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Evolution to broadband via optical ISDN

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A comprehensive broadband information network has been the goal of many Telecom operators worldwide. It is likely that such target networks will be single mode and will use time- and wavelength-division multiplexing and eventually coherent technologies to carry all services (including high-definition television).

At issue is whether fibring of the local-access network can proceed by direct installation of such comprehensive target systems in the 1990s, or whether fibre solutions could first become cost-effective for current narrowband services and then gracefully evolve to broadband services.

Regarding the technologies, there is more familiarity with star networks involving one or two fibres to each customer. In this paper, recent developments in the use of passive distributed networks are described, and optoelectronic issues affecting the adoption of star and distributed technologies are considered against the means of achieving future broadband infrastructures.

During the late 1970s and early 1980s optical communications research was focused on long-distance transmission. This research was highly successful by any standards, and by 1988 optical technologies have significantly penetrated intercity transmission routes in a number of countries. In the U.K. long-distance (trunk) network 200000 km of fibre have been installed by British Telecom making the intercity transmission routes in the U.K. predominantly optical. Mercury was able to benefit extensively from BT's investment in the U.K.'s optical capabilities and deployed optics from the start. On the same timescale optical transmission was being extensively deployed by BT in the interexchange (junction) feeder routes. Although early installations employed multimode fibre as the transmission medium, monomode technologies pioneered in the U.K. have emerged as the preferred medium in the U.K., the U.S.A. and elsewhere.

Why did this happen? The availability of monomode was important because to a large extent it allowed the long-distance network to be future-proofed. That is, it met current transmission needs, but it allowed evolution of the network to meet future growth in traffic without a change in technology. However, the main reason monomode optical technology penetrated long-distance routes was that it offered lower circuit costs than copper coax (coaxial cable) or multimode fibre technologies.

In parallel with these developments, British Telecom was pioneering the use of optical technologies to deliver a broadband service, entertainment cable television (CATV), in its Westminster franchise. Cost-in of new and initially expensive technologies such as monomode optics is eased in the long-distance sector because of the high levels of multiplexing, of individual customers signals, over single spans of 30–60 km of monomode fibre without expensive repeaters. In the local access network or in a CATV franchise, where transmission paths are short and connect directly to individual customers, the costs of new technologies can be prohibitive to implement. This was the case in Westminster where a switched or multistar analogue distribution system was developed around 1980 (figure 1) (Ritchie & Seacomb 1987). This system deployed multimode fibre down to a wideband switch point, then a copper coax drop to each customer; the copper would be replaced by fibre in later implementations as fibre and optoelectronic costs fell. Similar system topologies were later deployed in the U.S. local loop for telephony traffic. Here monomode feeders led out from the central office (main exchange) to remote demultiplexers/concentrators with copper drops to customers. The ultimate all-digital all-monomode broadband multistar system of this type, using point-to-point optics with remote switching, is being studied in this laboratory and a number of others around the world (Linnell, this Symposium; Purkey *et al.* 1988) to establish the functionality/cost trade-offs.

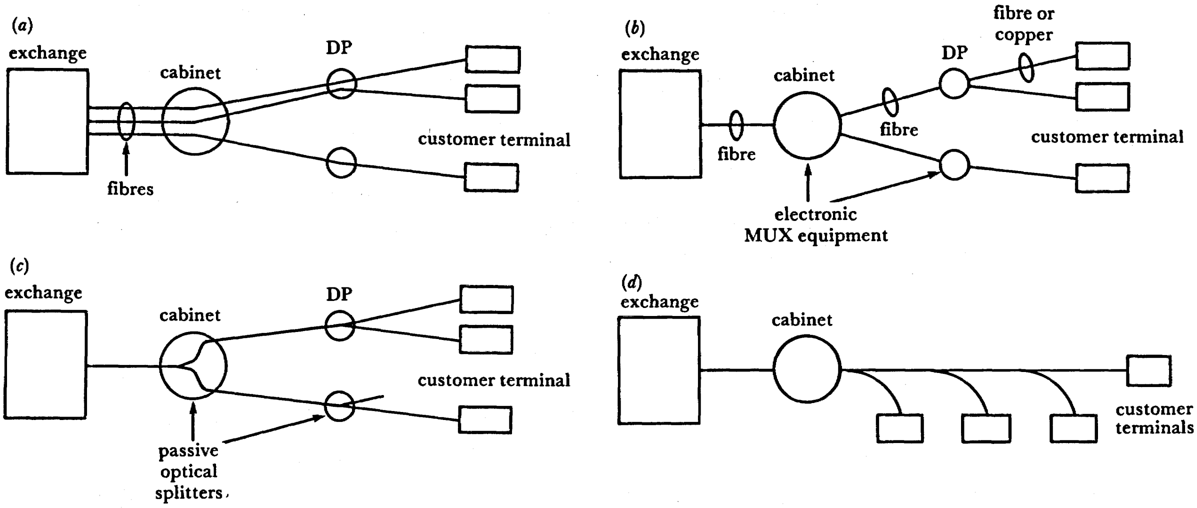

FIGURE 1. Optical local network options. (*a*) Single star; (*b*) multistar with active nodes; (*c*) multistar with passive nodes; (*d*) star-bus.

Meanwhile another approach based on passive node multistar networks emerged from this research laboratory between 1983 and 1985 (figure 1) (Payne & Stern 1986). Here direct monomode optical circuits from the exchange to the customer were configured by using passive optical splitters at the nodes, thereby avoiding the need for remote electronic multiplexers. These circuits were effectively 'transparent' over local network distances, i.e. they offered any bit rate up to many gigabits per second, and/or multichannel wavelength division multiplexing (WDM). Such fibre-all-the-way passive networks took advantage of the low loss and large bandwidth of monomode to, in principle, deliver broadband services to any customer. A rich variety of network functions was perceived, with loss-budget limitations being overcome in the future by use of optical amplifiers (O'Mahoney, this Symposium) and/or by coherent techniques (Baack, this Symposium). Perhaps the ultimate broadband passive network would involve a wavelength per customer implying a logical single star; that would require considerable development of optoelectronic component technology.

By early 1986 a view developed that fibre-all-the-way multistar solutions, with either passive or active nodes, might not cost-in for many years in the case of single-line domestic customers unless there was convergence of all services onto one bearer. The existence of a variety of competition/regulatory environments around the world governing just who can offer what mix of services direct to the customer does not make that convergence straightforward. Assuming those issues were resolved, the investment risk for widespread implementation of fully fibred systems to the home still remains high, given the current unpredictability of broadband take up, e.g. in the U.K. In the U.S.A. and some other countries historic penetration of CATV markets by using copper coax technologies may mean that extensive fibring to domestic customers will require the need for higher-performance broadband services (e.g. high-definition televison (HDTV)) to be established. In the U.K. the relative role of satellite-based and cable-based entertainment services remains uncharted. It is therefore not surprising that commercial fibring of domestic customers has not yet begun.

In some countries there are arguments for government initiatives to lay down a national fibre grid because of the larger benefits of advanced communications. If on the other hand progress with fibring is to follow normal commercial criteria, a useful approach is to segment the total customer base and determine the differential cost-in criteria for fibre. Given the difficulties of projecting lasting market demand for new services, can fibre be costed-in all the way for current narrow-band services in any market segment, and if so, will the adopted architecture allow flexibility in meeting changing customer demand and allow graceful evolution to future broadband services? British Telecom perceived a few years ago that the single-star architecture would meet those criteria for large-business customers, and since 1987 has been deploying flexible access systems to business customers with 25 lines and above in London (Dufour 1988). It is anticipated that by the end of 1989 50000 km of fibre will have been installed (one building currently has 15000 single-mode terminations), and over the next six years several million lines involving fibre-all-the-way will be rolled out to customers in this business sector. However, the economics of single-star fibre systems of this type start to become questionable for customers with less than 20 lines.

British Telecom now believes it has identified a potentially economic method (based on multistar with passive nodes (figure 1)), of serving the known service needs of the smaller-business customer segment with an all-fibre access network (Oakley *et al.* 1988). The same network would then provide the infrastructure for a wide range of future services from telemetry to CATV and then to fully integrated broadband integrated service digital network (BISDN). Telephony on a passive optical network (TPON) uses time-division multiple-access techniques to distribute basic telephony initially on one wavelength, while other wavelengths are reserved to support future services including broadband (Stern *et al.* 1988). The current system design for basic telephony involves a single laser transmitter and a receiver in the exchange serving up to 128 customers via a cascade of passive splitters and a transmission rate of only 20 Mb s^{-1}; this bit rate allows provision of a 144 kb s^{-1} ISDN line to each customer in an allocated time slot. In the upstream direction each customers transmitter operates in a low-duty cycle mode; synchronization to the exchange clock and a ranging protocol ensure that bursts of data arrive at the exchange receiver in the correct time sequence. The TPON approach maximizes the degree of fibre and optoelectronic sharing, and avoids the need in a U.K. type topology for remote electronics between exchange and customer; this reduces the up-front investment, and in the case of a 4-telephone-line customer 75% of the total per customer cost would only be incurred when that customer wanted service, given the TPON framework had been installed. A disadvantage of the approach is its apparent complexity. However, much of that complexity is contained in the bit transport controlling electronics which can be realized in one very large-scale integration (VLSI) chip. Security is often raised as a criticism of the distributed approach; however the security in TPON is potentially better than in current copper networks (Oakley *et al.* 1988).

To reserve spectrum space for new services, or to move from TPON to broadband (BPON), the basic telephony channel needs to operate in a defined wavelength slot by provision from the start of an identical wavelength filter in each customer's receiver and a wavelength defined laser in the exchange. There are numerous evolutionary strategies through TDM (Faulkner *et al.* 1988), WDM (Payne, this Symposium), FDM (Olshansky, this Symposium) or asynchronous transfer mode (ATD), which are the subject of on going research. The preferred uprate approaches will favour those where minimum additions need to be made to the basic TPON framework, allowing new services to be marketed without massive up-front investment. Where switched broadband services are required multistar systems with active nodes may be preferred, or head-end switched BPON approaches can be explored. However, discussion of broadband services brings back the question of how to cost-in fibre to the home. This is the largest segment and the most difficult one for fibre to begin to penetrate economically in the next few years; it is likely to need to be preceded by penetration of fibre into the small business sector and the consequent volume effects on fibre and optoelectronic price decline. The proponents of both active and passive star approaches both believe the problem will be cracked, the billion dollar question is when.

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