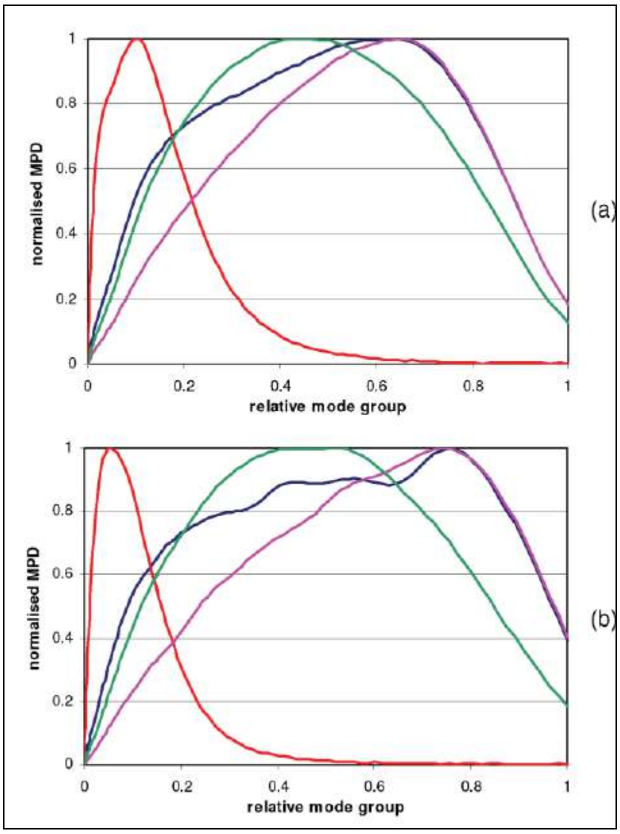

Fig 1: Plots of normalised MPD in a length of 62.5um tight-buffered fibre cable after (a) 202m, and (b) 1m

It is now useful to clarify the difference between the terms Equilibrium Mode Distribution and *Steady-State Distribution* (SSD), which are often used interchangeably. They have, however, very distinct definitions. An EMD has the property that irrespective of the launch distribution, the output is consistently the same and is a characteristic of the fibre, or device. In an SSD, the output distribution is the same as the input distribution. Thus, there may be many different SSD distributions for a particular fibre or device. For example, in the absence of mode coupling, an underfilled-mode distribution will remain largely unaffected by transmission through a long fibre and so could be regarded as an SSD. An EMD launch is clearly a special case of an SSD launch.

Furthermore, the EMD of a mode control device may have a different characteristic from the EMD of a fibre or device to which it is coupled, and loss measurements may display length-dependent transients. The advantage, however, of using a mode control device, with a given EMD, is that loss measurements will be completely independent of the type of test source used, enabling reproducible measurements to be obtained.

Another source of DMA may arise at connectors and splices. If a small amount of transverse offset is present between the two mating fibres, which could be due to a concentricity error in either the connector ferrule or in the fibre itself, then light travelling near to the core/cladding boundary will be preferentially attenuated. In particular, higher-order modes will be most affected. In order to demonstrate this, an experiment was carried out, consisting of measuring the insertion loss of 10 concatenated patchcords. Each patchcord was 3m long and of 50um graded-index fibre, and the connector types used were a combination of FC, SC and ST. The insertion loss was measured using a variety of light sources having different modal distributions. The loss results, shown in Figure 2, range from 0.5dB, for an axial singlemode launch, to 5.9dB for an offset singlemode launch, where only high order modes were excited. Some light sources were commercial test sets and other were empirical.

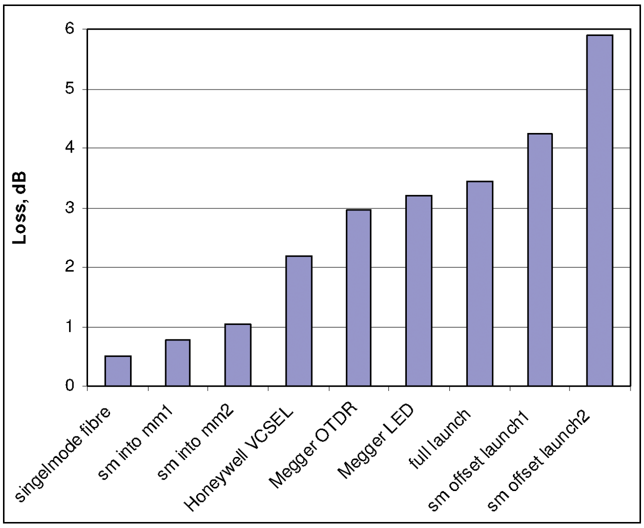

Fig 2: Insertion loss of 10 concatenated 50um patchcords for different launch conditions.

It is clear, therefore, from both bandwidth and channel loss requirements that a practical means of controlling the modal distribution would be advantageous to the industry. Such a device should be able to reproduce the same output mode distribution that was independent of the launched distribution so that measurements of channel loss would be the same regardless of what type of test source was used. The device would ideally also be adjustable during manufacture so that its output could be tuned to reflect particular requirements, or changes in the evolving standards.

Conclusion

To summarise, this paper has introduced the requirement for controlling the mode distribution in modern multimode fibre systems. Reproducible measurements, which are representative of the system operating parameters, can only be achieved by precise control of the mode distribution of test equipment. A description of Differential Mode Attenuation (DMA) and Differential Mode Dispersion (DMD) has been given and the results of an experiment, to demonstrate the effect of DMA on connector losses, have been presented. A patent survey on mode control techniques and commercial devices has been carried out.

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