PHOTONIC COMMUNICATION TECHNOLOGIES: ENABLING THE ZETTABYTE INTERNET

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  • Andrea Carena
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• www.optcom.polito.it
• The state of the Internet
• The role of photonics in enabling the Internet as we know it
• Coherent WDM Systems: a brief introduction
  • Implementation of a PM-QPSK system
• Future trends
• Future challenges
THE STATE OF THE INTERNET

TRENDS, TRAFFIC AND USERS
THE TRAFFIC GROWTH

Global IP Traffic

36% CAGR

Exabytes per month

Year


Cisco VNI Forecast and Methodology
GLOBAL INTERNET USERS

Individuals Using the Internet

11% CAGR

ITU 2016
WHAT LEAD US HERE?

**Consumerization of IT**
- The rise of the PC
- Smartphones and portable devices adoption
- Bring your own device (BYOD) trend

**Cloud Services**
- Self-provisioned IT services
- Storage services
- Elastic computing

**New IT markets**
- Video on Demand (VoD)
- Gaming
- Social Networks
- Ecommerce
ENABLING THE INTERNET AS WE KNOW IT

Which technologies allowed to create the Internet as we know it, and sustain the growth of its traffic?

OPTICAL COMMUNICATIONS TECHNOLOGY

OPTICAL DEVICES  OPTICAL SYSTEMS  OPTICAL NETWORKS
PHOTONIC TECHNOLOGIES: ENABLING THE INTERNET

THE UBIQUITY OF PHOTONICS IN DATA NETWORKS
THE INFRASTRUCTURE OF A DATA NETWORK

Core Network

Satellite Network

Mobile Network

Metro Network

Access Network

Datacenter
CORE NETWORK: THE ROLE OF OPTICS

Client Interface (e.g. 10 x 10 Gbps)

Router

Optical Network

Line Interface (e.g. 100 Gbps)

WDM Fiber System (e.g. 96 x 100 Gbps)

Reconfigurable Optical Add/Drop Multiplexer (ROADM)

WISH LIST

• Scale client rates
• Scale line rates
• Network flexibility
• Contain costs
WDM SYSTEMS

Transmitter

Optical Link

Optical Fiber Span < 120 km

Line Amplifier (EDFA/Raman)

Fiber Span

Receiver
COHERENT
WDM SYSTEMS

A BRIEF INTRODUCTION
How to encode information using an electromagnetic wave?

**LIGHT PROPERTIES THAT WE CAN MODULATE**

- **TIME**
  - Pulse Position Modulation (PPM)

- **QUADRATURE**
  - Intensity and Phase Modulations

- **FREQUENCY**
  - Frequency Shift Keying (FSK)

- **POLARIZATION**
  - Polarization Shift Keying (PSK)
• We can describe light as an electric field, in particular like

\[ E(t) = A(t) \cdot e^{j\phi(t)} \]

- Amplitude
- Phase

• This can be written as a complex number

\[ E(t) = E_R(t) + jE_I(t) \]
LEGACY MODULATIONS: IMDD

\[ E_I(t) \]

\[ E_R(t) \]
LEGACY MODULATIONS: PSK

\[ E_I(t) \]

\[ E_R(t) \]
We exploiting both real and imaginary part of the field!
COHERENT MODULATIONS: QPSK

Phase Reference is Arbitrary!
COHERENT MODULATIONS: HIGHER ORDER FORMATS

16-QAM (4 BPS)

\[ E_I(t) \]

\[ E_R(t) \]

64-QAM (6 BPS)

\[ E_I(t) \]

\[ E_R(t) \]
The propagating mode of an optical fiber is a degenerate mode:

- It is made of two orthogonal polarization traveling together along the fiber

- Light in the fiber can be thus described as

\[ E(t) = [E_{R,x}(t) + jE_{I,x}(t)]\hat{x} + [E_{R,y}(t) + jE_{I,y}(t)]\hat{y} \]

- Can we use this fact for our own benefit?
• Since the two orthogonal polarization are independent, we can double the amount of carried information, by transmitting a coherent signal on both of them.

• This is polarization multiplexing (PM)
• The first commercial implementation of a QPSK transceivers dates back to 2008
• Nortel (now Ciena) implemented a 40 Gbps transceiver based on PM-QPSK
• Two years later, Alcatel Lucent (now Nokia) started selling the first 100 Gbps transceiver based on PM-QPSK.
A PM-QPSK SYSTEM

A QUICK LOOK ON HOW TO IMPLEMENT PM-QPSK FIBER SYSTEM
A QPSK TRANSMITTER

Data Stream (real component)

Driver

Data Stream (imaginary component)

Driver

Laser

Mach-Zender Modulator

Mach-Zender Modulator

Phase Modulator

TX Signal

Single pol.

$E_R(t)$

$E_I(t)$

$jE_I(t)$

DSP+DAC

DSP+DAC
A PM-QPSK TRANSMITTER

Data Stream (real component)  Driver  Shaping Filter

Laser

Data Stream (imaginary component)  Driver  Shaping Filter

Data Stream (real component)  Driver  Shaping Filter

Data Stream (imaginary component)  Driver  Shaping Filter

Mach-Zender Modulator

Mach-Zender Modulator

Mach-Zender Modulator

Phase Modulator

Polarization Rotator

Polarization Beam Combiner

TX Signal (to fiber)

X-POL

Y-POL

Laser

Polarization Beam Combiner

TX Signal (to fiber)
RECEIVING PM-QPSK

WHAT IS THE EFFECT OF PROPAGATING THE SIGNAL THROUGH A FIBER LINK?

PM-QPSK Transmitter

$E_{TX}(t)$

Optical Fiber

Optical Amplifier

$\times N_s$

PM-QPSK Receiver

$E_{RX}(t)$
WHAT ARE WE UP AGAINST?

MAIN FIBER PROPAGATION IMPAIRMENTS

LINEAR EFFECTS
- Chromatic Dispersion (CD)
- Polarization Mode Dispersion (PMD)
- Polarization Dependent Loss (PDL)
- Loss

ASE NOISE
- Amplified Spontaneous Emission (ASE) Noise

NONLINEAR KERR EFFECT
- Nonlinear Interference (NLI)

They can be modeled as Gaussian Noise*! They are the bottom-line disturbances

They can be compensated electronically

MODELING FIBER PROPAGATION

PM-QPSK Transmitter \( E_{TX}(t) \) Linear Effects \( + \) \( n(t) \) Gaussian Noise \( E_{RX}(t) \) PM-QPSK Receiver
GAUSSIAN NOISE IMPACT

How can we receive this?
• We need to detect real, imaginary component for each polarization
• To do so, we need to add a local oscillator (LO) that is “aligned” with the component we wish to receive, than we use a photodetector to measure the corresponding current
$E_{RX}(t)$

**OPTCOM**

**RECEIVER STRUCTURE**

**X-POL**

- Optical Filter
- PBS
- 90 Deg. Hybrid
- Bal. PD
- DSP
- Decision

**Y-POL**

- LO Laser
- PBS
- 90 Deg. Hybrid
- Bal. PD
DSP STRUCTURE

electro-optical front-end

A/D conv, 2 samp/bit

CD comp, FIR

CD comp, FIR

PMD compensation

freq comp mtx

freq comp mtx

sample rate halving

ML Receiver

FEC

BER
• The introduction of DSP has caused a big change in optical communication technologies, allowing reconfiguration, cost reduction, and the development of new transmission techniques.
• IMDD modulation
• In-line dispersion compensation
• Only pre-defined transparent transmission
• No flexible transparent wavelength routing
• The transparent connectivity matrix is sparse and unchangeable
THE NOVEL PARADIGM

- DSP-based coherent-Tx/Rx & equalizer
- No in-line dispersion compensation
- Any-to-any optical transmission enabled by transparent wavelength routing
- The transparent connectivity matrix is indeed full and elastic, and depends on network use

Elastic optical network (EON)

Orchestrator
FUTURE TRENDS

WHAT FUTURE DATA NETWORK WILL FACE?
THE CHALLENGE

Global IP traffic

Exabytes per month


23% CAGR

THE ZETTABYTE ERA: >1 billions TB exchanged over IP each year

Cisco VNI Forecast and Methodology, 2015-2020
**Nolle: In 2017, Cost Per Bit Exceeds Revenues**

https://goo.gl/qPTVud

-2% CAGR

- **Global Fixed Broadband Revenues**
- **Global Fixed Voice Revenues**
- **Combined Fixed Voice and Broadband Revenues**
ACTORS’ WISH LISTS

TELECOM OPERATORS
• Pursuing growth
• Controlling Costs

VENDORS
• Develop the right technology to fit data growth
• Push its market adoption
• In this scenario, understanding **the merit of different technologies** on overall **network performance** is fundamental.

• This is required in order to **drive**

- **Network Upgrades**
- **Network Design**
- **Network Management**
A POSSIBLE SOLUTION; A HOLISTIC VIEW OF DATA NETWORK

PHOTONIC COMPONENTS

PHOTONIC TRANSMISSION TECHNOLOGIES

NETWORK MANAGEMENT AND CONTROL

INNOVATION AND VALUE CREATION
FUTURE CHALLENGES

FACING THE CAPACITY CRUNCH
How Much the Eye Tells the Brain

Brain can absorb up to 10 Mbps of visual information

IT IS DIFFICULT TO SAY THAT TRAFFIC WILL STOP GROWING

Subscribers Using Monte Carlo Methods

A First Look at Cellular Machine-to-Machine Traffic – Large Scale Measurement and Characterization

Machine-to-Machine traffic will become dominant
HOW TO COPE WITH SUCH GROWTH?

DEGREES OF FREEDOM

QUADRATURE

FREQUENCY

SPACE
QUADRATURE: INCREASE CONSTELLATION SIZE

- Log growth of capacity with number of points
- Complex from an electronic and transmission standpoint
**FREQUENCY: INCREASE BANDWIDTH USAGE**

- Linear growth of capacity with BW
- Issues with
  - Lack of components
  - Power Limitation
SPACE: INCREASE FIBER NUMBER

- Linear growth of capacity with core number
- Issues with
  - Lack of components
  - Receiver Complexity
  - Lack of integrated components
THE MOST PROBABLE FUTURE

FUTURE OPTICAL SYSTEMS
OPEN PROBLEMS

PHOTONIC COMPONENTS
- Wideband components
- Spatial and wideband switches
- Optical sources for SDM/WDM integration
- Photonic Circuit Integration

PHOTONIC TRANSMISSION TECHNOLOGIES
- Making coexistence of all transmission techniques possible in a reliable way

NETWORK MANAGEMENT AND CONTROL
- Orchestrate and manage all these degrees of complexity
HOLISTIC AND MULTIDISCIPLINARY APPROACH: IMPROVING THE REALITY TOGETHER

PHOTONIC COMPONENTS

PHOTONIC TRANSMISSION TECHNOLOGIES

NETWORK MANAGEMENT AND CONTROL

INNOVATION AND VALUE CREATION
THANK YOU!

QUESTIONS?

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