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PHOTONIC COMMUNICATION TECHNOLOGIES: ENABLING THE ZETTABYTE INTERNET

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  - Vittorio Curri
  - Andrea Carena
  - Other OptCom Group members
- www.optcom.polito.it

TALK OUTLINE

- 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

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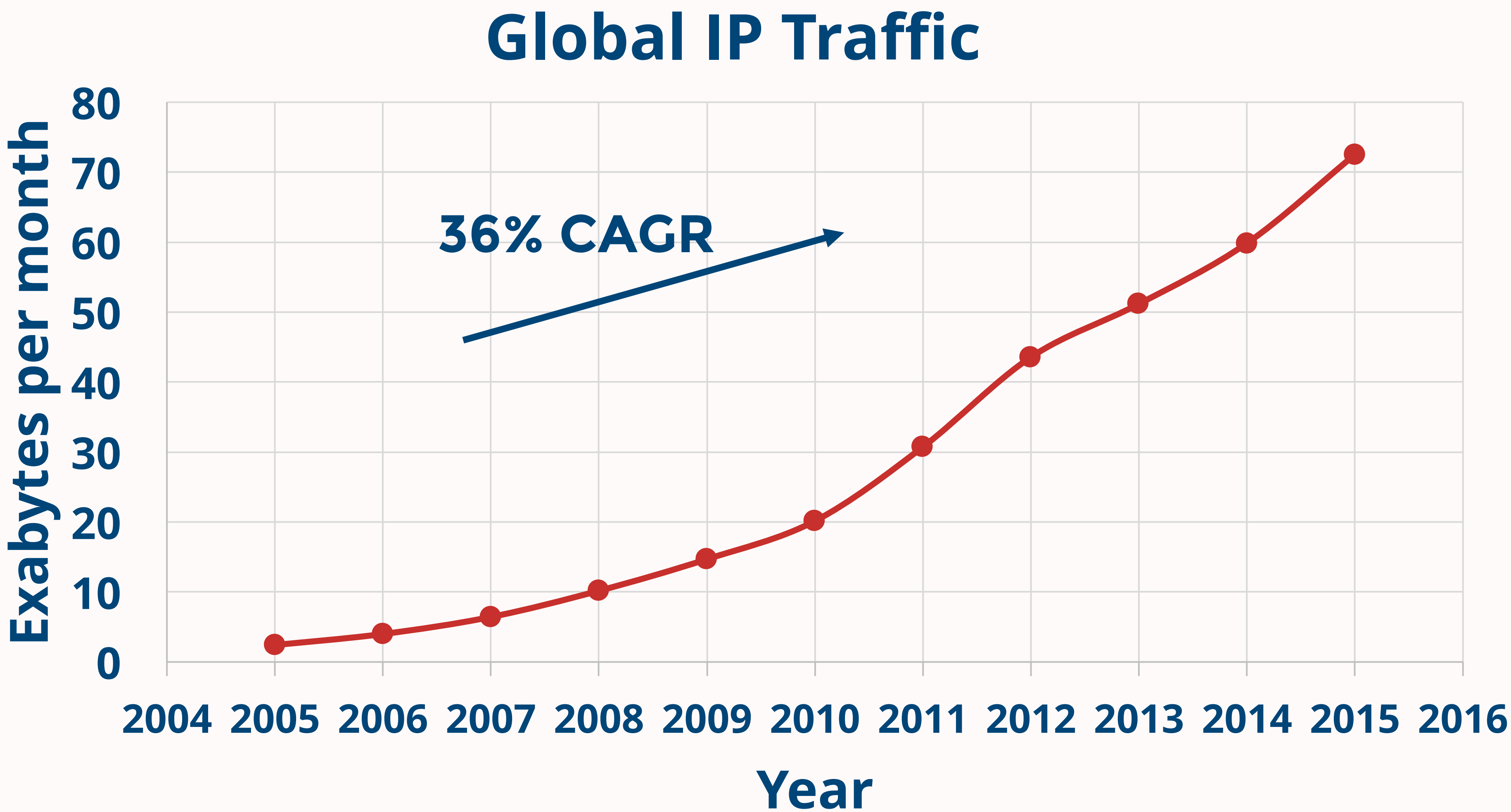
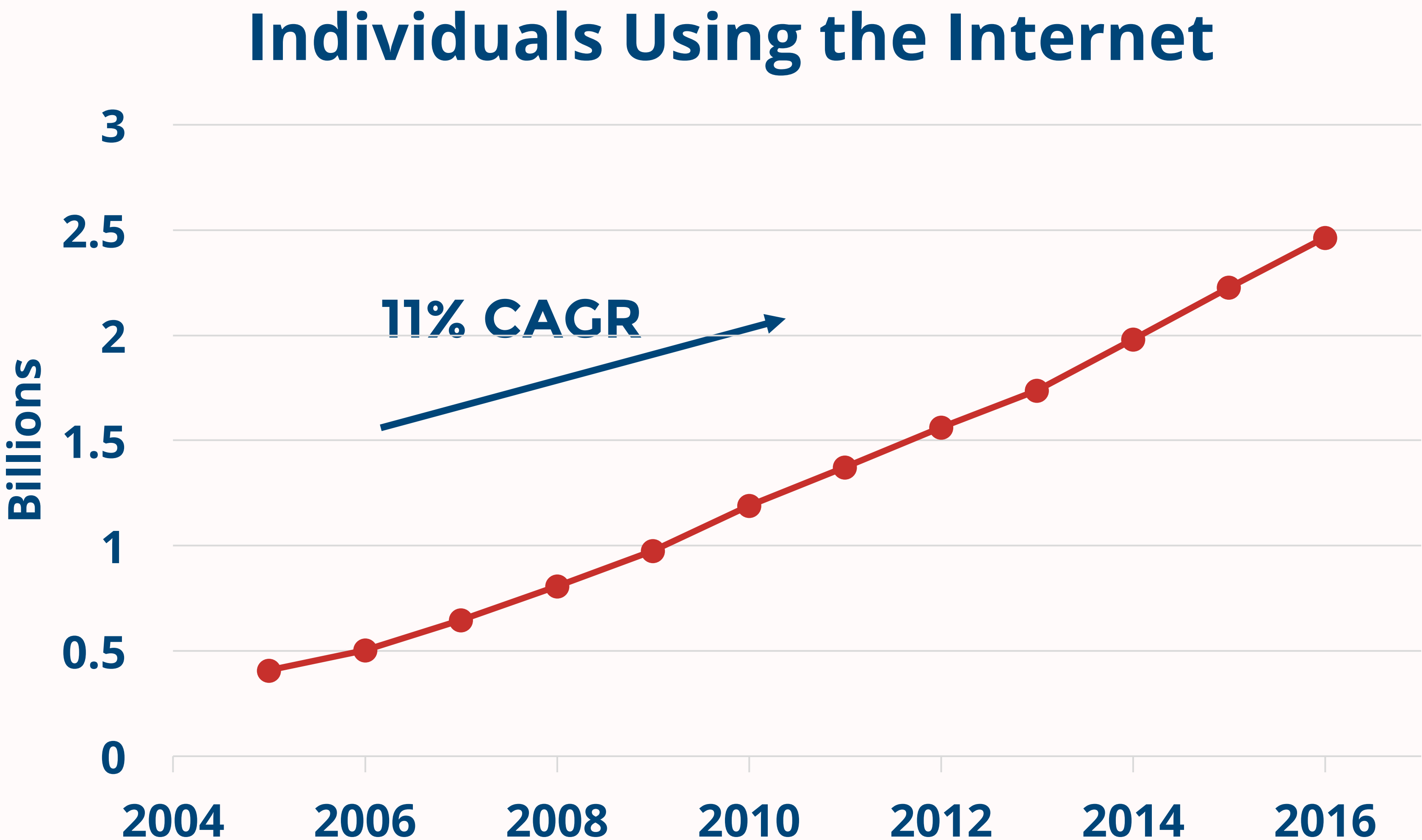
THE STATE OF THE INTERNET

TRENDS, TRAFFIC AND USERS

THE TRAFFIC GROWTH



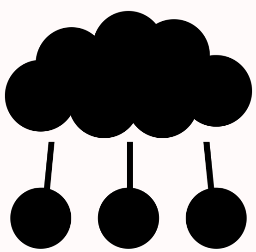
GLOBAL INTERNET USERS



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

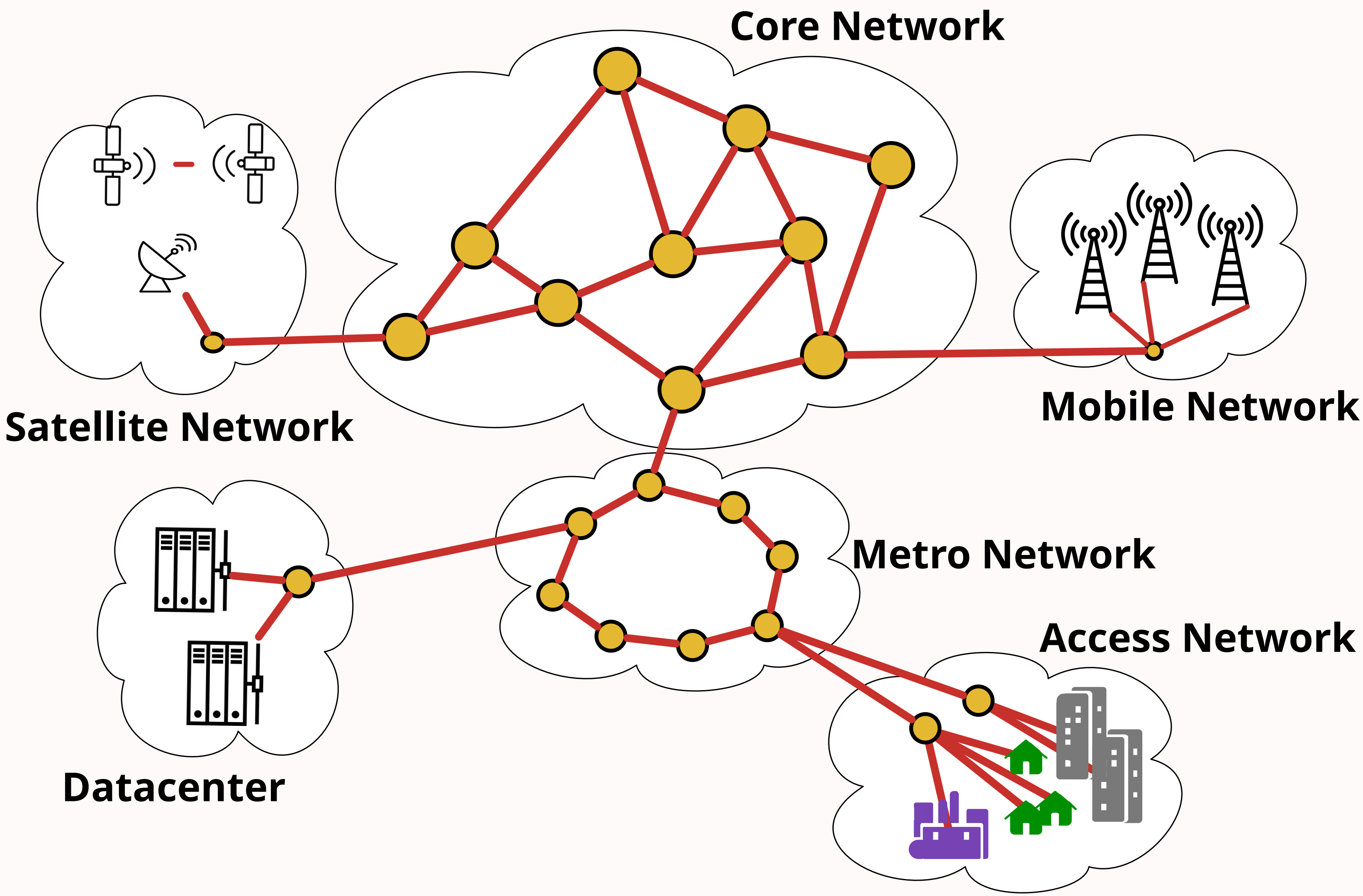
OPTICAL SYSTEMS

OPTICAL NETWORKS

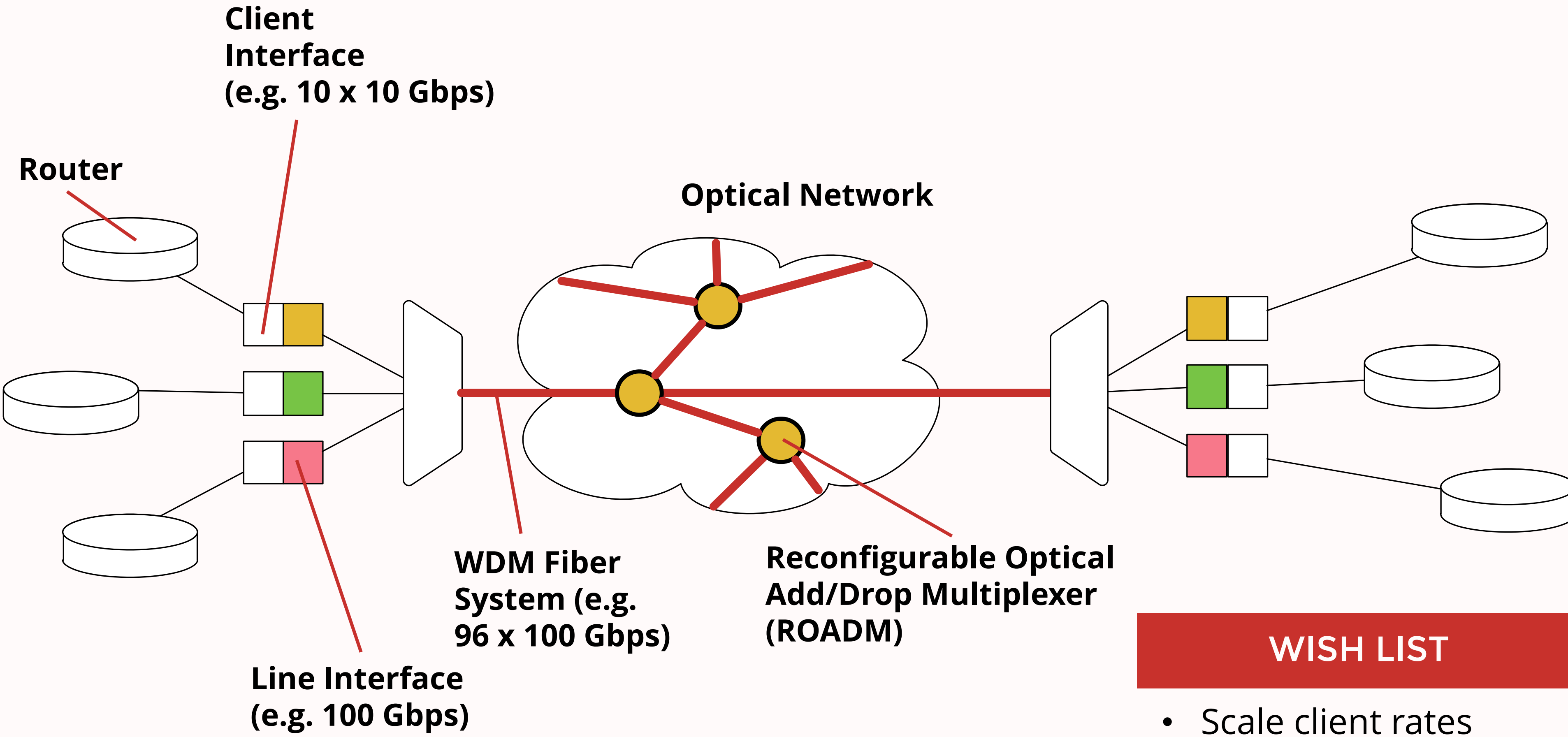
PHOTONIC TECHNOLOGIES: ENABLING THE INTERNET

THE UBIQUITY OF PHOTONICS IN DATA NETWORKS

THE INFRASTRUCTURE OF A DATA NETWORK



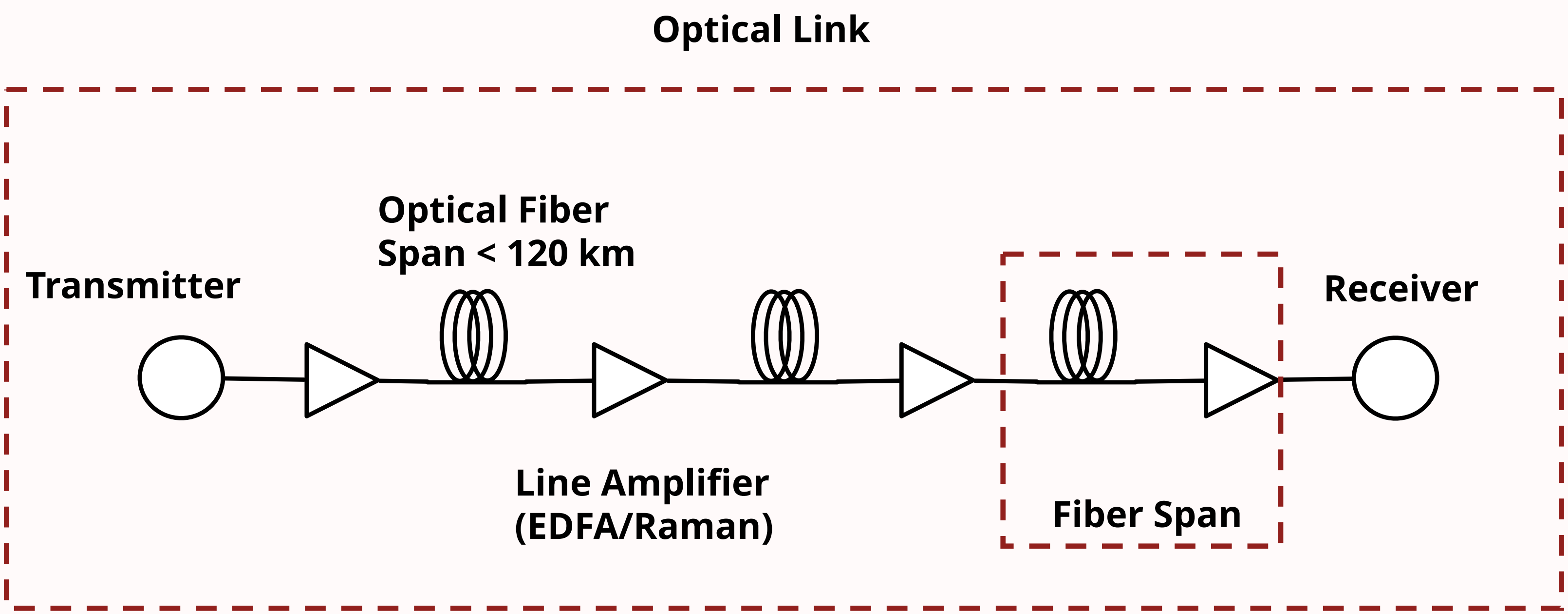
CORE NETWORK: THE ROLE OF OPTICS



WISH LIST

- Scale client rates
- Scale line rates
- Network flexibility
- Contain costs

WDM SYSTEMS


Optical Link
Optical Fiber
Span < 120 km
Transmitter
Receiver
Line Amplifier
(EDFA/Raman)
Fiber Span

COHERENT WDM SYSTEMS

A BRIEF INTRODUCTION

SENDING INFORMATION WITH LIGHT

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)

COHERENT MODULATION FORMATS

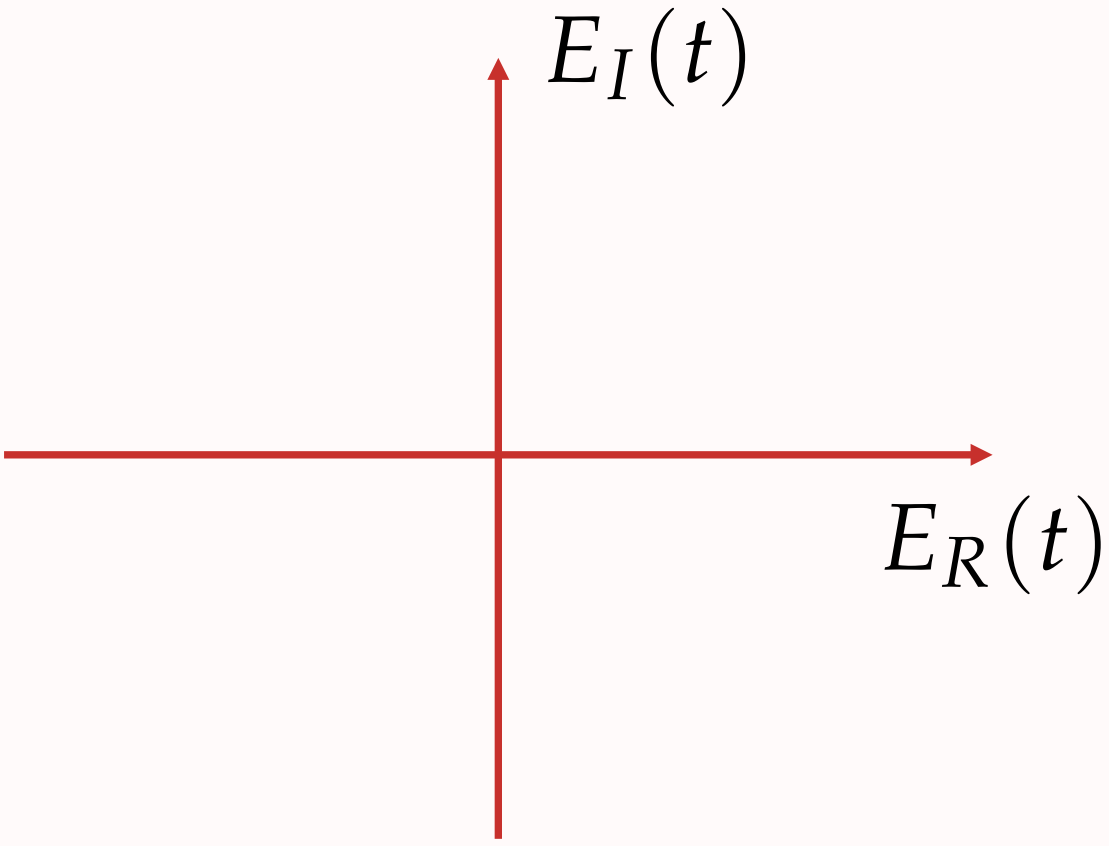
- We can describe light as an electric field, in particular like

$$E(t) = \underbrace{A(t)}_{\text{Amplitude}} \cdot e^{j\underbrace{\phi(t)}_{\text{Phase}}}$$

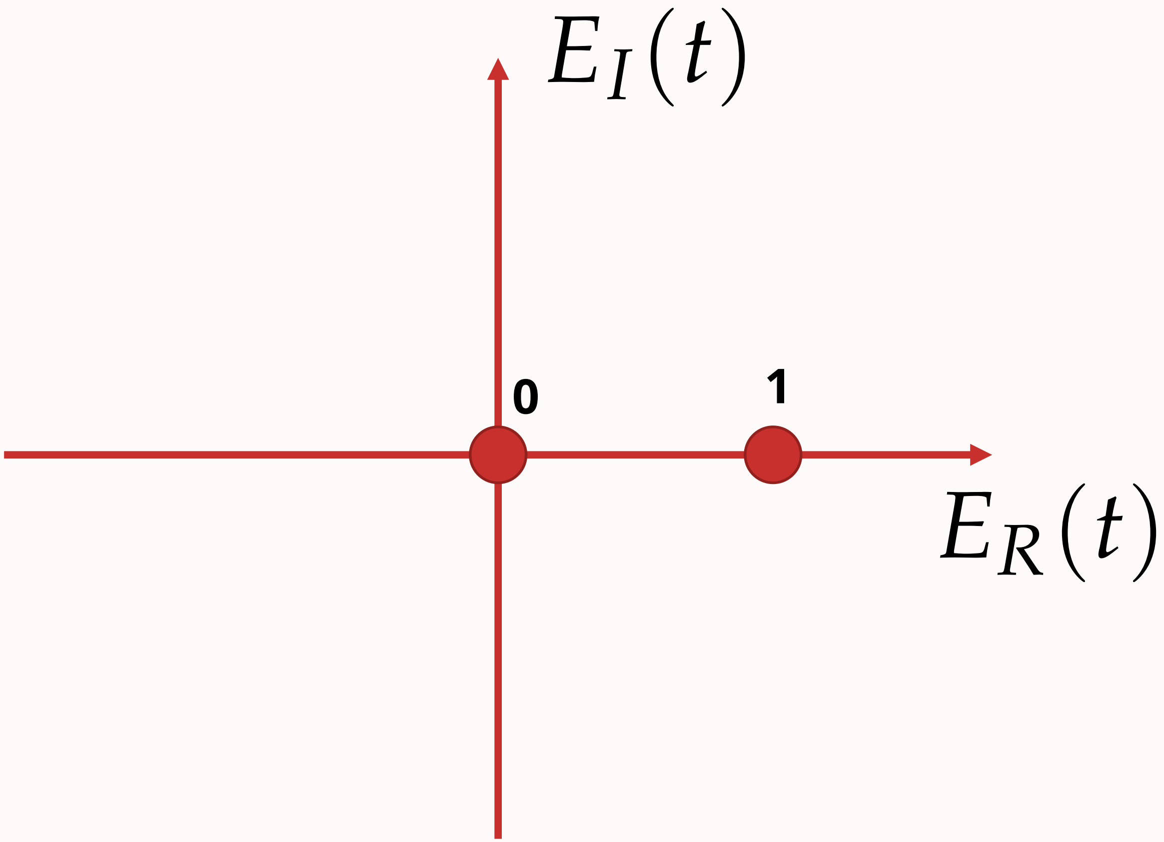
- This can be written as a complex number

$$E(t) = E_R(t) + jE_I(t)$$

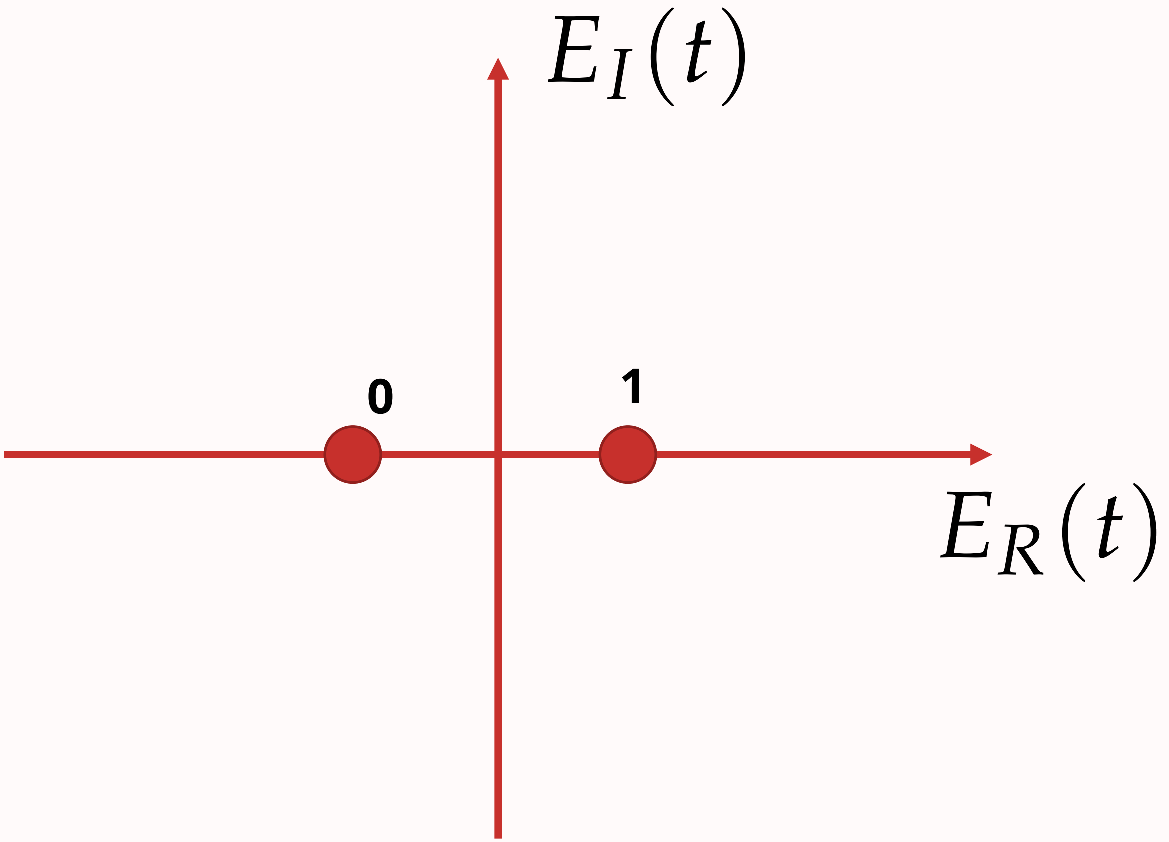
COHERENT MODULATION DRAWING BOARD



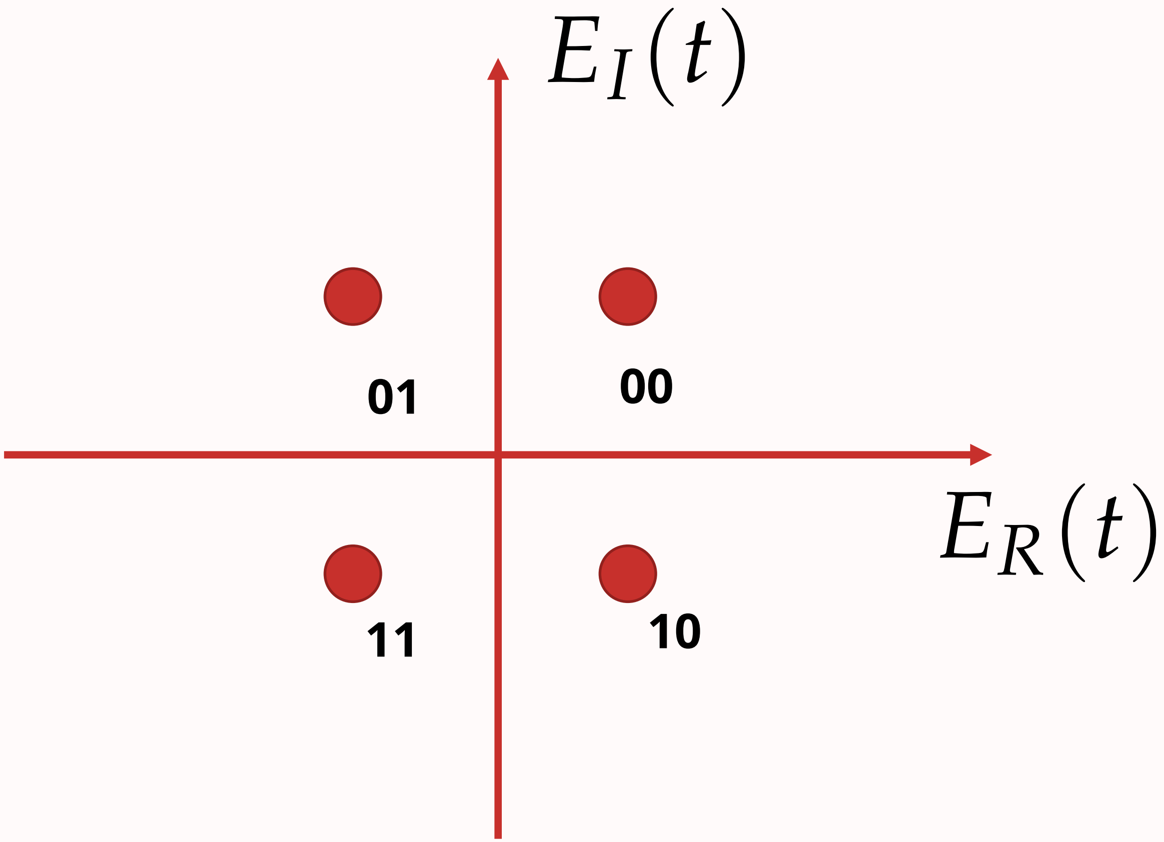
LEGACY MODULATIONS: IMDD



LEGACY MODULATIONS: PSK

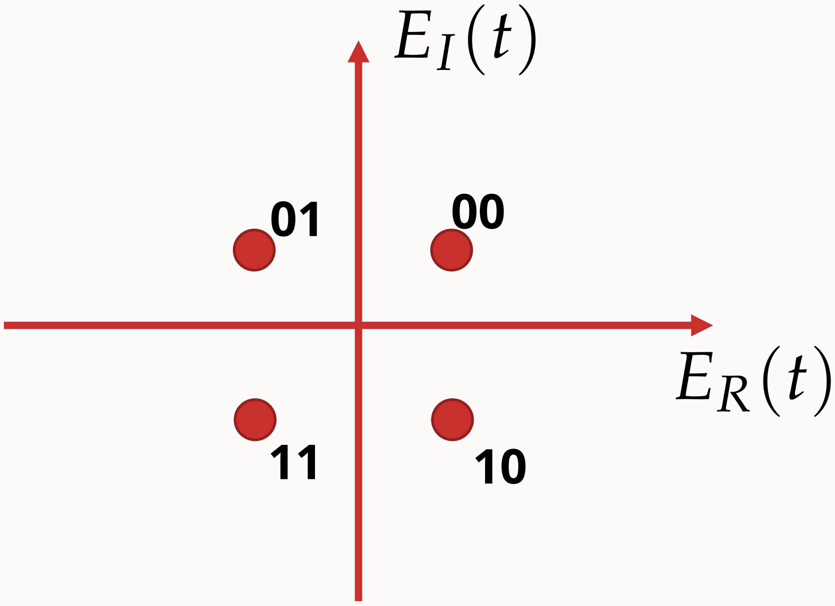


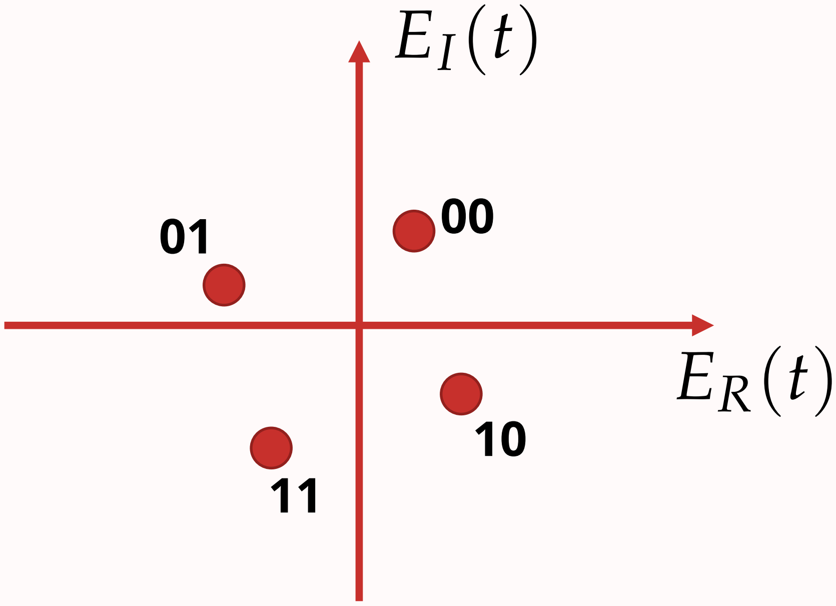
COHERENT MODULATIONS: QPSK / 4-QAM



We exploiting both real and imaginary part of the field!

COHERENT MODULATIONS: QPSK

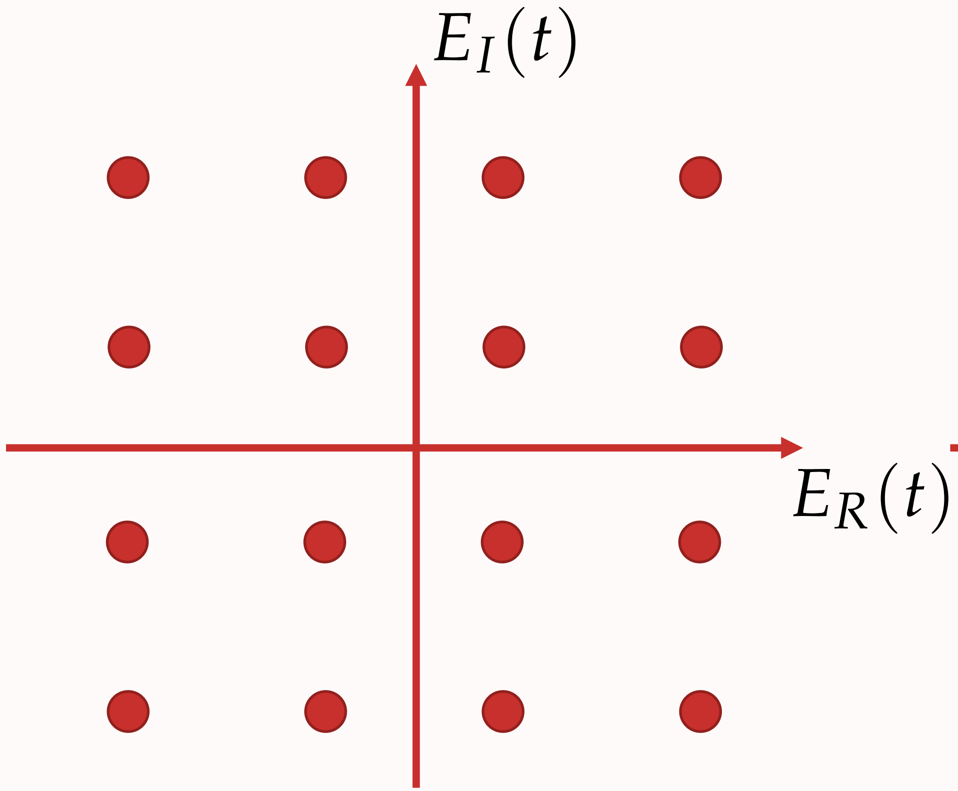




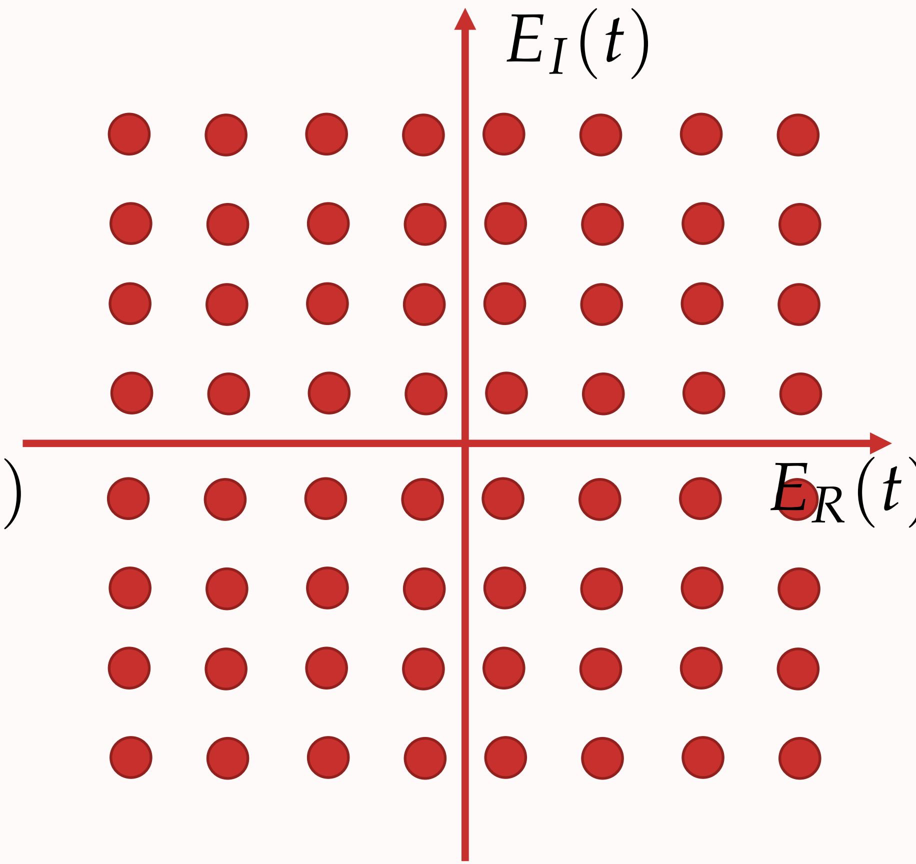
Phase Reference is Arbitrary!

COHERENT MODULATIONS: HIGHER ORDER FORMATS

16-QAM (4 BPS)



64-QAM (6 BPS)



EXPLOITING OPTICAL FIBER CHARACTERISTICS

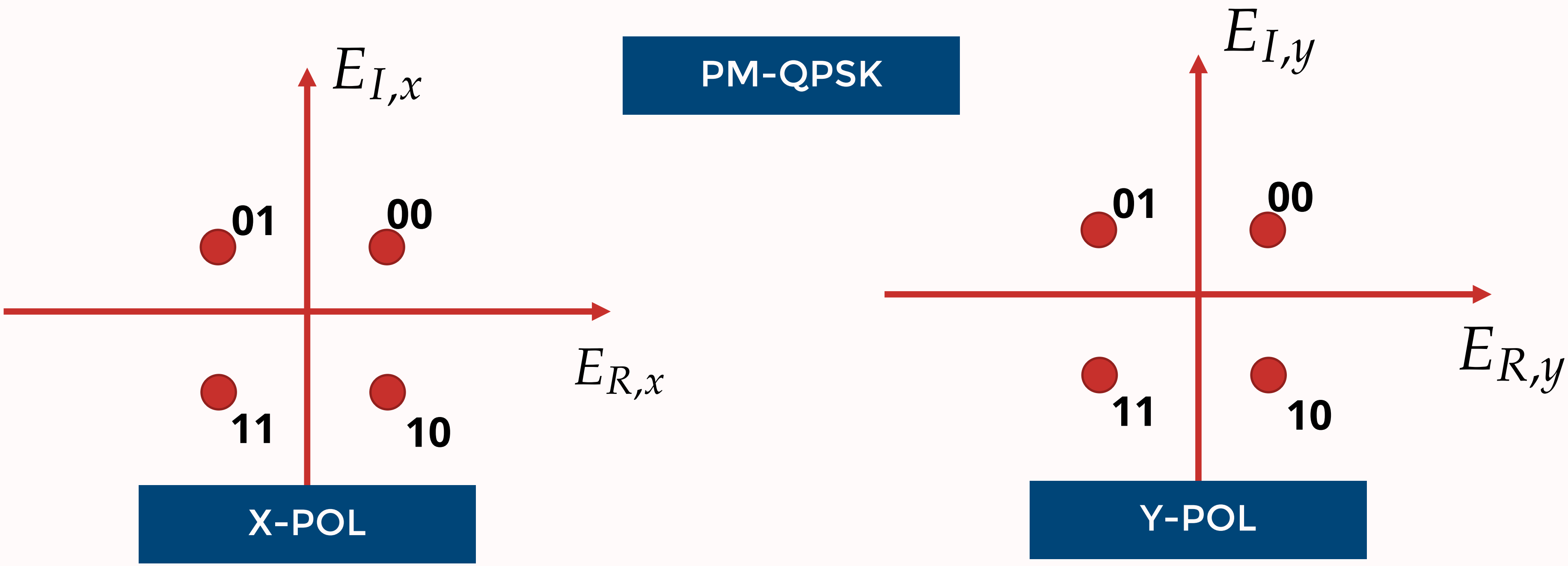
- The propagating mode of an optical fiber is a degenerate mode:
  - It is made of two orthogonal polarization traveling together along the fiber
- Light in the fiber can be thus described as

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

- Can we use this fact for our own benefit?

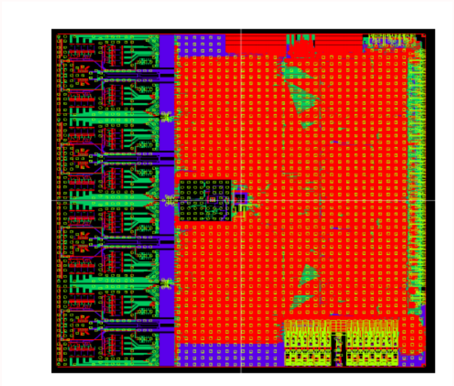
POLARIZATION MULTIPLEXING

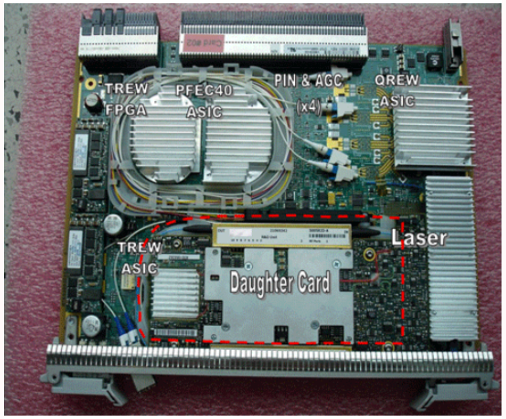
- Since the two orthogonal polarization are independent, we can double the amount of carried information, by transmitting a coherent signal on both of them.
- This is polarization multiplexing (PM)



PM-QPSK: THE MOST USED MODULATION FORMAT

- 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.





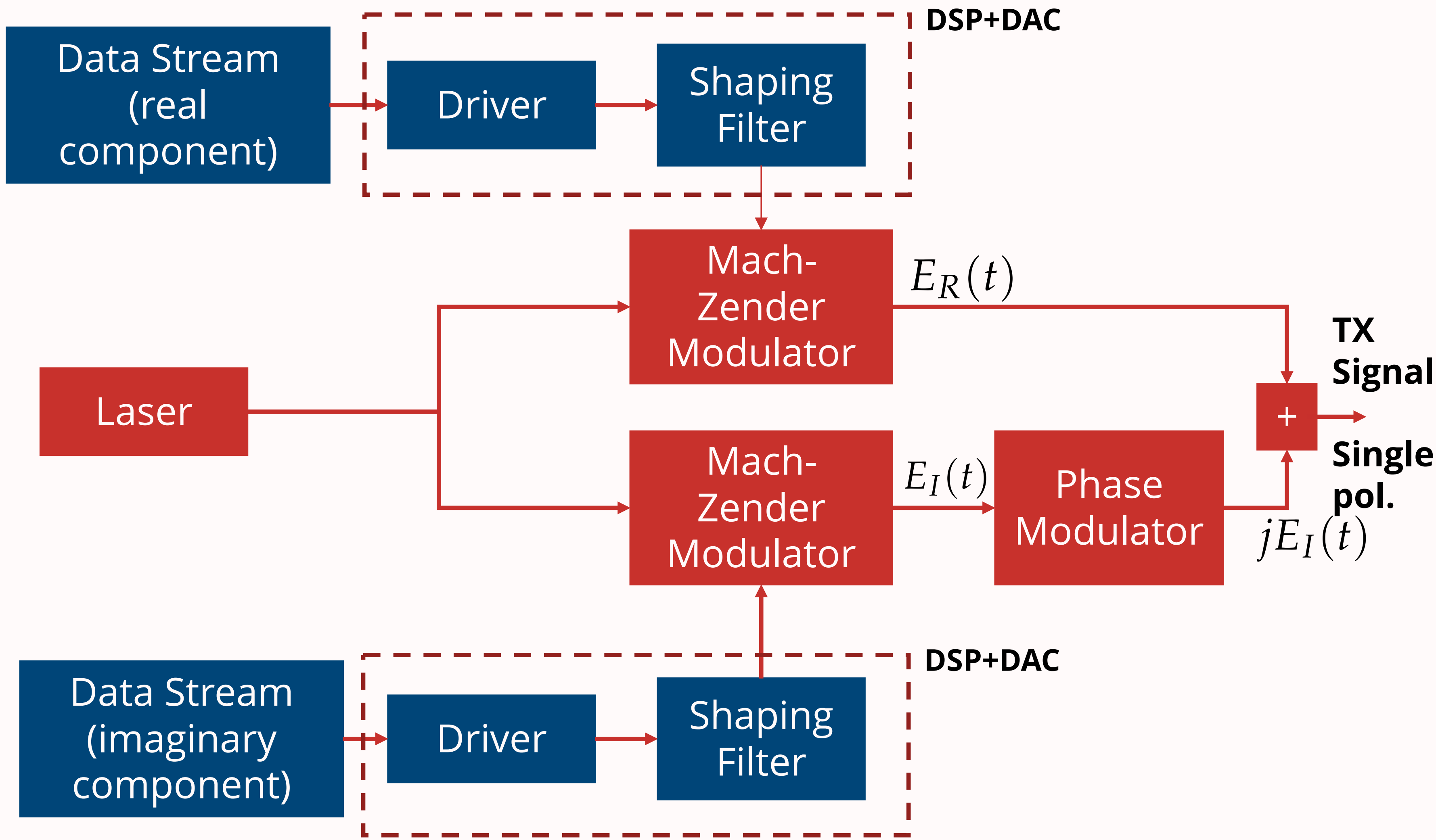
NORTEL 40G – COHERENT TRANSCEIVER

S. Han, K.T. Wu, and K. Roberts. "Real-time measurements of a 40 Gb/s coherent system." *O.E.* 16.2 (2008)

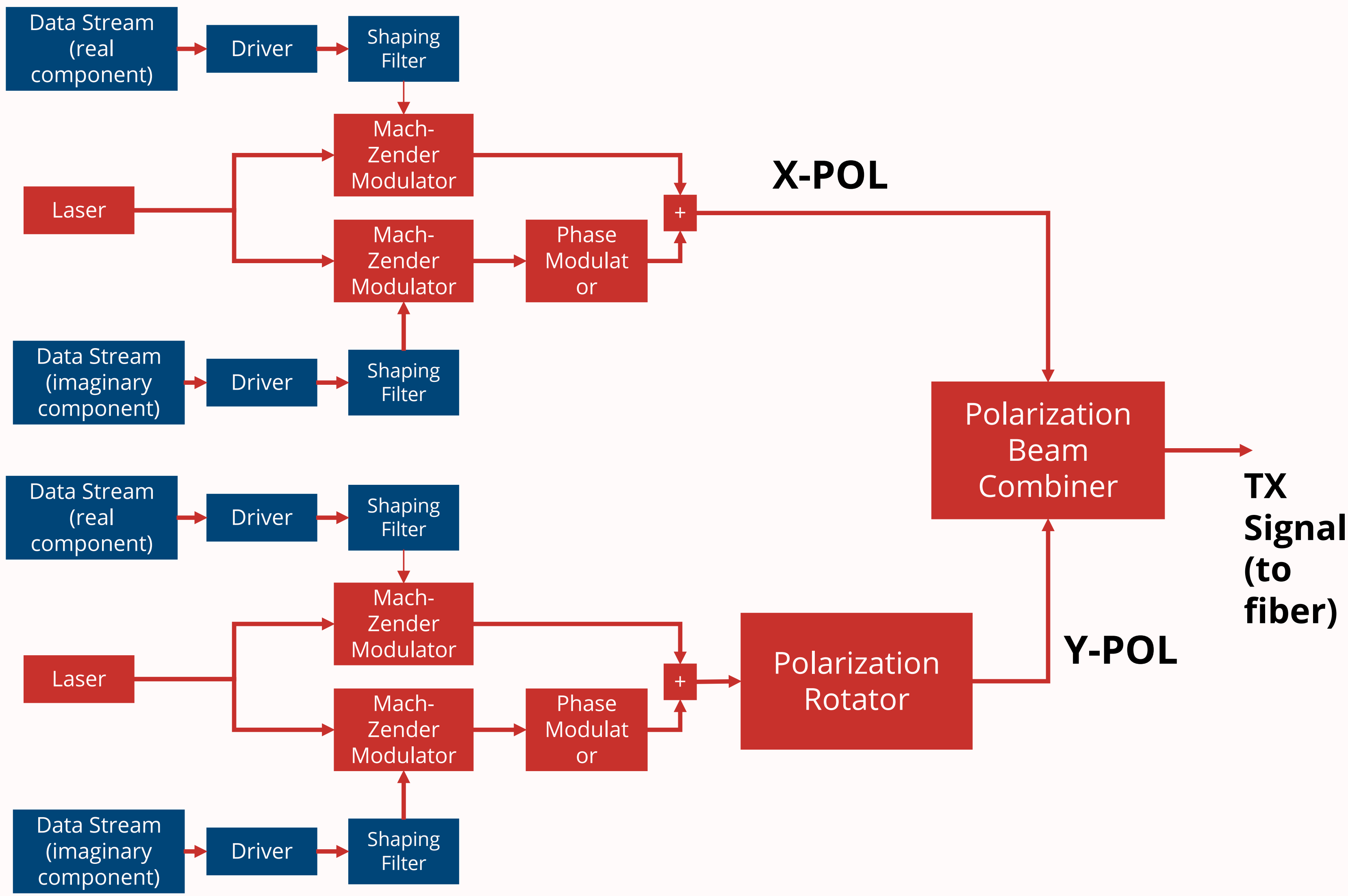
A PM-QPSK SYSTEM

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

A QPSK TRANSMITTER

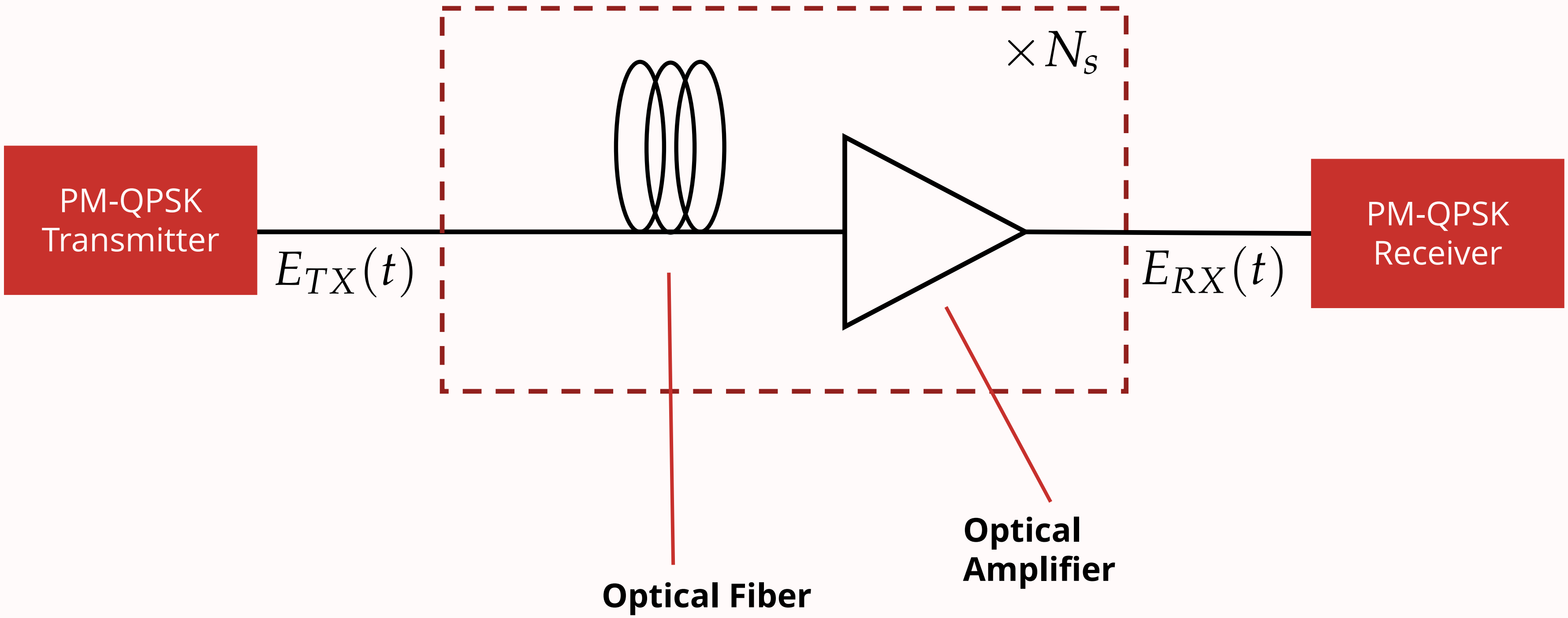


A PM-QPSK TRANSMITTER



RECEIVING PM-QPSK

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



WHAT ARE WE UP AGAINST?

MAIN FIBER PROPAGATION IMPAIRMENTS

LINEAR EFFECTS

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

They can be compensated electronically

ASE NOISE

- Amplified Spontaneous Emission (ASE) Noise

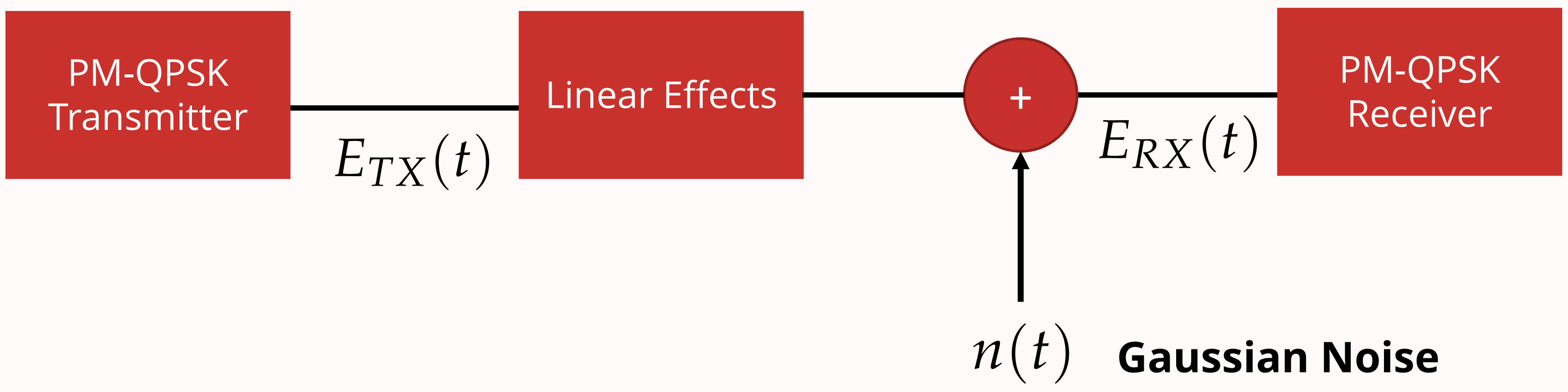
NONLINEAR KERR EFFECT

- Nonlinear Interference (NLI)

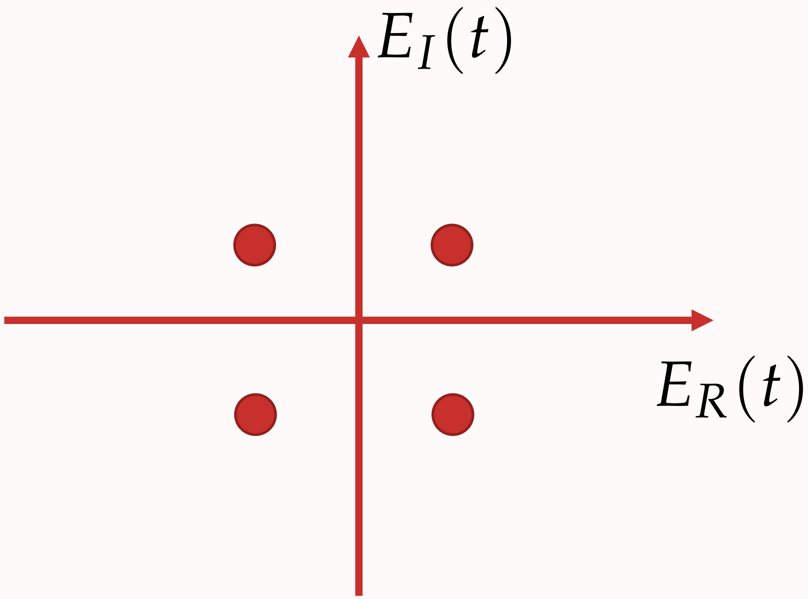
They can be modeled as Gaussian Noise*! They are the bottom-line disturbances

A. Carena, et. al. "Modeling of the impact of nonlinear propagation effects in uncompensated optical coherent transmission links" *JLT* (2012)

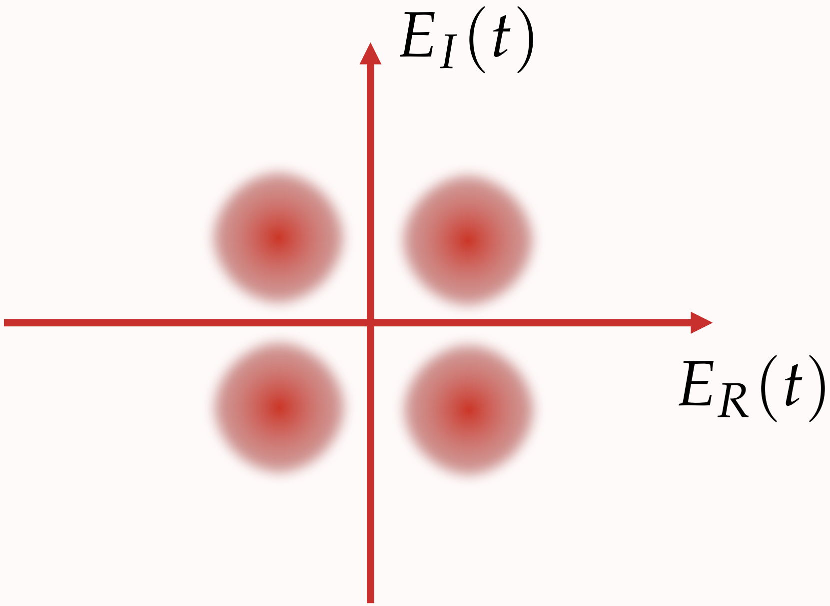
MODELING FIBER PROPAGATION



GAUSSIAN NOISE IMPACT



TRANSMITTED CONSTELLATION

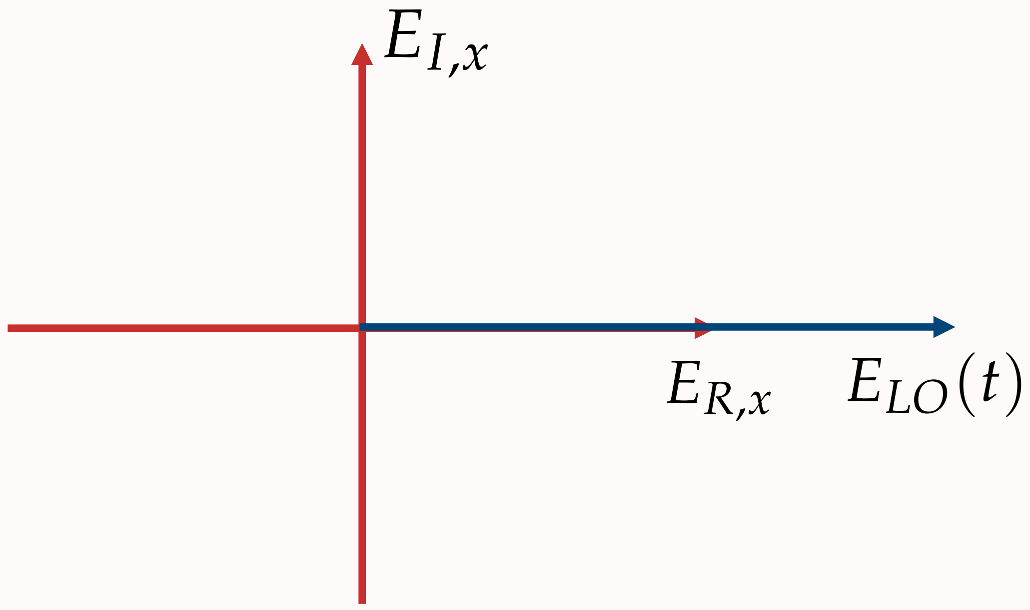


RECEIVED CONSTELLATION

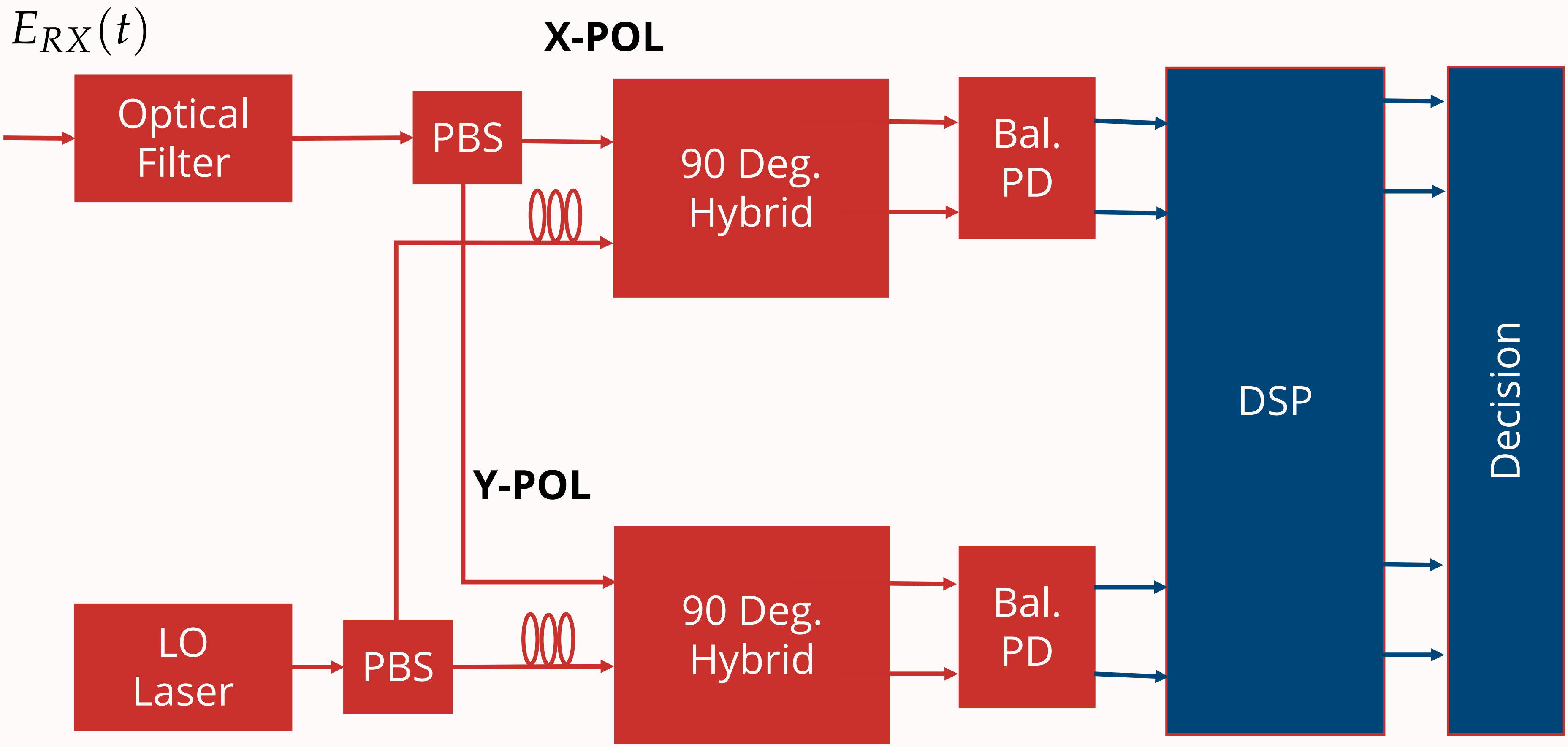
How can we receive this?

RECEIVER STRUCTURE: DETECTION BY INTERFERENCE

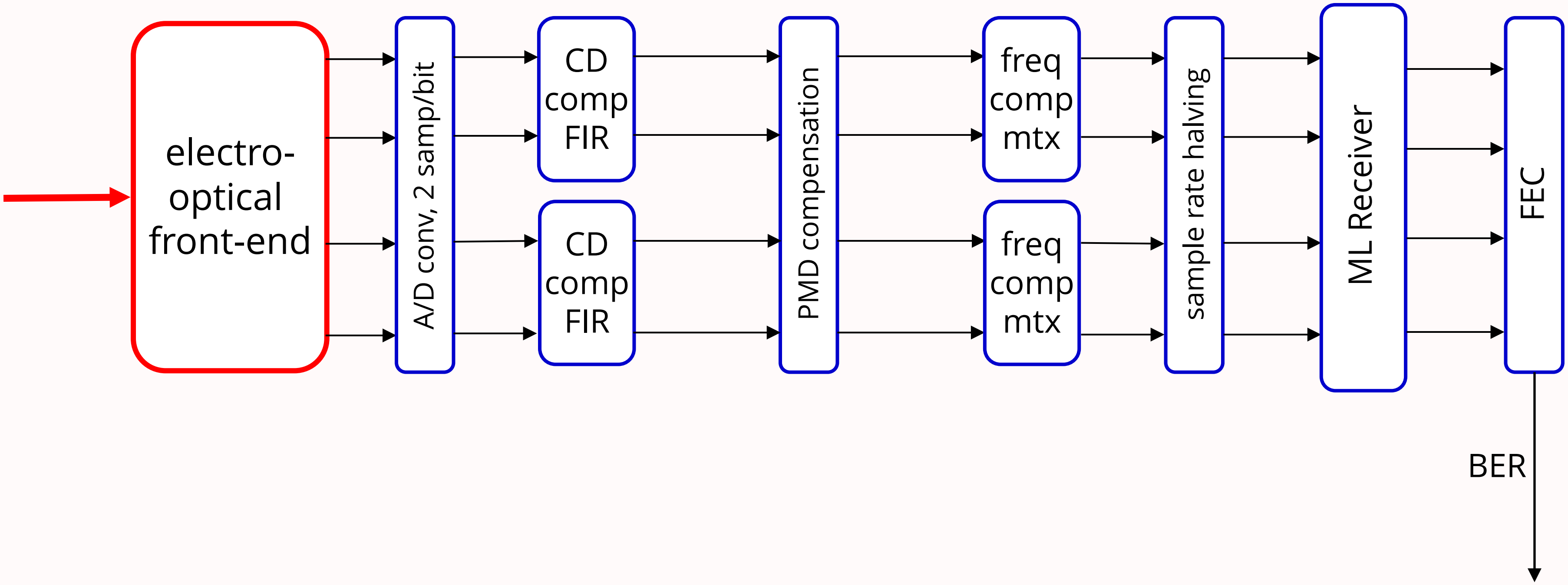
- We need to detect real, imaginary component for each polarization
- To do so, we need to add a local oscillator (LO) that is "aligned" with the component we wish to receive, than we use a photodetector to measure the corresponding current



RECEIVER STRUCTURE

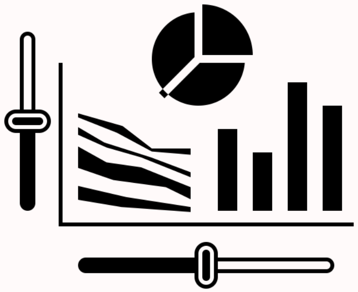


DSP STRUCTURE

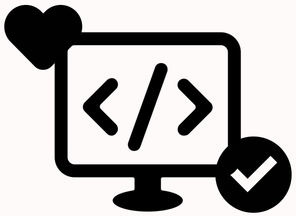


DSP: A GAME CHANGER

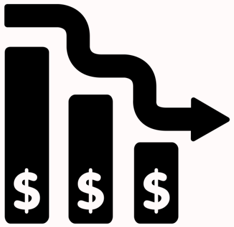
- The introduction of DSP has caused a big change in optical communication technologies, allowing reconfiguration, cost reduction, and the development of new transmission techniques.



Dynamically Reconfigurable

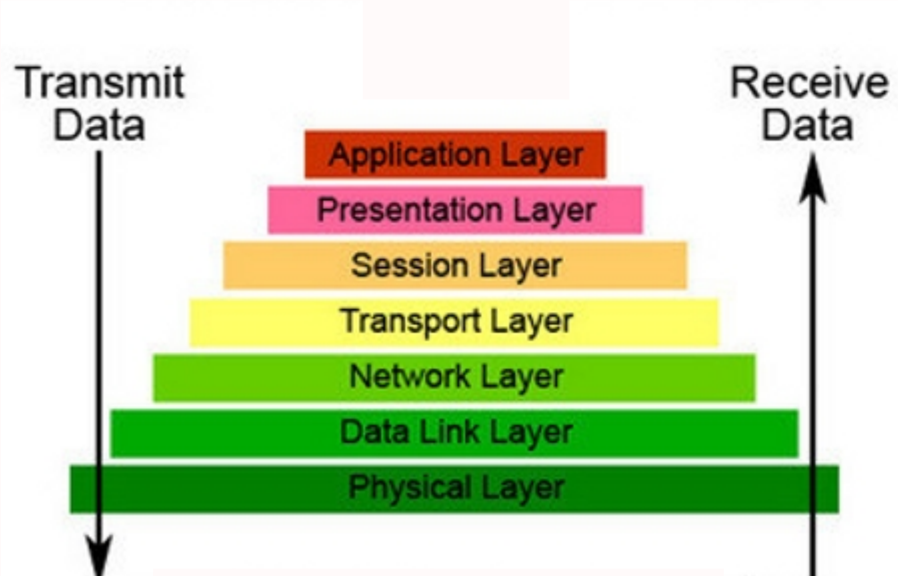


Relatively easy to reprogram

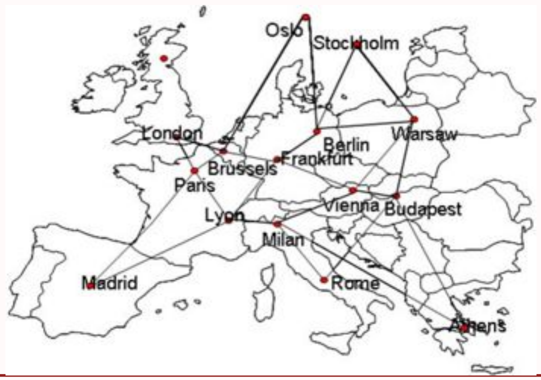


OPEX Reduction

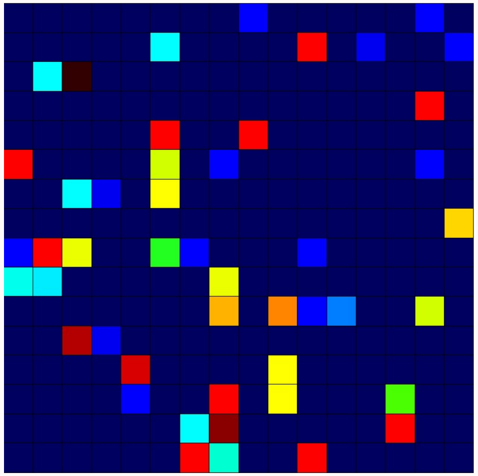
LEGACY NETWORK PARADIGM



Rigid WDM optical network

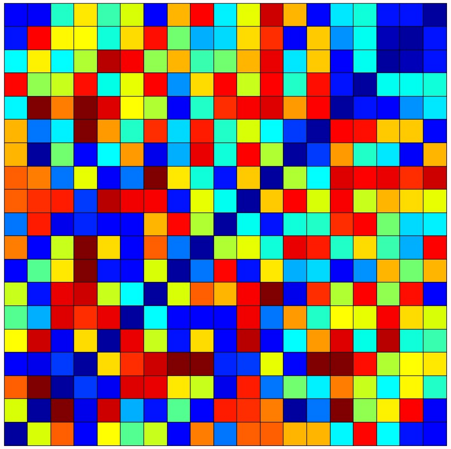


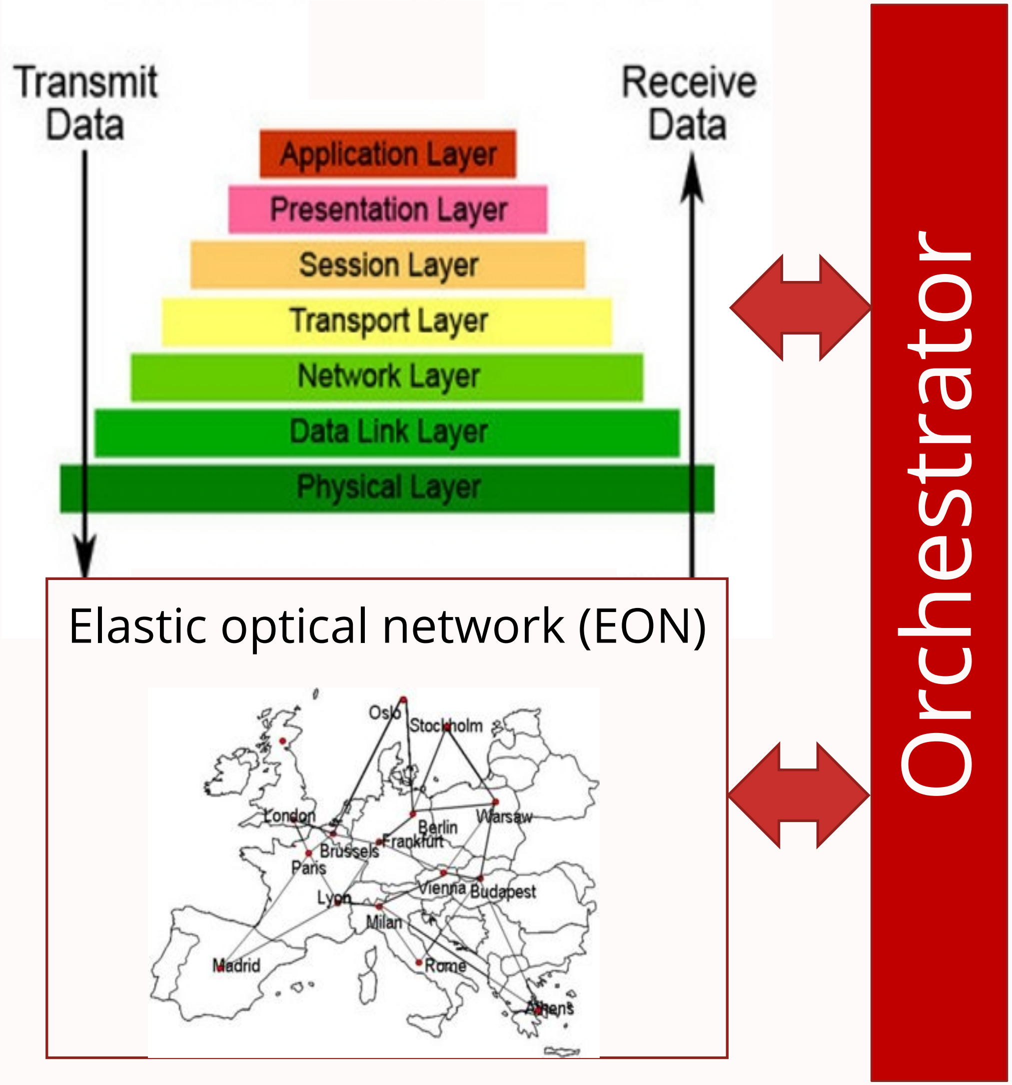
- IMDD modulation
- In-line dispersion compensation
- Only pre-defined transparent transmission
- No flexible trasparent wavelength routing
- The transparent connectivity matrix is sparse and unchangeable



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

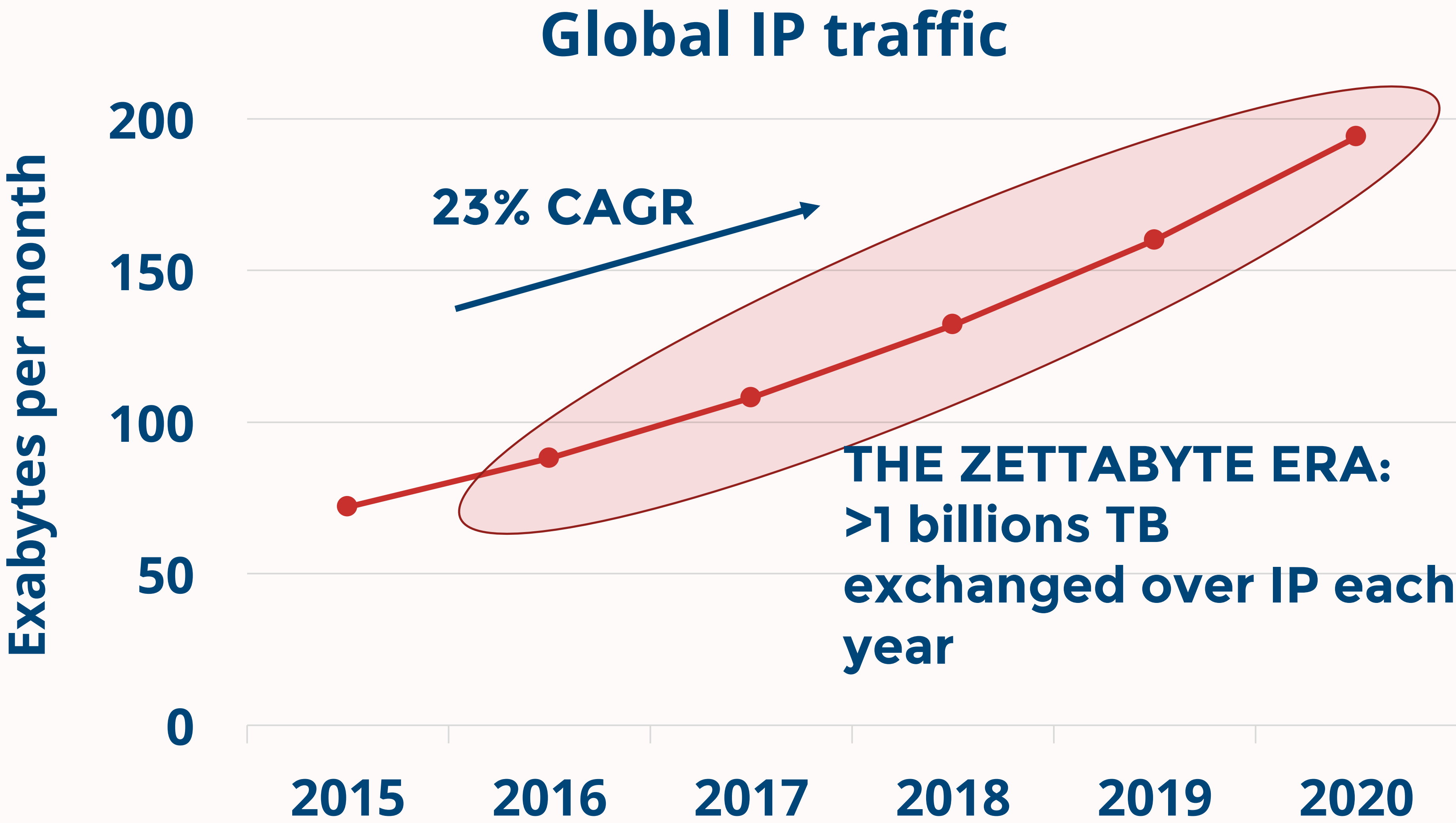




FUTURE TRENDS

WHAT FUTURE DATA NETWORK WILL FACE?

THE CHALLENGE

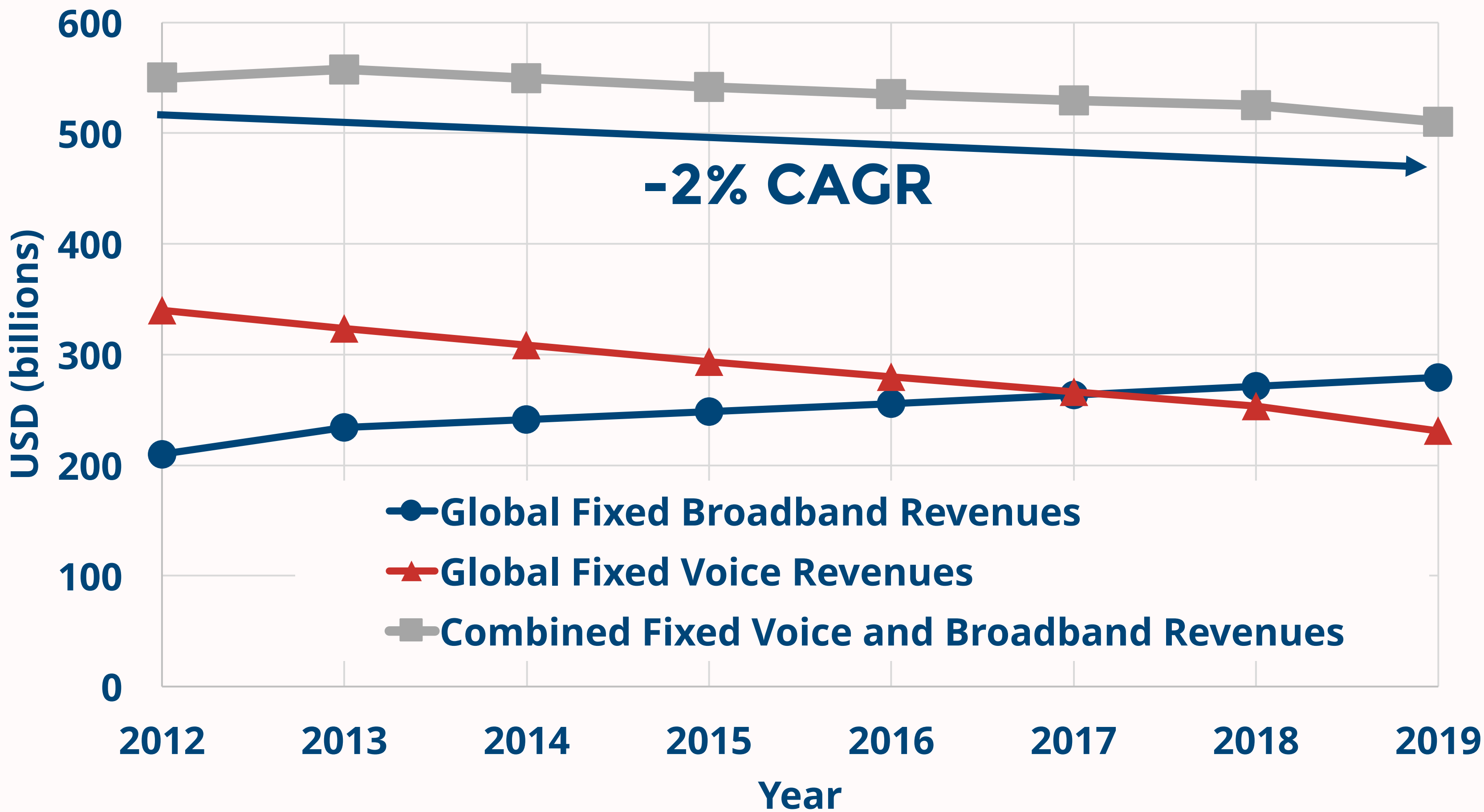


Cisco VNI Forecast and Methodology, 2015-2020

THE CHALLENGE

Nolle: In 2017, Cost Per Bit Exceeds Revenues

https://goo.gl/qPTVud



ACTORS' WISH LISTS

TELECOM OPERATORS

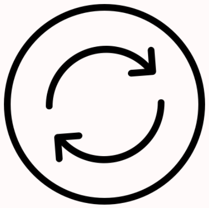
- Pursuing growth
- Controlling Costs

VENDORS

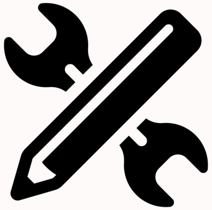
- Develop the right technology to fit data growth
- Push its market adoption

A COMMON NEED

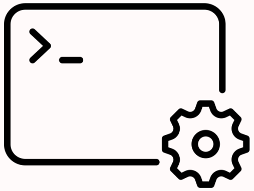
- In this scenario, understanding **the merit of different technologies** on overall **network performance** is fundamental.
- This is required in order to **drive**



Network Upgrades

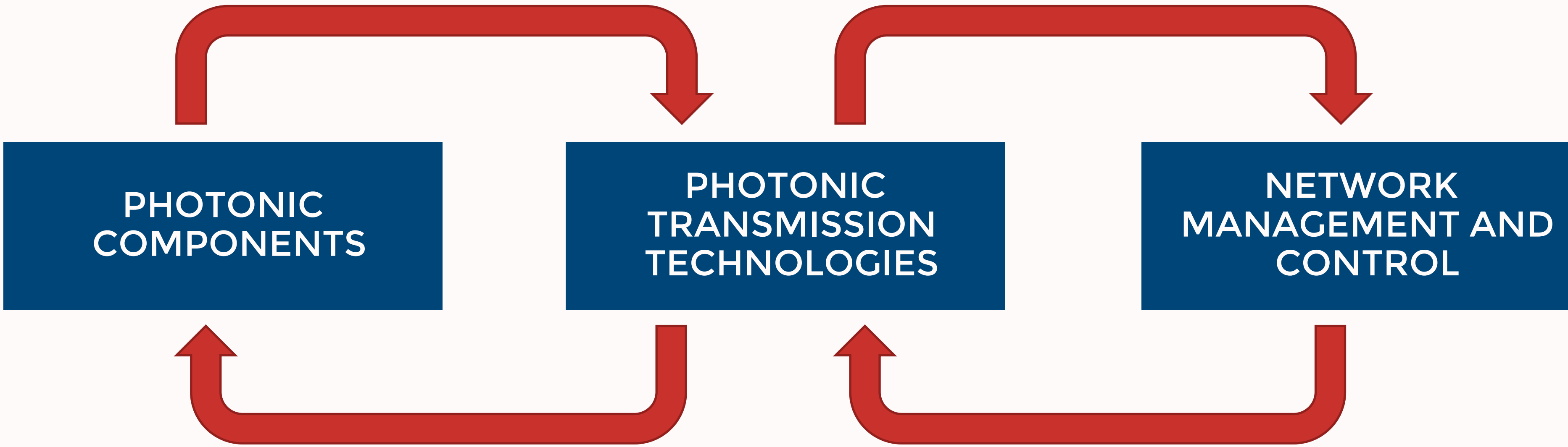


Network Design



Network Management

A POSSIBLE SOLUTION; A HOLISTIC VIEW OF DATA NETWORK



INNOVATION AND VALUE CREATION

FUTURE CHALLENGES

FACING THE CAPACITY CRUNCH

IS THERE A LIMIT TO THE GROWTH OF TRAFFIC?

Current Biology *16*, 1428–1434, July 25, 2006 ©2006 Elsevier Ltd All rights reserved DOI 10.1016/j.cub.2006.05.056

How *Much* the Eye Tells the Brain

Kristin Koch,[1] Judith McLean,[1] Ronen Segev,[2]
Michael A. Freed,[1] Michael J. Berry II,[2]
Vijay Balasubramanian,[3] and Peter Sterling[1,*]
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Princeton, New Jersey 08544
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University of Pennsylvania
Philadelphia, Pennsylvania 19104

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

Ed Harstead and Randy Sharpe

the killer app

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

M. Zubair Shafiq† Lusheng Ji‡ Alex X. Liu† Jeffrey Pang‡ Jia Wang‡
†Department of Computer Science and Engineering, Michigan State University, East Lansing, MI, USA
‡AT&T Labs – Research, Florham Park, NJ, USA

Machine-to-Machine traffic will become dominant

HOW TO COPE WITH SUCH GROWTH?

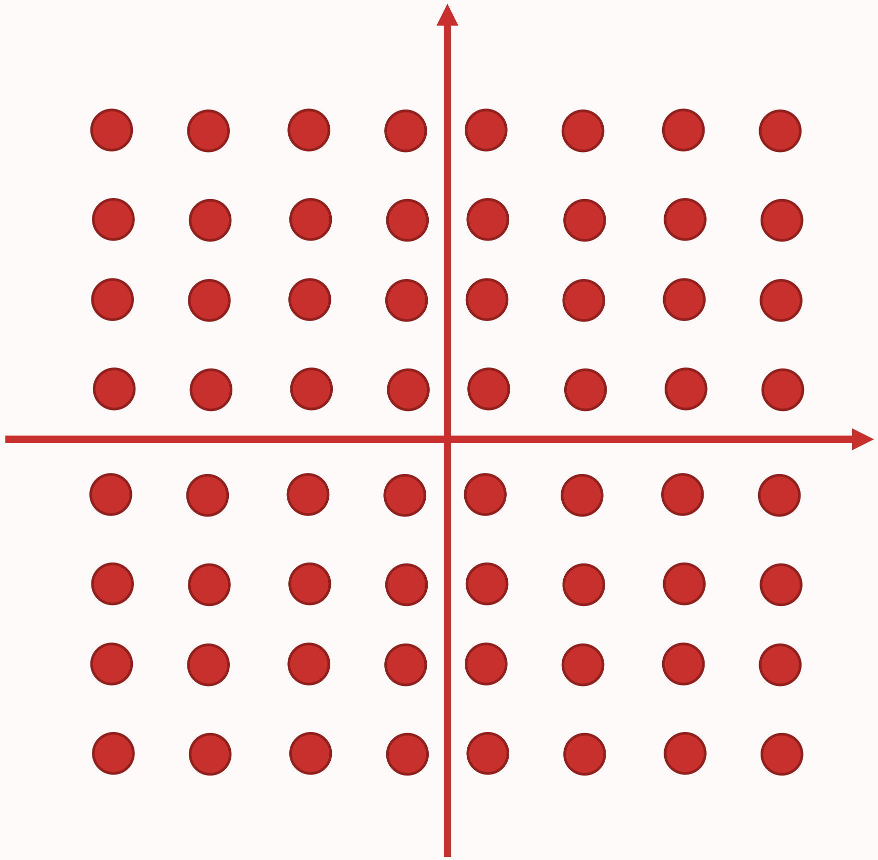
DEGREES OF FREEDOM

QUADRATURE

FREQUENCY

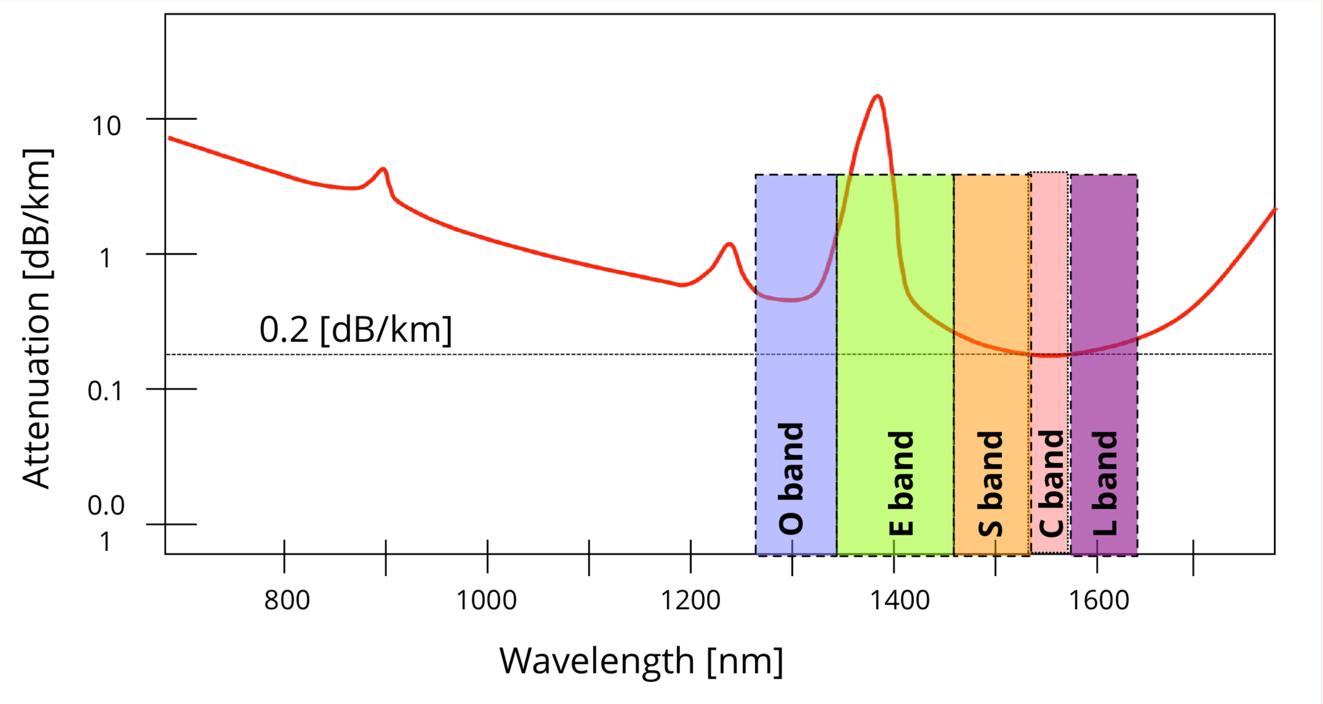
SPACE

QUADRATURE: INCREASE CONSTELLATION SIZE



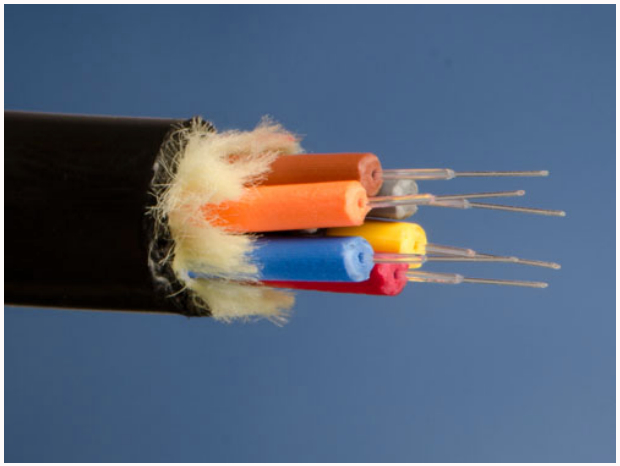
- Log growth of capacity with number of points
- Complex from an electronic and transmission standpoint

FREQUENCY: INCREASE BANDWIDTH USAGE

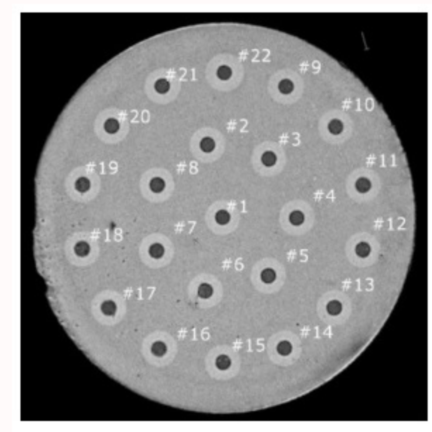


- Linear growth of capacity with BW
- Issues with
  - Lack of components
  - Power Limitation

SPACE: INCREASE FIBER NUMBER



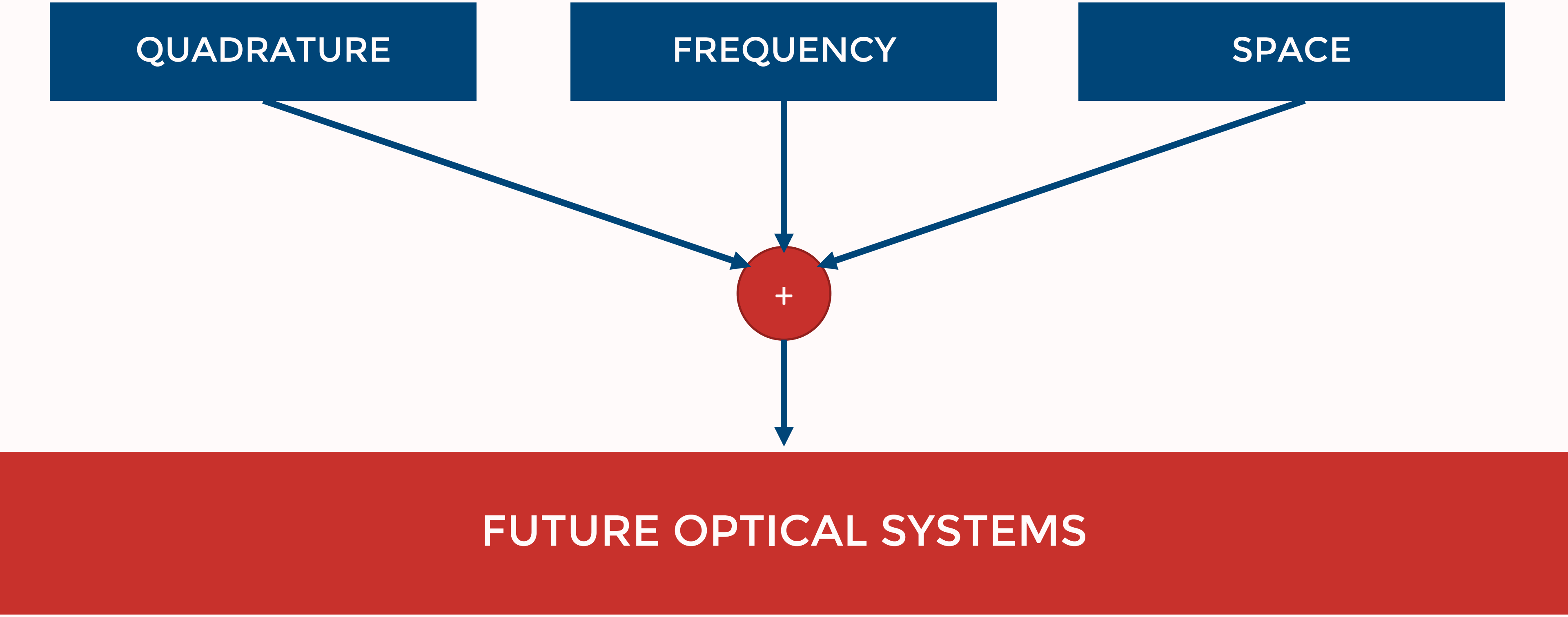
Integration →



Puttnam – ECOC 2015

- Linear growth of capacity with core number
- Issues with
  - Lack of components
  - Receiver Complexity
  - Lack of integrated components

THE MOST PROBABLE FUTURE



OPEN PROBLEMS

PHOTONIC COMPONENTS

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

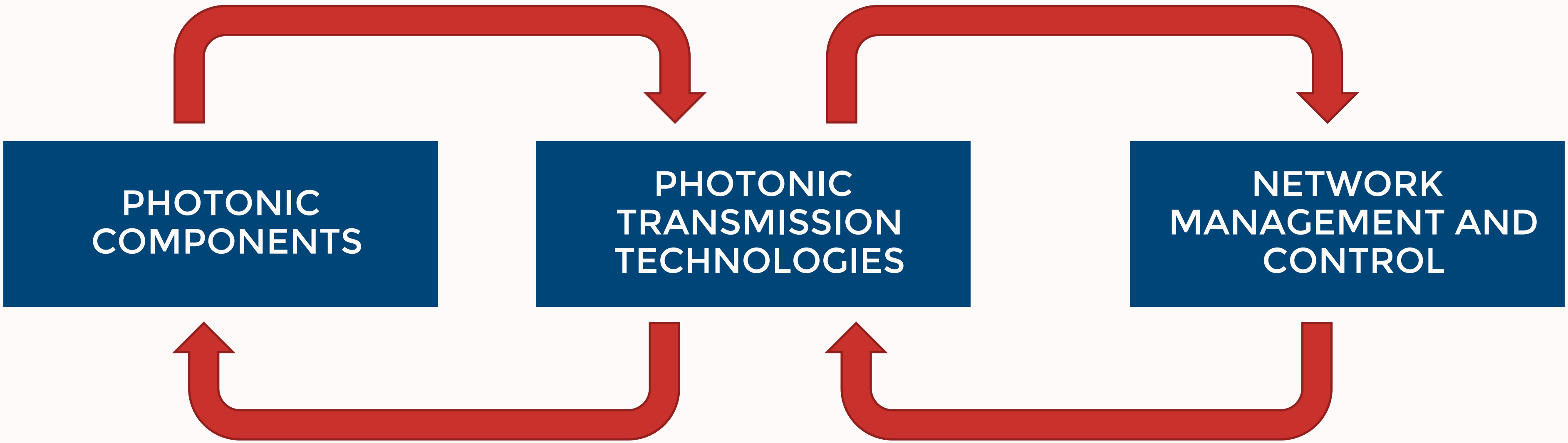
PHOTONIC TRANSMISSION TECHNOLOGIES

- 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



INNOVATION AND VALUE CREATION

THANK YOU!

QUESTIONS?

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6) “Nolle: In 2017, Cost Per Bit Exceeds Revenues” – online goo.gl/qPTVud
7) K. Koch et al., “How much the eye tells the brain,” Current Biology **16**, 1428–1434, (2006)
8) E. Harstead and R. Sharpe, “Forecasting of access network bandwidth demands for aggregated subscribers using Monte Carlo methods,” IEEE Comm. Mag. **53**(3), 199-207 (2015).
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