Mode Group Diversity Multiplexing for Multi-service In-house Networks using Multi-mode Polymer Optical Fibre

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By selectively launching and detecting separate mode groups in a highly multimode (polymer) optical fibre, its transport capacity can be increased and a number of broadband services can be carried independently in a single network infrastructure. The statistically varying mode-mixing incurred during transport is counteracted by adaptive electrical signal processing at the network terminals. Using cheap electrical signal processors and arrayed VCSELs and photodetectors, this so-called mode group diversity multiplexing method can offer the same functionality as wavelength multiplexing at lower costs, and provides a new extra dimension for optical multiplexing. First experiments suggest the technical feasibility of the concept.

Introduction

Optical fibre is gradually penetrating towards the end user, driven by his need for more capacity that is fueled by a.o. fast internet applications and interactive video services. When optical fibre approaches the user's residence, and even enters his home, the costs of installing and maintaining the fibre network become ever more important. In comparison with single-mode optical fibre, Polymer Optical Fibre (POF) is much easier to handle and to install due to its large core and its ductility. However, its losses are still higher, but are diminishing thanks to continuous improvements being made in the fibre materials. The POF's bandwidth is considerably less due to the modal dispersion resulting from its multimode waveguiding. For in-building networks with a reach of less than a kilometre, Gigabit Ethernet data transport at 1.25 Gbit/s using current Graded-Index POF has been realised [1]. Wavelength Division Multiplexing (WDM) can further extend the network capacity and enables integration of different services in a single network, by creating independent signal-format transparent communication channels in a single fibre. However, WDM requires wavelength-specific sources (or wavelength slicing techniques), plus wavelength-selective network functions, which are still quite costly. In this paper, an alternative technique named Mode Group Diversity Multiplexing (MGDM) is proposed to create a number of independent communication channels in a single multimode fibre, which avoids the use of wavelength-specific components but relies on electrical signal processing to unravel the individual channels.

Mode Group Diversity Multiplexing system concept

Looking from an information theory angle, multimode fibre can have a larger transport capacity than single-mode fibre, as it guides many modes. However, usually all these modes are excited simultaneously, and dispersion among the modes smears out the data pulses and thus reduces the transport capacity. By selectively launching a subset of the whole collection of modes, the dispersion is reduced and a substantially larger capacity may be achieved. An up to fourfold bandwidth increase has been reported by exciting less than 50% of the fibre modes [2]. Moreover, one may launch various subsets of modes separately, and feed independent data streams into them. When these mode groups can be individually detected at the receiving end, each subset may constitute an independent communication channel. However, mode mixing in the fibre causes crosstalk between the mode groups. As shown in Fig. 1, N mode groups may be launched by N lasers at the transmitting end, and at the receiving end M (with $M \geq N$) photodetectors each detect a different part of the intensity pattern generated by the mode groups. The output signal of each detector is made up of a certain mixture of the mode groups, caused by the mode mixing in the fibre. Electrical signal processing can be used to unravel the mixture, yielding the separate data streams again.

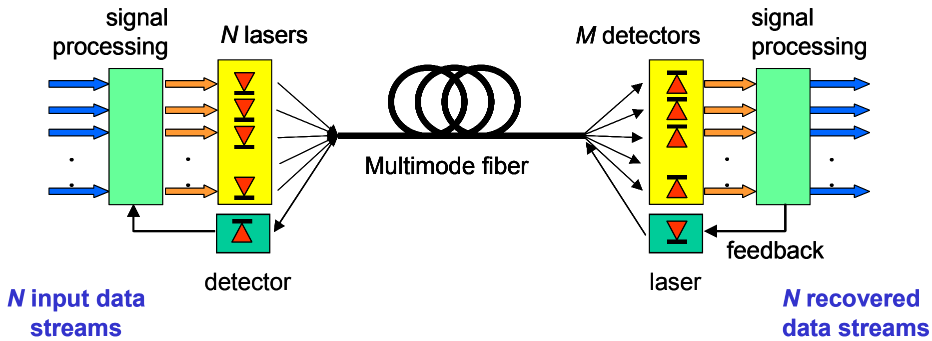

Fig. 1 Mode Group Diversity Multiplexing

Mathematically speaking, the transfer of the N laser transmitter inputs to the M detector outputs is described by an NxM transfer matrix, of which the matrix elements $c(n,m)$ indicate the coupling of transmitter n to detector m. Fig. 2 illustrates the mathematical model for N=M=2. The complex matrix elements $c(n,m)$ have an amplitude representing the path attenuation, and a phase representing the phase delay of the path (n,m). Random fluctuations in the mode mixing process will yield fluctuations in the complex elements $c(n,m)$. When the optical sources at the transmitter site have a coherence time larger than the differential delay times between the modes, a speckle pattern due to interference between the modes will occur across the area sampled by the detectors. The coherence time of the sources may be deliberately reduced by means of e.g. high-frequency modulation in order to reduce the contrast of these speckle patterns.
The signal processing at the receiver actually uses the inverted transmission matrix to unravel the data streams. Therefore, as a first step the transmission matrix elements must be retrieved from the system, and stored in the signal processor at the receiver. At the transmitter site, a signal processing circuit initialises the system by sending some training data sequences, which are known a priori by the receiver, and are used to determine the transmission matrix elements. Subsequently, the signal processing circuit at the transmitter encodes the data to be sent, and the redundancy added can be deployed by the receiver to detect errors. These errors may have risen due to changes in the transmission matrix elements as a result of the fluctuating mode mixing process in the fibre. The error monitoring information can be used to update the matrix elements stored in the signal processor at the receiver. If too many errors are occurring, the receiver site may ask via a feedback channel to the transmitter to send again a training data sequence for a new system initialisation.

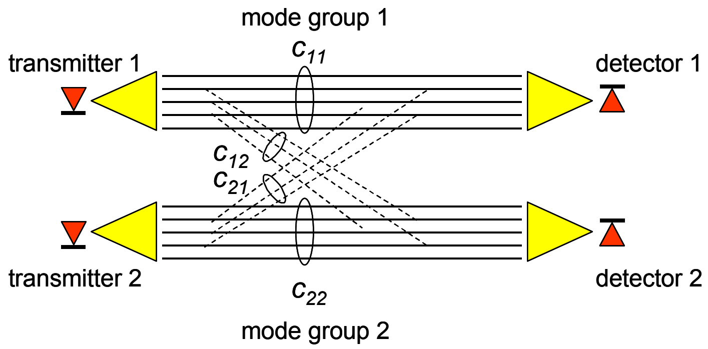

Fig. 2 Modelling the optical system transfer function (for *N*=*M*=2)

Some early experiments have shown the technical feasibility of the concept for *N*=*M*=2 with a data rate of 1 Mbit/s per channel, using a computer for off-line signal processing [3]. With appropriate high-speed processing circuitry, the technique should be scalable up to Gbit/s on-line signal processing speed.

Measurements on POF have indicated how the launching conditions at the input facet influence the near-field intensity pattern at the output facet. Different mode groups thus may provide different communication channels, as exemplified in Fig. 3 [4].

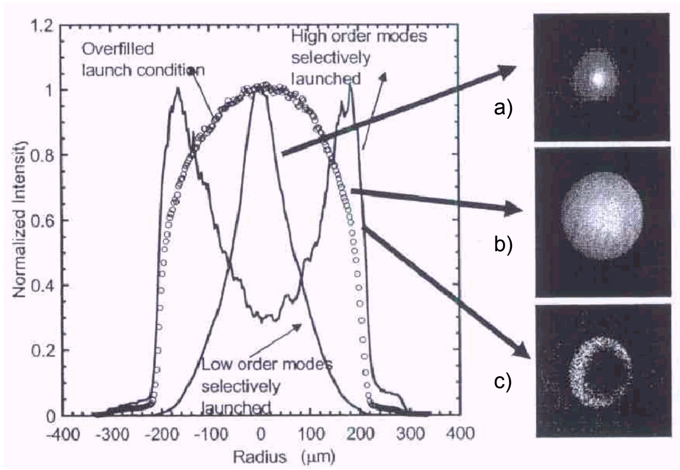

Fig. 3 Near-Field Patterns at output of multimode POF, depending on launching conditions [4]

a) Exciting low order modes only; NFP clearly focused in core centre

b) Exciting all modes, resulting in NFP spread out over whole fibre core

c) Exciting high order modes only; NFP concentrated in ring shape close to core-cladding boundary

Multipath wireless systems such as MIMO (Multiple Input Multiple Output) wireless LANs use space-time codes and specific signal processing techniques; cf. Lucent's BLAST project. There are some similarities with the MGDM transmission concept using several mode groups in multimode fibre as proposed here, and therefore derivatives of these techniques may be applicable.

Basically, as illustrated in Fig. 4, MGDM may enable integration of different types of broadband services in a single in-house fibre infrastructure. For instance, broadband wireline services such as Gigabit Ethernet may be supported by the same infrastructure as wireless services such as wireless LAN.

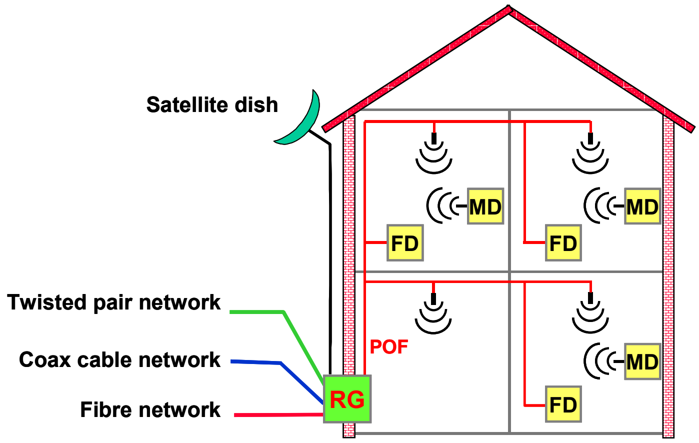

Fig. 4 Transparent In-House Network with Polymer Optical Fibre, integrating wireline and wireless services in a single infrastructure
(MD = Mobile Device; FD = Fixed Device; RG = Residential Gateway)

System realisation

In order to yield a low-cost system realisation, it is essential to integrate the optical and the electrical functions. Launching the different mode groups may be achieved by an integrated array of vertical cavity surface emitting laser diodes; this VCSEL array may be coupled easily to the POF by a simple lens system, or even by butt-joining it to the large fibre core. At the receiving end, an array of integrated photodetectors can do the spatially resolved detection. The electrical signal processing can be implemented first in Field Programmable Gate Arrays (FPGAs) offering design flexibility, and subsequently in less flexible but more cost-effective Application Specific Integrated Circuits (ASICs).

Conclusions

By using separate mode groups in a multimode (polymer) optical fibre, independent communication channels can be established in a single fibre infrastructure. Thus multiple services can be integrated in one versatile in-house infrastructure, offering the same functionality as wavelength multiplexing but at lower costs provided the electrical signal processing and the arrayed optical sources and detectors can be realised cheaply.

Acknowledgement

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