Ultrafast all-optical signal processing how and why?

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Summary

Demand for fast and secure high capacity networks is growing. Currently offered solutions are hampered by the reappearance of electronic bottleneck. It is believed that to fully utilize transmission bandwidth of optical networks ultrafast all-optical signal processing may need to by implemented. Such approaches will be discussed.

Introduction

Growing demand for the fastest possible networking is being fuelled by a rapid penetration of multimedia applications into our daily lives. This triggered unparallel demands for communication networks which could offer high-speed low-cost approach to networking. With the increasing evidence it is becoming clear that sooner than later we will not be able to fully fulfil those demands even if state-of-the-art electronics known to us today is deployed. We urgently need alternative solutions.

Discussion

Today, we already benefit from advancements which revolutionized data communications through introduction of optics into the network transport layer. Here optical fibre offers enormous point-to-point transport capacity which until recently has been able to fully accommodate rapidly growing volumes of voice and data traffic.

Soon after the introduction of optical fibre technology it did not take too long to realize that the bandwidth of available electronics would not be sufficient to fully support serial data rates which could be carried by the fibre. A solution to this problem was found by introducing data parallelism via the approach called "Wavelength Division Multiplexing (DWDM)." Commercially deployed WDMA networks today can multiplexed many wavelength data channels, each carrying multi Gbit/s of serial optical data onto a single optical fibre thus achieving aggregate throughputs exceeding several Terabits per second (Tbit/s). However the demand for more transmission capacity over a single optical fibre is still growing. With this phenomenon a new bottleneck has emerged at fibre endpoints where data routing and switching takes place to redirect the carried traffic to its final destinations.

Currently, the majority of routers rely upon electronic data processing by electronic crossbar switches to read, process, and route all incoming optical data. These electronic crossbars, however, do not provide sufficient capacity to interconnect multiple fibres carrying terabits of data due to their limited processing speed and scalability since they rely upon bandwidth limited electronics made of materials such as silicon, gallium arsenide, or indium phosphide. Their ultimate maximum switching speed is limited by a frequency response of used semiconductor. It also seems that the metal oxide semiconductor technologies, which are used in the majority of high spec digital devices like microprocessors, are not likely to scale beyond tens of GHz [1]. Even the highest performance electronics based upon III-V materials like indium phosphide has only reached a few hundred GHz in the laboratory conditions [2].

Today we have several well established approaches for data and signal processing. One example is the use of microprocessors based on digital electronic logic gates. This approach is very cost efficient and relies on replicating only few “types” of -in concept quite simple- building blocks called *logic gates* which are combined into extremely powerful microprocessor. However the major drawback for manufacturers is the fact that semiconductor materials/substrates which can be used today are “running” out of the bandwidth and can not longer offer desired speeds. This so called *electronic bottleneck* is preventing manufacturers from producing faster and faster microprocessors. Therefore to get around this problem and to keep up with growing demands for more processing power, the chip makers have moved away from the concept of building faster chips to a concept of parallelism. This resulted in a production of ‘multi-core’ processors.

Given all the above, it seems unlikely that electronics alone will soon (if ever?) deliver the needed bandwidth to support the available capacity offered by optical fibres. Because of this reason we need to keep looking for alternative solutions. To address this issue a great attention is being paid to a development of viable approaches which could help us to surpass the “underperforming” electronics. There is a strong believe supported by a strong experimental evidence that solutions via all-optical signal processing could deliver needed results.

From a historic perspective we should note the attempt to use the optics for computing purposes. This field was named ‘*optical computing*’. However the definition of optical computing is at best a very vague term even today. A significant amount of research in that area took place in the mid 1980’s and was primarily focussed on trying to develop an optical equivalent of an electronic computer by utilising then known optical technologies. Despite injections of substantial funding little or no progress was made in that direction. Since then optical technologies have significantly matured. Many important advances were made in the area of optical switching thanks to large investments into optical communications (telecom) in 1990’s and early 2000. More importantly these advances made under the above activities spawned a branch of technology that is more readily defined as *‘optical signal processing’*. In parallel to activities in the telecom the research community has been also working on solutions how to bypass the lack of ultra high-speed electronics by using ultrafast all-optical signal processing. If ultra high-speed signal processing can be successfully implemented using optical domain these niche applications of optics will bring great benefits to many fields not only to telecom.

Conclusions

The most relevant area for applications of ultrafast all-optical signal processing which also immediately represents market opportunities is undisputedly telecom, especially its optical layer. These relatively niche applications will be highlighted. We will also discuss relevant and promising all-optical approaches which if cheaply implemented may result in manufacturable *fast all-optical devices.* We will also discuss the applicability of such devices in the future market space.

References

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