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Optical Computing Alternative for High Speed Interconnectivity and Storage

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ABSTRACT

Optical computing is the science of making computing work better using optics and related technologies. Optical computing is dead only if we foolishly define it as the attempt to supplant electronics. Optical computing generally means that the optical manipulation of discrete manipulating data. The hope for optics lies in doing things that are provably impossible for electronics. This paper consists of different types of optical computing environments (mainly digital, analog and quantum), how the network has been transported in optics (since 1990, SDH and SONET specifications have been extended based on demand for the transport of new tributary signals and also based on new capabilities provided by the evolution in component technology), architecture of optical computing, role of non-linear materials in optical computing. How optical computing has been used in today's computing world and what is the future scope of optical computing, what are the devices used for optical computing.

Keywords: *SDH, SONET, FEC, OTN*

INTRODUCTION

Optical computing is the science of making computing work better using optics and related technologies. Optical computing is dead only if we foolishly define it as the attempt to supplant electronics. The hope for optics lies in doing things that are provably impossible for electronics. Optics has the ability to solve hectic problems in computing hardware. With the growth of computing technology the need of high performance computers (HPC) has significantly increased. Optical computing is approximately 60 years old and it is a well-defined domain with its own specialized conferences, sections in the scientific journals and its own research programs and funding. The increase demand for high-performance information processing and scientific computations indicate the need for massive parallel computing systems. Numerous information processing systems and concepts in space and time have been studied during the past decades. Yet, optical computing and processing in space and time has so far failed to move out of the lab. The free-space and guided-wave devices are costly, bulky, and fragile in their alignment. The construction of optical subsystems directly on-chip, with the same lithographic tools as the surrounding electronics has been made possible by the advances in these tools, which can now create features significantly smaller than the optical wavelength; experts predict lithographic resolution as fine as 16nm by year 2020 [1].

Optical computation is the most feasible technology that can replace electronics, and promises impressive speeds that can enhance processing power and data rate transmission. Major advantage of optics lies in its interconnection technology which is reflected in the overall performances of the computing and processing machines [2, 3].

Some optical practitioners have viewed as a competition between optics and electronics. This has been a tragic waste of time, money, and talent. The competition is essentially imaginary—an artifact of the all-optical computer syndrome. Both optics and electronics have roles, but they are not the same. Whenever an optoelectronic computer competes directly with an electronic computer, it loses. Electronics is far more mature, far cheaper, far better funded. The significant changes happened in optical computing over the past six decades is as shown the following figure1.

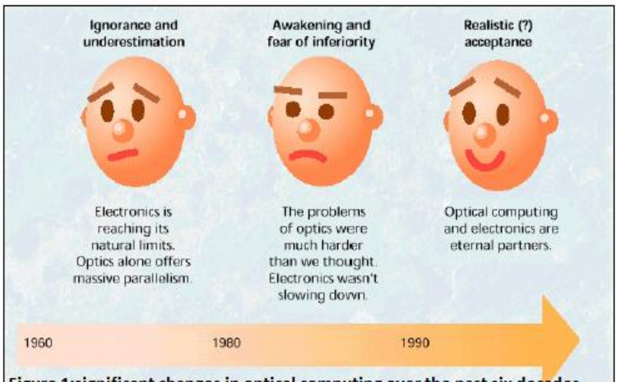

Figure 1:significant changes in optical computing over the past six decades

In this paper we describes digital, analog and quantum optical computing, optical transport network (OTN) and other optical networks, devices used for optical computing, architecture of optical computing, role of non-linear materials in optical computing.

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2. WHY OPTICS FOR COMPUTING

Lasers, fibers, and optical components have already proved their reliability and high levels of performance in many applications such as CD-ROM drives, laser printers, photocopiers and scanners, Storage Area Networks (SANs), optical switches, all-optical data networks, holographic storage devices, and biometric devices at airports to track weapons and drugs. At the same time, the promise of optical computing comes from the many advantages that optical interconnections and optical integrated circuits have over their electronic counterparts. Optical computing is immune to electromagnetic interference and free from electrical short circuits. Photons of different colors can travel together in the same fiber or cross each other in free space without interference or cross-talk. Photons have low-loss transmission and provide large bandwidth, offering multiplexing capacity for communicating several channels in parallel without interference. Optical materials are compact, lightweight, inexpensive to manufacture, more facile with stored information than magnetic materials, and possess superior storage density and accessibility compared to magnetic materials. Progress in holographic storage devices can enable storage of the entire U.S. Library of Congress onto a sugar-cube-size hologram. Furthermore, optical parallel data processing is easier and less expensive than electronic. In addition, optical computing systems offer computational speeds more than 107 times faster than the currently fastest electronic systems. This means a computation that takes a conventional computer more than 11 years to solve would take an optical computer less than one hour. The following table 1 describes different people view about how input, computation and output takes place in computing.

Table1: Different people opinion about computing

Function	What Electronic-computer Practitioners Say	What theoretical-Physics Practitioners Say	What Optical-computer Practitioners Say
Input	Input data and Instructions	Prepare a general wave function involving data	Set up apparatus and insert data onto SLM
Computation	Compute each step using gates or switches	Propagate general wave function	Optical wave front propagates.
Output	Extract the desired results Discard the intermediate results(garbage)	Take a measurement. There is no record of intermediate results.	Extract the desired result. There is no garbage

2.1 Digital Optical Computing

Digital computing with the use of optical components was considered at least as early as the 1940's by von Neumann. Optical or optoelectronic or photonic computing has rapidly risen as an important area of research and is now one of the fastest emerging technologies. Optics is viewed as an interconnection technology basically for its large bandwidth. The advantages of parallel processing gets multiplied several times when the possibility of interconnection in two or even three dimensions are considered. Optical Computing, which actually means the optical manipulation of discrete numerical data. A specific aspect of optical computing is that the signal is transmitted not by electrons, but by photons. There are three properties of optics which make it an attractive candidate for Computing. First is the large bandwidth of optical sources which may approach to a giga hertz. Second is the large space bandwidth product. The third characteristics are related to the non interfering connectivity of optical paths. For the generation of image patterns and for their input into the optical processing path, two basic techniques support high data rate. The first one is intended for data arriving as a succession of electrical signals through several input channels simultaneously. The second technique is used for the input of task execution that is algorithm. Instructions and constants are stored by read only (main) optical memory. [7]

2.2 Optical Analog Computing

We can think of a general computation as an operation, ***B***, applied to a set of input functions, *f*,, *i* = I;..*N*, to produce a set of output functions, *g*, *j* = **I;.** . *M* in the form

e [f , (X) ,..',f(;X),...,fN(X)] = ***[g , (y) , . . . , g , (y) , . . . , g , (y)] .*** (I)

Here ***x*** and ***y*** are the sets of independent variables associated with the input and output functions, respectively. We define an analog system as one where the dependent variables *f*, and *gj* can assume any of a continuum of values. If the dependent variables are restricted to a specific set of discrete values, the system will be called digital. The independent variables ***x*** and ***y*** can, of course, also be analog in that they may take on any one of a continuum of values, in which case the system will be referred to as continuous. If only discrete values of the independent variables are allowed, we say that the system is sampled. Historically, most of the work in optical computing has been in the analog, continuous domain. Typically, in optical systems, the dependent variables are either complex amplitudes or intensities. In order to utilize the parallel processing capabilities of optics, the independent variables are generally two orthogonal spatial coordinates the simplest and most common example of this type of common operation is optical imaging where a two-dimensional intensity (or amplitude) pattern is in essence transmitted from one location in space to another. Operations of the analog, continuous variety have been widely developed over the last twenty years. There exists a fairly well-defined repertoire of operations which can be performed, including such important operations as addition, subtraction, and multiplication of images, two-dimensional Fourier transformation, correlation, convolution, and other operations derivable from these. For a further exposition of these operations the interested reader is referred to the literature. There are four major drawbacks to optical analog processing.

These drawbacks are limited flexibility, noise accumulation, Deterministic noise and input-output device limitations. The first three problems are peculiar to analog systems and can be circumvented by going to a digital system. The problem of devices is shared with both analog and digital systems although the constraints are very different in the two cases. In the following, we will briefly expand upon these problems of analog systems to emphasize the interest in developing DOPs. The first difficulty is the limited flexibility provided by the available optical analog computing software. As mentioned above the available operations are primarily some simple arithmetic operations and Fourier transformation. These are certainly powerful operations, and particularly in the case of the Fourier transformation, have much higher throughputs in optical implementations than is possible electronically. However, these operations are inadequate for many desirable computations. Although considerable work is being done to extend the range of available operations (see for example) the extensions will not lead to the general processing capabilities available with digital systems. The flexibility of digital systems is a major factor behind the interest in developing digital optical computing techniques. The second major drawback associated with optical analog systems is their noise susceptibility. Although the noise advantages of a digital system over an analog system are perhaps intuitively apparent, the following discussion provides a more quantitative comparison. It also points out that the important consideration is noise propagation through a cascade of operations rather than noise in a single operation. [9]

2.3 Quantum Optical computing

Optical computing is intrinsically quantum computing. Each photon is a quantum of a wave function describing the whole system. With all of the work on more-exotic but still nonfunctioning quantum computers which attempt to manipulate atoms to perform operations, involving quantum entanglements and the like many researchers lose sight of the fact that optical computers allow simple, low-cost quantum computing today. This type of computing is not fashionable because it is not exotic. But quantum computing is the reason, for example, that optical processors sometimes dissipate far less energy than their electronic cousins to perform the same operation. Future quantum optical computers will exploit quantum randomness as well. Optical-processor folks are taking a bottom-up approach to quantum computing. Many theoretical physicists are taking a top down approach. Surely we will meet somewhere in between in the next century. Practical quantum computers will become more exotic and exotic quantum. Computers will become more practical. Then the Turing model will at last be broadened to acknowledge that we can safely perform many operations virtually. To achieve useful electronic quantum computing, we may have to make fermions behave like bosons. This late 20th century magic is now possible, as demonstrated by experiments in cavity quantum electrodynamics. In a superconductor, pairs of fermions Cooper pairs behave without interaction under some conditions. Researchers have controlled atoms by trapping single photons in small, superconducting cavities. So electronic quantum computing seems possible in principle but is far from practical. In the short term, quantum computing is something only optics can do.

3. ARCHITECTURE OF OPTICAL COMPUTING

The use of optical systems, in particular highly parallel systems, leads to certain implications in the design of computing. The basic requirements of an optical computing architecture for information processing are: (i) optical sources (ii) input information for processing (iii) a method of modulating the sources to carry the input information and finally (iv) an information processing or decision-making stage as shown in the figure2. In short, processing optical information involves generation, propagation and detection of light. Therefore, a digital optical computing

Architecture is an embodiment of reconfigurable and addressable optical interconnects in 2D or in 3D for large volume parallel processing and computing. Interconnections in an optical computing system are implemented using lenses, lens let arrays, beam splitters, spatial light modulators, etc. The benefits of using free-space optical imaging systems are that the path lengths remain constant over the entire field and also the transit time differences are extremely small, of the order of femto seconds. Tolerances caused by aberrations are almost negligible.

Optical logic arrays are used to implement logic functions. The optical shadow casting (OSC) or the optical logic array processor (OLAP) architecture offers interesting methods for performing spatial logic operations in optical domain. Implementation of any specific logic operation is decided by the choice of the operational kernels, which are in the form of a two-dimensional array of sources. The input operands are spatially encoded as two-dimensional patterns

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and superimposed. The operational kernels then project an image of the superimposed input on the decoding mask plane. The light emerging from the decoded mask is the output image.

An off-shoot of image logic processing is the cellular logic processing where the data are represented as cells and operation is based on interconnections between cells. Notable practical demonstration has been made on optical cellular processing during the last few years.

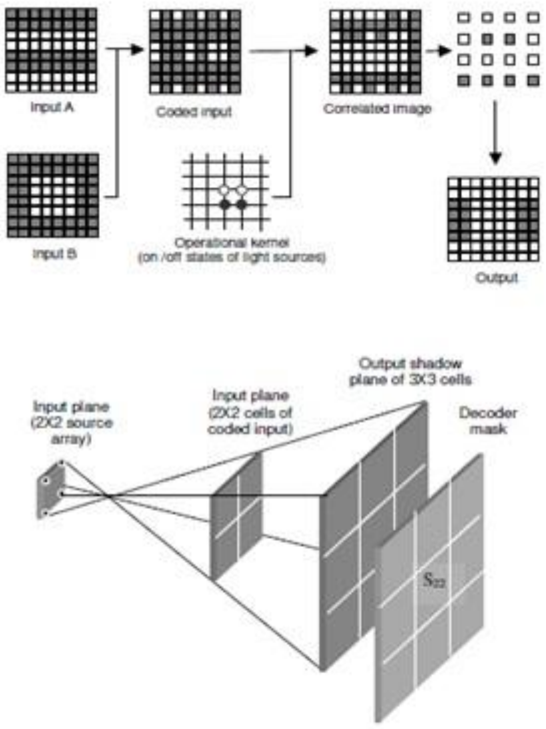

Figure 2: Optical logic processing architecture

Input-output is generally performed by the CPU or by a system closely coupled to the CPU. The CPU accesses the memory through a binary addressing unit and memory contents are returned to the CPU through a single or small number of lines. This multiplexing scheme reduces the communications requirements and minimizes the number of lines. This serial addressing of memory results in a tradeoff of time for interconnection complexity. The eventual limitation on computing speed is known as the von-Neumann bottleneck. Current high-performance electronic computers operate with very short clock cycles; this means that coaxial electronics with very short physical wire lengths are needed to avoid electromagnetic interference (EMI), crosstalk, and clock skew problems. The coaxial electronics for interconnections requires terminating resistors on the ends of cables, further reducing system energy efficiency.

Parallel optical computing architectures will strongly influence algorithms for computationally intensive tasks. Some particularly interesting applications are in image analysis and image understanding, where cellular logic arrays could be implemented in an optical parallel processor. Another important application is in artificial intelligence, where computational demands are extreme. Optical computers could be used to rapidly implement associative memory and symbolic substitution operations important for production rule based algorithms. [9]

3.1 Optical Processor Architecture

The architecture of a generic optical processor for information processing the processor is composed by three planes as shown in the figure3. The input plane, the processing plane, and the output plane. The data to be processed are displayed in the input plane, most of the time this plane will implement an electrical to optical conversion. The principles and the potential of optical processors could be demonstrated but no real-time applications were possible, making the processor most of the time useless for real life applications. The processing plane can be composed of lenses, holograms or nonlinear components. This is the heart of the processing, and in most optical processors, this part can be performed at the speed of light.

The speed of the whole process is limited by the speed of its slowest component that is most of the time the input plane SLM, since the majority of them are operating at the video rate. The SLM is a key component for the development of practical optical processors, but unfortunately also one of their weakest components. Indeed, the poor performance and high cost of

SLMs have delayed the fabrication of an optical processor for real-time applications.

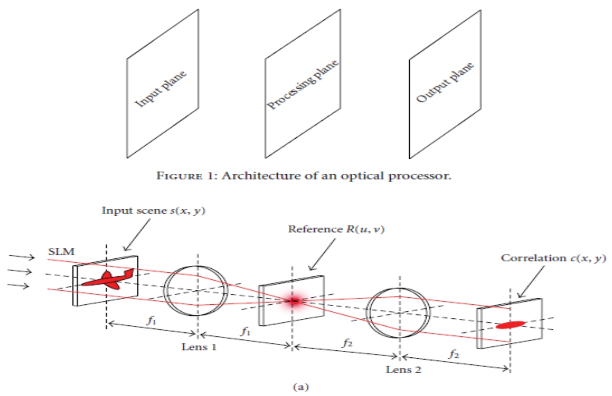

Figure 3: Optical setup

4. OPTICAL COMPUTING TODAY

The traditional field of optical computing is no longer so active, it is not dead but it has evolved. Applied Optics has no longer an issue per month on the subject, but in each issue there is a section “Information is processing” with an average of only 4 papers per issue. There are no longer specialized large international conferences named

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"Optical Computing". However, it should be noted that there are still two conferences organized by the SPIE on the subject: "Optical Pattern Recognition" since 20 years in Orlando in the frame of the SPIE conference "Defense, Security, Sensing", and "Optics and Photonics for Information Processing" in San ego in the frame of the SPIE conference "Optics and Photonics". The research on optical correlators is continued by fewer research teams, however it should be noted that the Jet Propulsion Laboratory **(**JPL) is still working on optical correlators for real time automatic target recognition correlators for real time automatic target recognition. Some of the algorithms developed for pattern recognition initially for optical processing are now used successfully in digital computers. DOEs are now mature and are part of numerous industrial products. All the research on the fabrication of DOEs made possible the fabrication of nano structures and very exciting new fields of research such as nano photonics, nano fluidics and optofluidics. The list of the papers presented in 2009 at the SPIE conference "Optics and Photonics" reflects the growing interest in all the research related to nano science and nano optics. Bio photonics is an exponentially growing field that is largely benefiting from the past research in optical processing. Typical examples are the optical tweezers and the optical trapping. Thanks to the digital holography, where the holographic plate is replaced by a camera, holography is again finding industrial applications particularly for the quality control of manufactured products, for digital holographic microscopy opening completely new fields of applications for optical microscopy. For information processing, optics is also finding a place where it has a unique feature such as the polar metric imaging, or multispectral imaging. Security applications are also a promising field for optical information processing. It is well known that optics is used commonly for the communication systems. [8]

4.1 Devices Used For Optical Computing

4.1.1 Logic Gates

Logic gates are implemented optically by controlling the population inversion that occurs to provide lasing. A controlling laser is used to control population inversion thus causing switching to occur.

4.1.2 Holographic Truth Table

- Destructive interference will light to be emitted or not based on phase relationship Logic based on gratings
- 1 is represented by vertical grating causing light
- 0 is represented by horizontal grating causing darkness1

4.1.3 Holographic Storage

- Holographic data storage has 4 components *Holographic material;* thin film on which data is to be stored
- *Spatial Light Modulator (SLM)*; 2D array of pixels, each of which is a simple switch to either block or pass light
- *Detector array;* 2D array of detector pixels, either as Charge-coupled device (CCD) camera or CMOS detector pixels to detect existence of light
- *Reference arm;* arm carrying the laser source to produce the reference beam.

4.2 Optical NAND Gate

In an optical NAND gate the phthalocyanine film is replaced by a hollow fiber filled with Polydiacetylenes. Nd: YAG green picoseconds laser pulse was sent collinearly with red cw He-Ne laser onto one end of the fiber. At the other end of the fiber a lens was focusing the output on to the narrow slit of a monochromatic with its grating set for the red He-Ne laser. When both He-Ne laser and Nd: YAG laser are present there will be no output at the oscilloscope. [10]

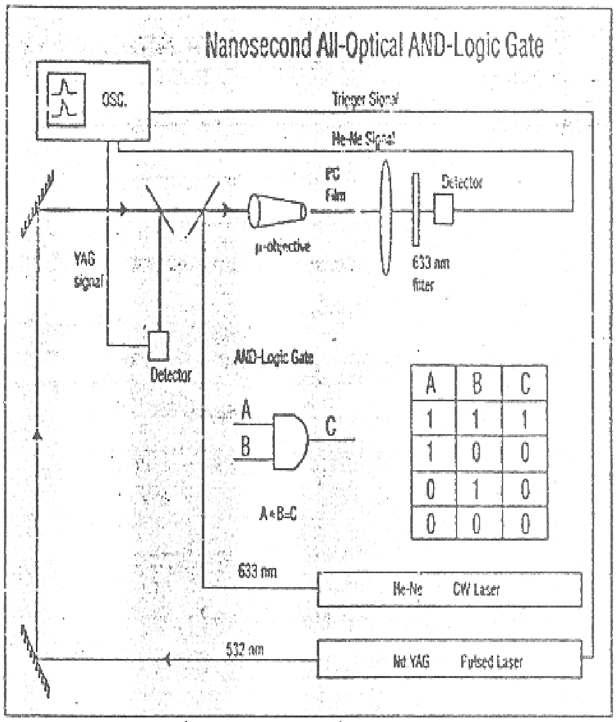

Figure 4: Optical logic AND gate

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4.2.1 Interconnections in Optical Computing

- Optical interconnection technologies are relatively mature.
- Fiber optic cables and optical transceivers are widely used.
- Applications of optical communications like fiber channel and computer networking are already being used.
- Although there is a basic speed limitation is optoelectronic conversion delays.
- WDM is used to get around this limitation.
- Chip to Chip and On-Chip interconnection possibilities are still being examined.
- Promising but there are problems regarding dense organization of optical processing units.

4.2.2 Optical processor

- When an analog signal is processed digitally it must first be converted into a discrete form using an analog-to-digital converter (ADC) before it can be processed. Generally the signal is then processed with a discrete Fourier transform (DFT), or another discrete signal processing algorithm, and converted back to an analog form with a digital-to analog converter (DAC)
- Processing an analog signal in a digital architecture with an optical Fourier signal processor with an optical coprocessor

The above mentioned procedure is depicted in the following figure5

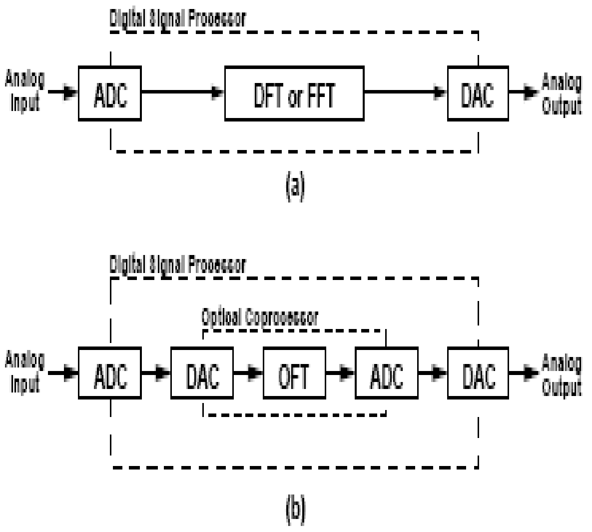

Figure 5: Processing Analog Signal with a Digital Signal Processor

4.3 Role of NLO In Optical Computing

The role of nonlinear materials in optical computing has become extremely significant. Non-linear materials are those, which interact with light and modulate its properties. Several of the optical components require efficient nonlinear materials for their operations. What in fact restrains the widespread use of all optical devices is the in efficiency of currently available nonlinear materials, which require large amount of energy for responding or switching. Organic materials have many features that make them desirable for use in optical devices such as:

1. High nonlinearities
2. Flexibility of molecular design
3. Damage resistance to optical radiations

Some organic materials belonging to the classes of phthalocyanines and Polydiacetylenes are promising for optical thin films and wave guides. These compounds exhibit strong electronic transitions in the visible region and have high chemical and thermal stability up to 400 degree Celsius. Polydiacetylenes are among the most widely investigated class of polymers for nonlinear optical applications. Their sub picoseconds time response to laser signals makes them candidates for high-speed optoelectronics and information processing. To make thin polymer film for electro-optic applications, NASA scientists dissolve a monomer (the building block of a polymer) in an organic solvent. This solution is then put into a growth cell with a quartz window, shining a laser through the quartz can cause the polymer to deposit in specific pattern.

4.4 Optical Transport Network

Since 1990 the SDH and SONET specifications have been extended based on demand for the transport of new tributary signals and also based on new capabilities provided by the evolution in component technology. The later enabled the transport of multiple colors (wavelengths) on a single optical fiber. This was one of the reasons to start development of a new set of recommendations to use this feature: the Optical Transport Network (OTN) sometimes called "digital wrapper." SONET was developed in the United States through ANSI T1X1.5 committee. ANSI work commenced in 1985 with the CCITT (now ITU) initiating a standardization effort in 1986. The US wanted a data rate close to 50Mbps. But the Europeans wanted the data rate to be around 150 Mbps. A compromise was reached and the US data rates were made subset of ITU specification, known formally as Synchronous Digital Hierarchy (SDH).

SONET/SDH networks are configured as linear networks, where SONET/SDH nodes know as Add Drop Multiplexers (ADMs) are hooked together in a line. There may be two or four fibers between the two consecutive ADMs with one set serving as "protection" or "back up".

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Add/drop multiplexers (ADMs) are places where traffic enters and leaves as shown in the following figure 6. The traffic can be at various levels in the SONET/ SDH hierarchy. Also SONET network elements can receive signals from a variety of facilities such as DS1, DS3, ATM, Internet, and LAN/MAN/WAN. They can also receive signals from a variety of network topologies.[4]

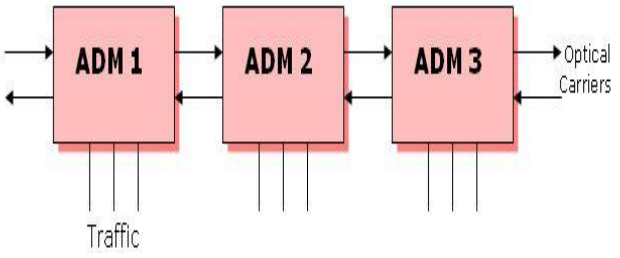

Figure 6: Configuration of SONET/SDH Networks

4.4.1 SDH and SONET Terms

An SDH Virtual Container (VC) is the equivalent of a SONET Synchronous Payload Envelope that exists in two forms, the {STS - n SPE} as shown in the figure 7 And the {VT n SPE}. It is used to refer to a Container and it's associated Overhead (OH) information fields.

- C – n – X — a contiguous concatenated payload *Container* of size X times the size of a container C – n. For (n = 4, 3) the X = 1 … 256 and for (n = 2, 12, 11) the X = 1 … 64.

4.4.2 OTN Terms

- OPUk —an Optical channel Payload Unit of order k (k = 1, 2, 3),the equivalent of an SDH C – n. It has its own payload – associated overhead.

- ODUk — an Optical channel Data Unit of order k (k = 1, 2, 3), the equivalent of an SDH VC – n, that transports an OPUk. It has its own associated overhead.

- ODUk – Xv — a Virtual concatenated ODUk. Used to transport an OPUk – Xv.

- OTUk — an Optical channel Transport Unit of order k (k = 1, 2, 3), the equivalent of an SDH TUG – n.

- OTM – n,m — an Optical Transport Module , n represents the maximum number of supported wavelengths and m represents the (set of) supported bit – rate. [5]

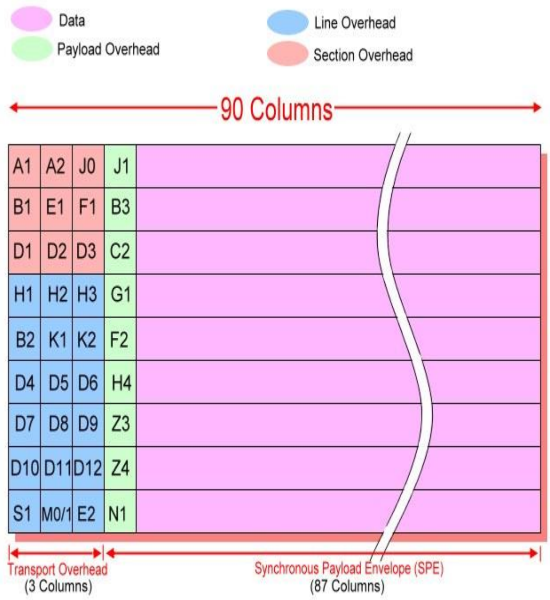

Figure 7: The Basic SONET Frame

4.5 Other New Optical Networks

The Optical Transport Network (OTN) is relatively a new ITU-T recommendation that was developed for long-haul transport at data rates from 2.5 to 40 G bit/s.

OTN, like the NG-S, defines a synchronous payload within a fixed frame length, a comprehensive overhead to support a variety of client payloads, and FEC to provide margin for fixed fiber span or increased fiber span at BER objectives that can be met.

In OTN multiplexed frames such as SONET/SDH, when M STM- 16/STS-48 signals are to be interleaved to achieve M x 2.5 G bit/s transmission data rates, the FEC encoding function is performed in the terminal transmission equipment (TTE) at each STM-16 signal and before the interleave. At the receiving TTE, de-interleaving is performed to separate the STM-16 signals.

If the number of errors exceeds the capability of the FEC, then uncorrected errors tend to form bursts of errors. Since the FEC is at the physical layer, it may not be possible to report uncorrected errors to the next data link layer.

4.5.1 FEC in OTN

In OTN, the FEC encoding function is performed in the terminal transmission equipment (TTE) at each STM-1 6 signal and before interleave. The OTN FEC uses extensively the non binary Reed-Solomon RS (255, 239) error correction code, which operates on byte symbols. A RS (255, 239) FEC coder calculates 16 check bytes over 239 byte symbols and adds them after the 239 bytes. The structure of the RS (255/239) Reed-Solomon error correction code n/k (n = 255, k = 239).

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1 SYMBOL=8 bits(m=8)
1 2 239
254 255

Data block size, k=239. (2t=n-k=16)
Code block size, n=255
(Correctable symbols=8)
(Detectable errors=16)

OTN uses the no binary Reed-Solomon RS (255, 239) error correction code, which operates on byte symbols.

OPU-k

The basic unit of OTN is the optical channel payload unit (OPU-k), in which the client signals are mapped. The k denotes the nominal bit rate that the OPU supports.

k = I corresponds to 2,488,320.000 k bit/s ± 20 ppm (2.5 G bit/s),
k= 2 corresponds to 9,995,276.962 k bit/s ± 20 ppm (1 0 G bit/s)
k = 3 corresponds to 40, 1 50, 51 9.322 k bit/s ± 20 ppm (40 G bit/s).

The OPU-k unit consists of four rows of 3810 bytes each, including 2 bytes overhead placed at the leading end of each row to support adaptation of a variety of client signals in the OPU-k payload as shown in the figure 8.

ODU-k

When the OPU-k's are formed, the optical channel data unit k (ODU-k) is formed by adding 14 byte-columns of overhead at the leading end of the OPU-k.

The first 14 bytes of the first row in the ODU-k are reserved for the frame alignment signal (F AS) (bytes 1 to 7), the multi frame alignment signal (MF AS) (byte 8), and overhead for the next frame, the optical channel transport unit k (OTU-k) (bytes 8 to 14).

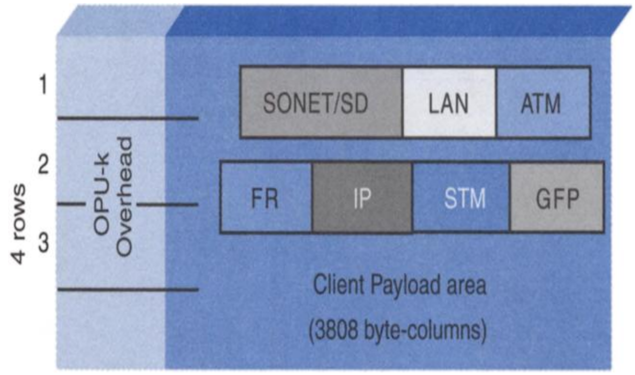

Figure: 8 OPU-k (3810 COLUMNS)

The OPU-k unit consists of four rows of 3810 bytes each, including 2 bytes of overhead placed at the leading end of each row. Note that the numbering starts at 15.

The FAS field consists of the fixed-frame alignment sequence as shown below.

o x A l 0 x A l 0 x A l 0 x A2 0 x A2 0 x A2.

The MFAS contains the frame number in a 256 multi frames. The OTU overhead consists of the section monitoring (bytes 8 to 10), general communications channel-O (GCCO) (bytes 11 and 12), and two reserved (bytes 13 and 14).

The remaining ODU-k overhead (bytes 1 through 14 of rows 2 to 4) is partitioned in sections. One section is for the end-to-end ODU-k path, another section supports six levels of tandem connection monitoring, and others are used for performance, maintenance, and operational functions. The complete overhead functionality is spread over up to 64 ODU-k frames. The ODU-k path overhead is terminated where the ODU-k is assembled and disassembled. The overhead for tandem connection is added and terminated at the source and sink of tandem connections.

The optical channel data unit-k (ODU-k) is formed by adding 14 byte-columns of overhead at the leading end of the OPU-k.

The optical channel data unit k (ODU-k) supports the following functions:

- Adaptation of client signals via the Optical Channel Payload Unit k (OPU-k)
- End-to-end path supervision (ODU-kP)
- Tandem connection monitoring (ODU-kT)

OTU-k

The construction of the optical channel transport unit k (OTU-k) is completed by adding OTU-k overhead bytes and by appending the FEC code at the end of the ODU-k frame.

The OTU overhead consists of the section monitoring (bytes 8 to 10), the general communications channel 0 (GCCO) (bytes 1 1 and 12), and reserved (bytes 13 and 14). The FEC area consists of 4 rows with 256 bytes each. Thus, the final OTU-k frame consists of 4 rows by 4080 columns. The final nominal OTU-k bit rates with ±20 ppm tolerance. [6]

5. APPLICATIONS

The following are the various applications of optical computing.

1. High speed communications: The rapid growth of internet, expanding at almost 15% per month, demands

faster speeds and larger bandwidth than electronic circuits can provide. Terabits speeds are needed to accommodate the growth rate of internet since in optical computers data is transmitted at the speed of light which is of the order of 3.10*8 m/sec hence terabit speeds are attainable.

2. Optical crossbar interconnects are used in asynchronous transfer modes and shared memory multiprocessor systems.
3. Process satellite data. [10]
4. Optical Computing in VLSI Technology:

Many researchers have been investigating suitable optical logic devices, interconnection schemes, and architectures. Furthermore, optics may provide drastically new architectures to overcome some architectural problems of conventional electrical computers.

5. Optical computing as expanders:

The optical expander described utilizes high-speed and high-space-bandwidth product connections that are provided by optical beams in three dimensions.

6. CONCLUSION

Research in optical computing has opened up new possibilities in several fields related to high performance computing, high-speed communications. The acceptability of digital optical computing systems as off-the-shelf or dedicated system is still not very high. Optical computing is mostly analogue when electronic computing is digital. The digital optical Computers were not able to compete with the electronic due to the lack of appropriate optical components. Optical processing is useful when the information is optical and that no electronics to optics transducers are needed.

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