COMBINED MODULATION FORMATS FOR IP OVER WDM NETWORKS SUPPORTED BY GMPLS[1]

Sulur(1), Ton Koonen(2), Idelfonso Tafur Monroy(3), Huug de Waardt(4)
(1) COBRA Research Institute, Eindhoven University of Technology, The Netherlands, E-mail: sulur@tue.nl
(2) As (1) above, but E-mail: A.M.J.Koonen@tue.nl
(3) As (1) above, but E-mail: I.Tafur@tue.nl
(4) As (1) above, but E-mail: h.d.waardt@tue.nl

ABSTRACT

GMPLS (generalized multiprotocol label switching) for supporting IP over WDM networks provides quick and efficient forwarding of IP packets because it uses label swapping as a single forwarding algorithm, thus yielding low latency and enabling scaling to terabit rates. Combined ASK/FSK or ASK/DPSK modulation format for payload/label is proposed for labeling IP over WDM networks supported by GMPLS. In this approach, the optical label swapping preserves the optical transparency of the payload that is required for all-optical packet switching networks. Simulation results show that a combined ASK/FSK modulation format is easier to implement and it tolerates a much larger laser linewidth than the combined ASK/DPSK modulation format, but also requires more careful fiber dispersion compensation in order to reduce the impact of the phase-to-intensity conversion.

1. INTRODUCTION

Internet traffic is growing fast and the Internet protocol (IP) framework is becoming the dominant form of data transport. IP networks need to provide high speed (Terabit/s), large capacity, good performance and fast packet forwarding rates (implying low latency). Up to 50% of IP traffic consists of packets smaller than 522 bytes and 50% of these packets are in the 40-44 bytes range. Therefore, new low latency packet forwarding and routing technologies are required [1].

Optical switches/optical cross connects and WDM (wavelength division multiplexing) devices that enable to deploy the huge bandwidth offered by the optical fiber are commercially available. Therefore, in order to simplify the network layers, transporting IP packets directly over WDM network by skipping the ATM and or the SONET/SDH layer is preferred.

GMPLS extends MPLS to include lambda switching next to label switching and fiber (space) switching [2]. GMPLS provides quick and efficient forwarding of IP packets because it uses only a single forwarding algorithm, based on label swapping. Therefore, IP/GMPLS is a low latency, low overhead routing technique that simplifies packet forwarding and enables scaling to terabit rates.

We propose an orthogonal labeling of IP packet (e.g. an orthogonal modulation of the label information with respect to the modulation format of the IP payload). Label information is either modulated in FSK (frequency shift keying) or DPSK (differential phase shift keying) format, while IP payload is in ASK (amplitude shift keying) format [3]. The IP payload is transmitted at a data rate of 10 Gb/s while the label is transmitted at a data rate of 622 Mb/s. The label data rate is limited by electronic processing as we propose an opto-electronic technique for label processing. However, this data rate composition is able to handle 100% of IP traffic if the maximum label size is 20 bits, because 20 bits of label occupies the same duration as a 40 bytes of IP payload.

2. IP OVER WDM NETWORKS SUPPORTED BY GMPLS

IP packets from access network are managed in an ingress router. Aggregation, buffering, and FEC (forwarding equivalence class) creation are some processes performed in the ingress router. FEC is a group of IP packets that are forwarded over the same path and treated in the same manner. After these processes, a fast tunable laser followed by an external chirp-free amplitude modulator is used to carry IP packets at data rate of 10 Gb/s. A label written in FSK format by direct modulation of a fast tunable laser or in DPSK format by using external phase modulation is imposed on the IP packet or FEC. Then, the labeled IP packet or FEC are directly transported into a given wavelength and optical fiber port. The label is a short, fixed length value that is contained in each IP packet or FEC and used to forward the packet through the core network.

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The label binding is informed to the next hop or LSR (label switching router) by either label distribution protocol (LDP) or piggyback on top of routing protocol.

The LSRs perform routing and forwarding operations within the core optical network by label swapping, wavelength conversion, and optical fiber port changing based on its forwarding table (see Fig. 2). The forwarding table consists of a sequence of entries, where each entry consists of an incoming label, and one or more subentries where each subentry consists of an outgoing label, an outgoing interface (wavelength/WDM channel and fiber port), and the next hop address. The LSR extracts the label from the packet and uses it as an index in its forwarding table. Once the entry indexed by the label is found (this entry has its incoming label component equal to the label extracted from the packet), for each subentry of the entry found the router replaces the label in the packet with outgoing label from subentry and sends the packet over outgoing interface specified by the subentry and to the next hop specified by the subentry.

To perform label swapping, a portion of incoming signal is tapped for label processing (opto-electronic technique). During label processing, the IP payload is kept in the optical domain (using fiber delay line). We propose an all-optical label swapper with wavelength converter (AOLSWC) based on semiconductor optical amplifiers (SOAs) integrated in a Mach-Zehnder interferometer (MZI) as shown in Fig. 3. Replacing label is easy because the FSK or DPSK information contained in the IP payload is lost during propagating in MZI equipped with SOAs, and simultaneously the payload intensity modulation is transferred from the incoming signal to the outgoing wavelength set by the tunable laser. Then a new label is imposed orthogonally to the IP payload by direct modulation of fast tunable laser for FSK format or by using external phase modulation for DPSK format. Therefore, the optical label swapping preserves the optical transparency of the payload that is required for all-optical packet switching networks.

As IP packets leave the core optical network, an egress router removes the labels and performs a final wavelength conversion to an output fiber port, then delivers the IP packets to the access or metro network.

3. COMBINED ASK/FSK AND ASK/DPSK MODULATION FORMATS

We simulated the combined ASK/FSK and ASK/DPSK modulation format by using VPI software. First, we compare both the combined modulation formats based on the laser linewidth and transmission distance. We used a direct detection system both for ASK and FSK or DPSK balanced receivers. The payload and label data are written by using a pseudo random bit sequence (PRBS) with different periodic length, namely, 2^{23}–1 and 2^{7}–1 [4]. Secondly, we compare both the combined modulation formats based on the label swapping (erasure and reinsertion) and wavelength conversion performance.

3.1. Analysis of Transmission Performance

For a combined modulation format, the value of the modulation depth of the ASK data is crucial. The modulation depth should not be too large in order that for ASK '0' bit transmitted, there should be enough optical power for the FSK or DPSK signal to be correctly detected. On the hand, it should be sufficiently large in order to allow adequate ASK payload detection. Therefore, the modulation depth of the ASK data should be adjusted in such a way that an optimum value of receiver sensitivity for both ASK and FSK or DPSK receivers is obtained. Sensitivity for ASK and FSK or DPSK receivers is defined as the average received signal power that is required to achieve a bit error rate (BER) of 10^{-9} and a BER of 10^{-12} (as label detection should be extremely reliable), respectively.

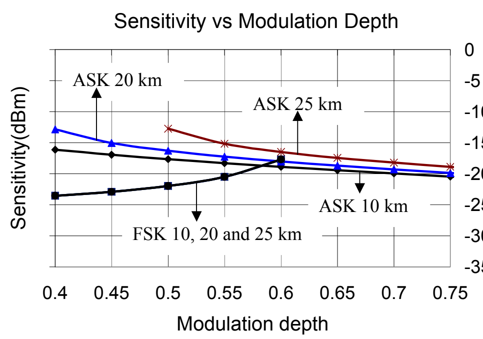

Figure 1. Sensitivity as a function of modulation depth at FSK frequency deviation of 10 GHz and linewidth of 50 MHz for several length of SMF.

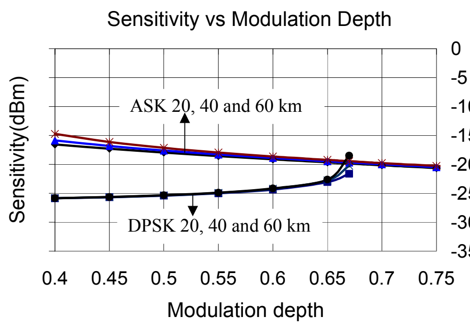

Figure 2. Sensitivity as a function of modulation depth at linewidth of 10 MHz for several length of SMF.

The transmission distances that can be achieved at wavelength of 1553.6 nm by both combined modulation formats are shown in Fig. 1 and Fig 2. The combined ASK/FSK modulation format can achieve only up to 25 km of SMF (single mode fiber) at laser linewidth of 50 MHz and FSK frequency deviation of 10 GHz, while combined ASK/DPSK can achieve 60 km SMF at laser linewidth of 10 MHz without any degradation performance. The reason is that fiber dispersion has large impact on phase to intensity conversion for combined ASK/FSK.

Fig. 3 and Fig. 4 show the influence of laser linewidth on receiver sensitivities for both combined modulation formats. We employed 60 km SMF plus 9.6 km DCF (dispersion compensating fiber) for complete dispersion compensation at wavelength 1553.6 nm. Combined ASK/FSK modulation format does not need a stringent requirement on the value of the laser linewidth, while combined ASK/DPSK is sensitive on that parameter. For example, the ASK/FSK system is able to show a good performance even with a value of 250 MHz for the laser linewidth, while the ASK/DPSK system is only able to operate for values of the laser linewidth less than 19 MHz.

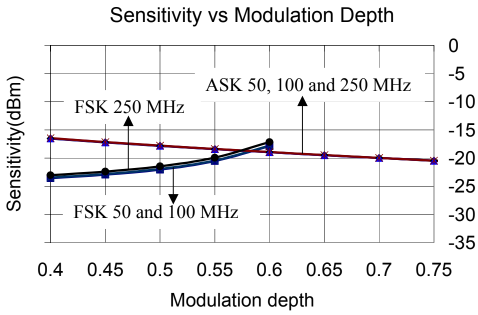

Figure 3. Sensitivity as a function of modulation depth at FSK frequency deviation of 20 GHz and for several values of laser linewidth.

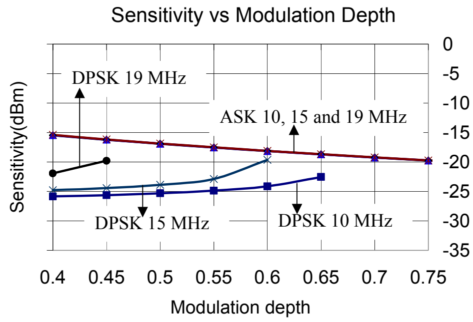

Figure 4. Sensitivity as a function of modulation depth for several values of laser linewidth.

The ASK/DPSK modulation format provides a rather large range of operating ASK modulation depth values, up to 0.65 depending on the laser linewidth, while the ASK/FSK system offers only up to 0.6.

Direct demodulation of FSK encoded data is simpler than direct demodulation of optical encoded DPSK. FSK can be directly detected by using a band pass optical filter for FSK to ASK conversion, while DPSK demodulation requires the use of a stabilized Mach-Zehnder interferometer configuration.

3.2 Analysis of Performance of AOLSWC

We analyzed an AOLSWC for both combined modulation formats after transmission of 60 km SMF and 9.6 km DCF. We found that the ASK modulation depth for AOLSWC should be set 15% lower than the optimum one which is obtained from simulation of the laser linewidth and transmission properties (0.45 for combined ASK/FSK modulation format and 0.5 for combined ASK/FSK modulation format, see Fig. 3 and Fig. 4) in order to avoid a large chirp. This yields an ASK receiver sensitivity of –16 dBm for the combined ASK/FSK modulation format (2 dB power penalty) and an ASK receiver sensitivity of –18 dBm for the combined ASK/DPSK modulation format (2 dB power penalty).

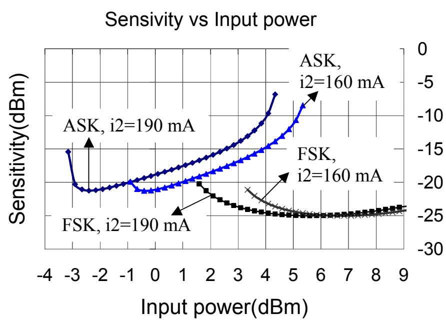

Figure 5. Sensitivity as a function of input power for both ASK and FSK receivers. Injection current to SOA 1 and CW probe power is 300 mA and 0 dBm, respectively. Injection current to SOA 2 (i2) is varied.

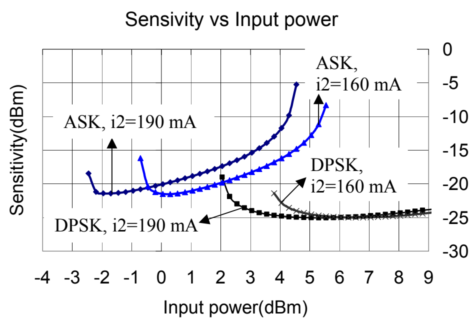

Figure 6. Sensitivity as a function of input power for both ASK and DPSK receivers. Injection current to SOA 1 and CW probe power is 300 mA and 0 dBm, respectively. Injection current to SOA 2 (i2) is varied.

Fig. 5 and Fig. 6 show the requirement of input power level in order to ensure an AOLSWC works properly for both combined modulation format. The parameters of SOA are similar to those in [5], except the active region volume (we used 1000x1.2x0.2 μm^3). A wavelength conversion from 1553.6 nm to 1549.6 nm has been performed.

Fig. 5 and Fig. 6 indicate that label swapping and wavelength conversion for both combined ASK/FSK and ASK/DPSK modulation formats can be performed. However, the input power level should be set carefully to the operating point of label swapper and wavelength converter. We found that the input dynamic range of AOLSWC is limited to around 2.5 dB for both the combined modulation formats.

The ASK/FSK modulation format does not require the use of an external modulator because direct modulation of a tunable laser can be used to obtain FSK modulation. In an ASK/DPSK system, an external phase modulator is still required.

4. CONCLUSIONS

The combined ASK/FSK or ASK/DPSK modulation format can be applied for labeling IP over WDM networks supported by GMPLS with payload transparency and low latency of IP packets forwarding.

In comparison with the combined ASK/DPSK modulation format, the combined ASK/FSK modulation format is easier to implement and it tolerates a much larger laser linewidth, but also requires a more careful fiber dispersion compensation in order to reduce the impact of noise due to the phase to intensity conversion.

Label swapping and wavelength conversion for both combined ASK/FSK and ASK/DPSK modulation formats can be performed. However, the input power should be set carefully to the operating point of label swapper and wavelength converter.

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