Scaling Optical Capacity to Meet Internet Demand

Drew Perkins: CTO, Infinera

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what THE NETWORK will be

"Technology and Architecture to Enable the Explosive Growth of the Internet"*

- Internet demand "set to grow by a factor of 1,000 over the next 20 years"

Let's look at one way we can enhance spectral efficiency in practical transport networks

	Benefit factor	Percentage of traffic subject to benefit	Effective capacity multiplier
Available excess capacity in today's networks	3	100%	3
Increased spectral efficiency	10	100%	10
Expanded transmission band	2	100%	2
Multicore single-amp fiber	7	100%	7
More efficient IP packing	2	80%	1.7
Multicast/asymmetric/caching	4	20%	1.2
Dynamic networking	5	25%	1.3
		Total effective capacity multiplier	~1100

*Adel A. M. Saleh and Jane M. Simmons; IEEE Communications Magazine, January 2011

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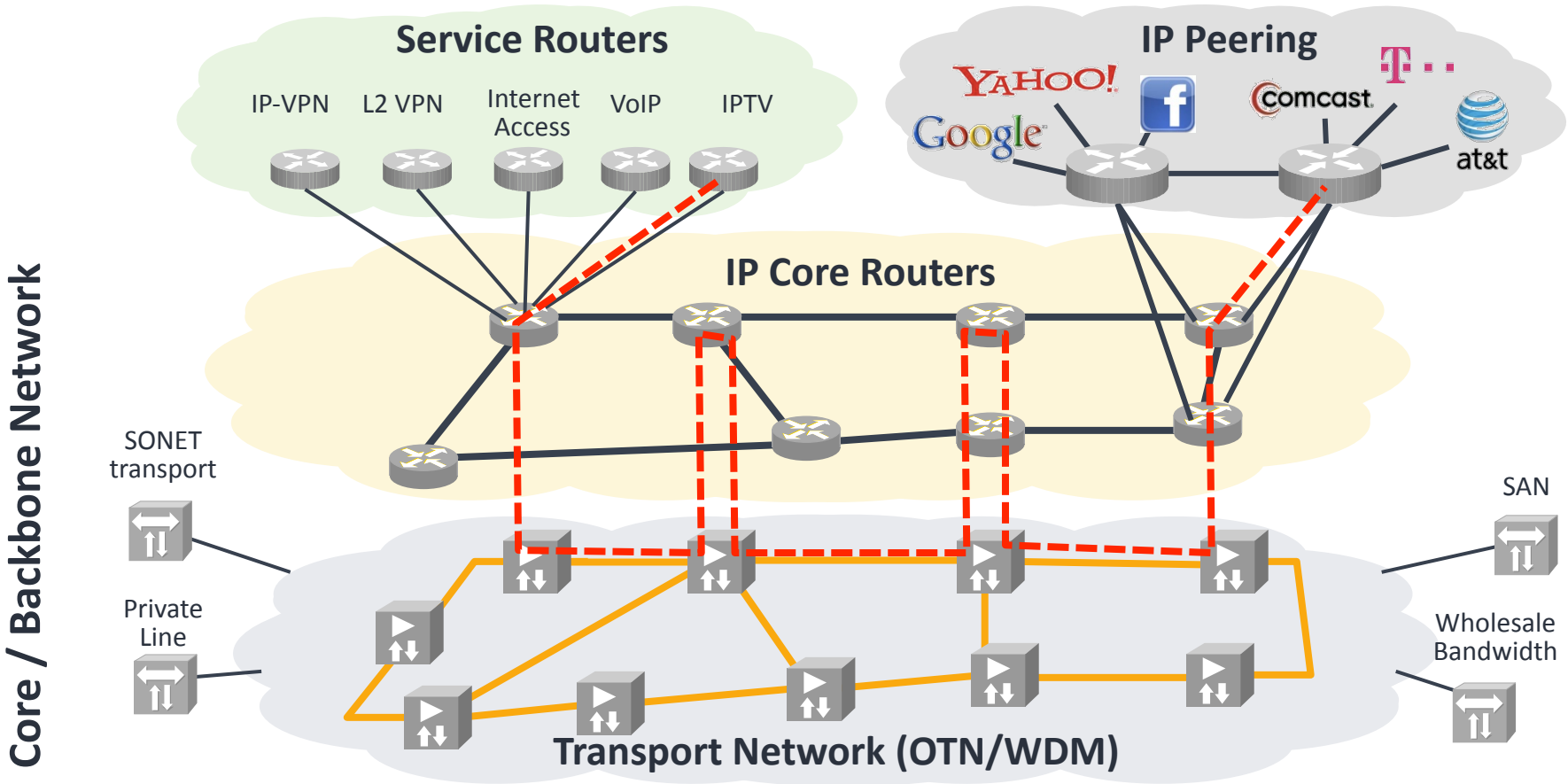
Understanding The Transport Layer



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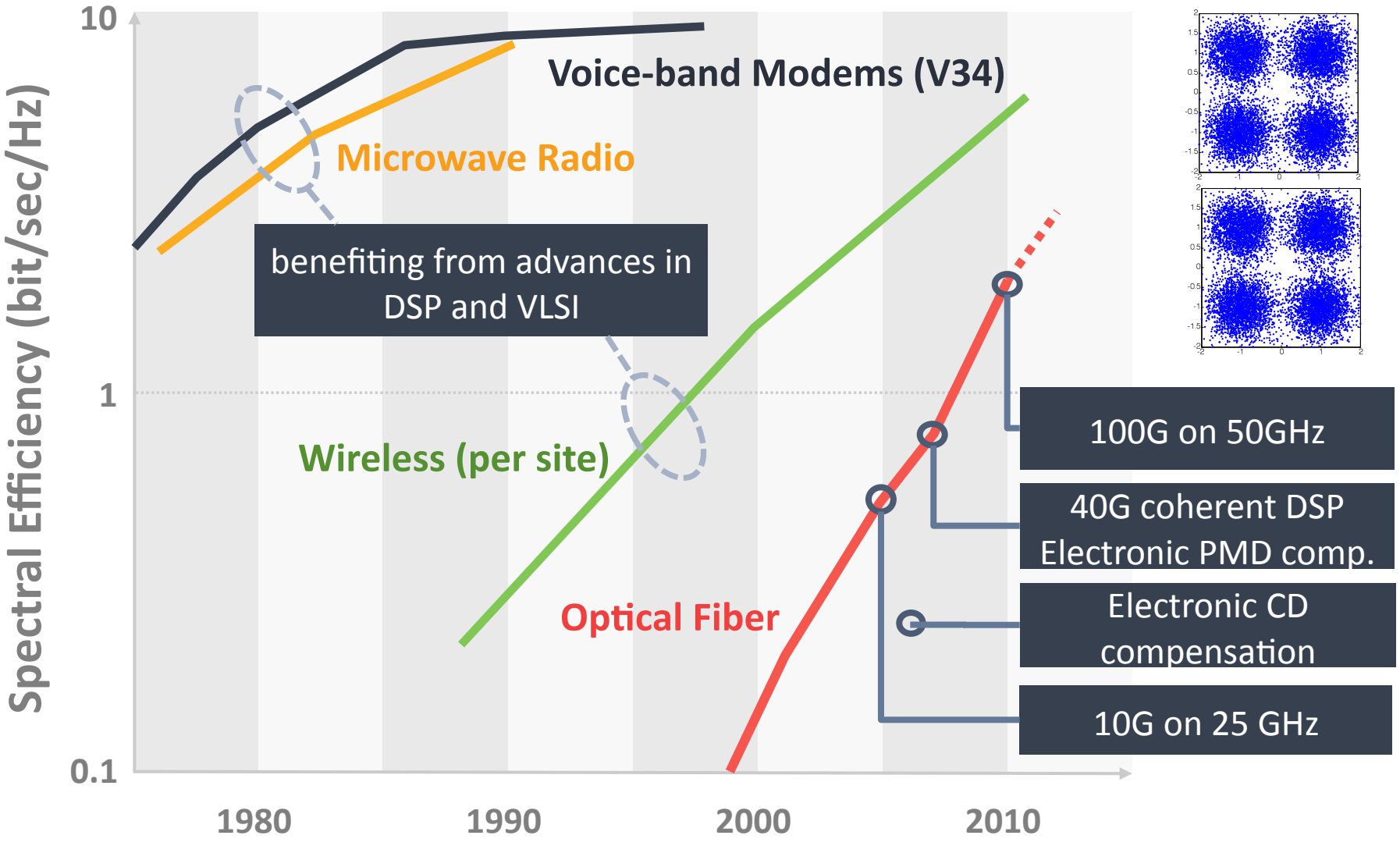
Total Fiber Capacity

- A key factor in scaling the network is the product of the *data rate of a single wavelength*, and the *number of wavelengths* on a fiber
  - In other words, the *total fiber capacity*

- How has the optical transmission industry responded to the challenge to scale total fiber capacity?

Progress in Optical Communications



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What's Changed So Far

Since the advent of DWDM…

Intensity Modulation	**Phase Modulation**
Direct Detection	**Coherent Detection**
ITU Frequency Grid	**ITU Frequency Grid**

now

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What Comes Next For Terabit Transport?

Since the advent of DWDM…

Intensity Modulation	Quadrature Amplitude Modulation (QAM)
Direct Detection	Coherent Wave Combining and Separation
ITU Frequency Grid	Grid-less Super-Channels

…so what has to change

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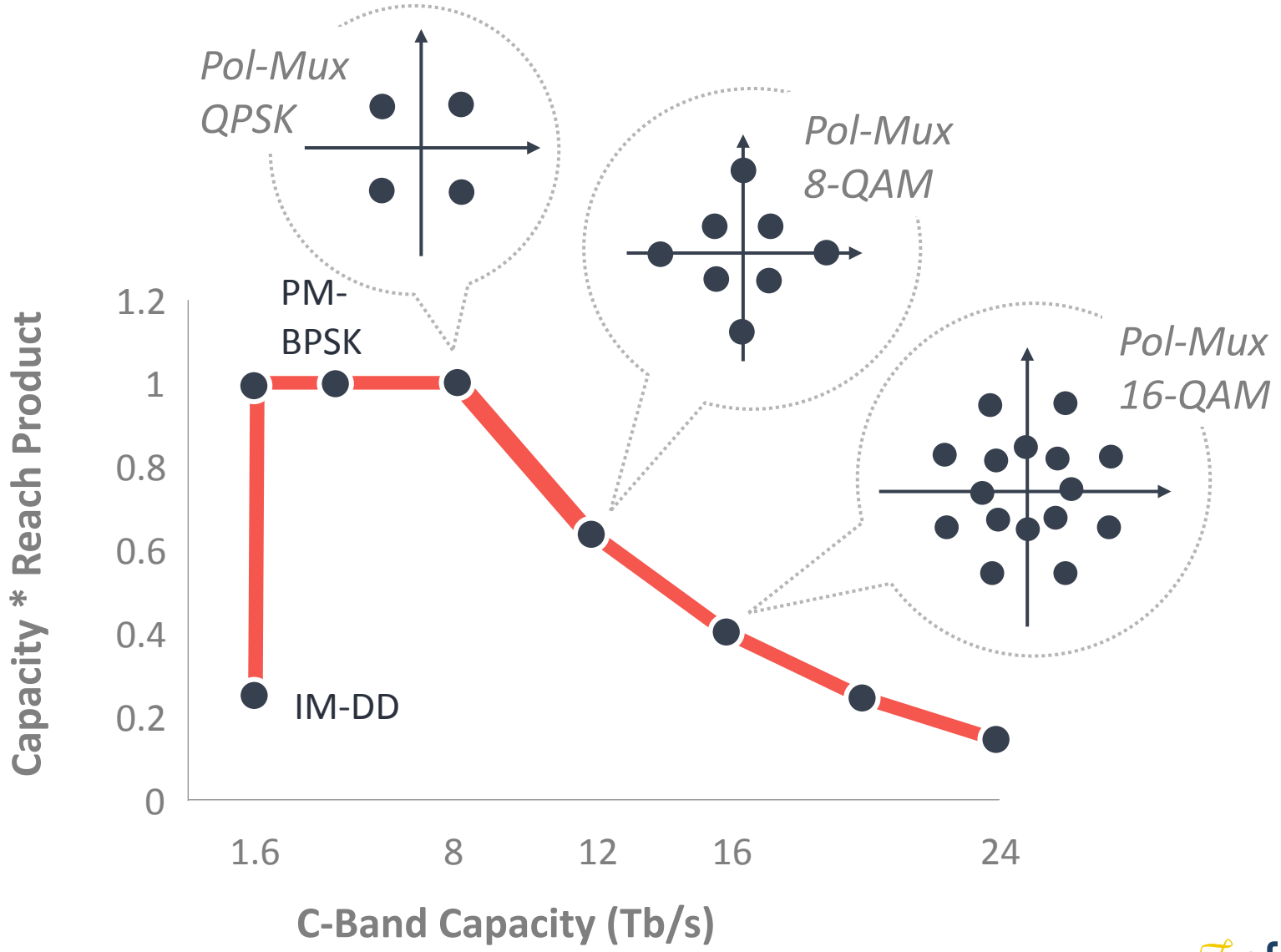
Advanced Modulation Formats



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Advanced Modulation Benefits

- Phase-based modulation is generally more tolerant of fiber impairments
- We can put more bits per symbol
  - Magnitude of fiber impairments scale with square of symbol rate
- Phase-based modulation allows us to use coherent detection
  - Advanced digital signal processing is then possible

The result is that 100G waves have the same, or even better reach than 10G IM-DD

But We Have a Problem…

Practical advanced modulation and coherent detection only get us to 100G waves

How do we get to “Terabit waves”?

Do we even want “Terabit waves”?

We need a *Terabit unit of capacity* that can be managed in “one chunk”, and has the maximum spectral efficiency

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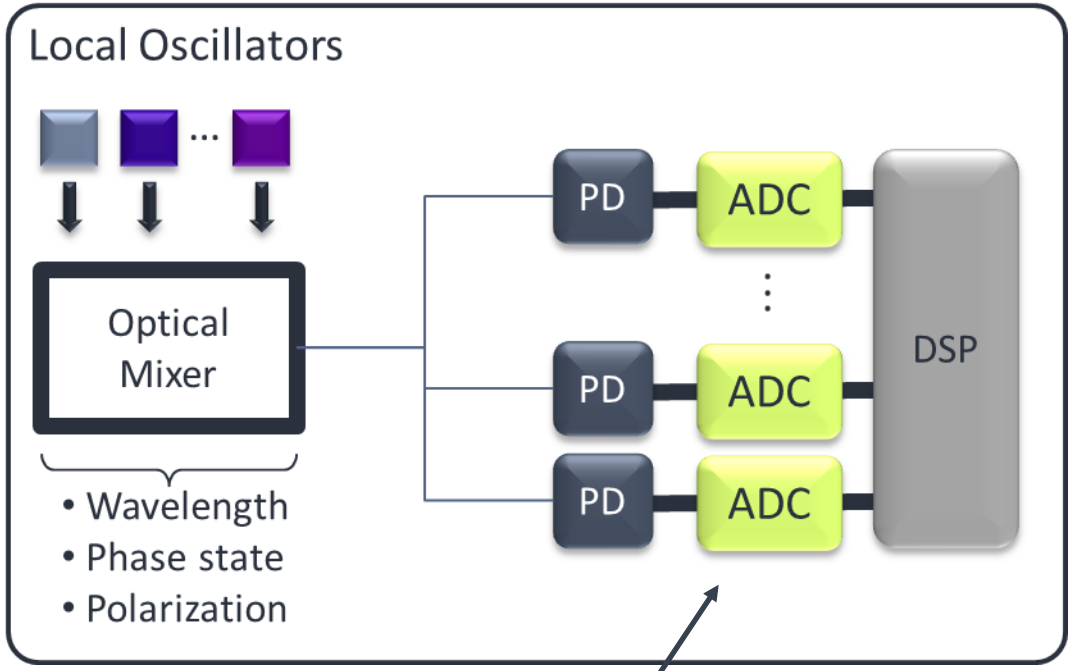
The Problem With Single-Carrier Terabit

This is a simplified coherent detector



Coherent detection requires very high speed Analog to Digital Converters

Can we actually build them?

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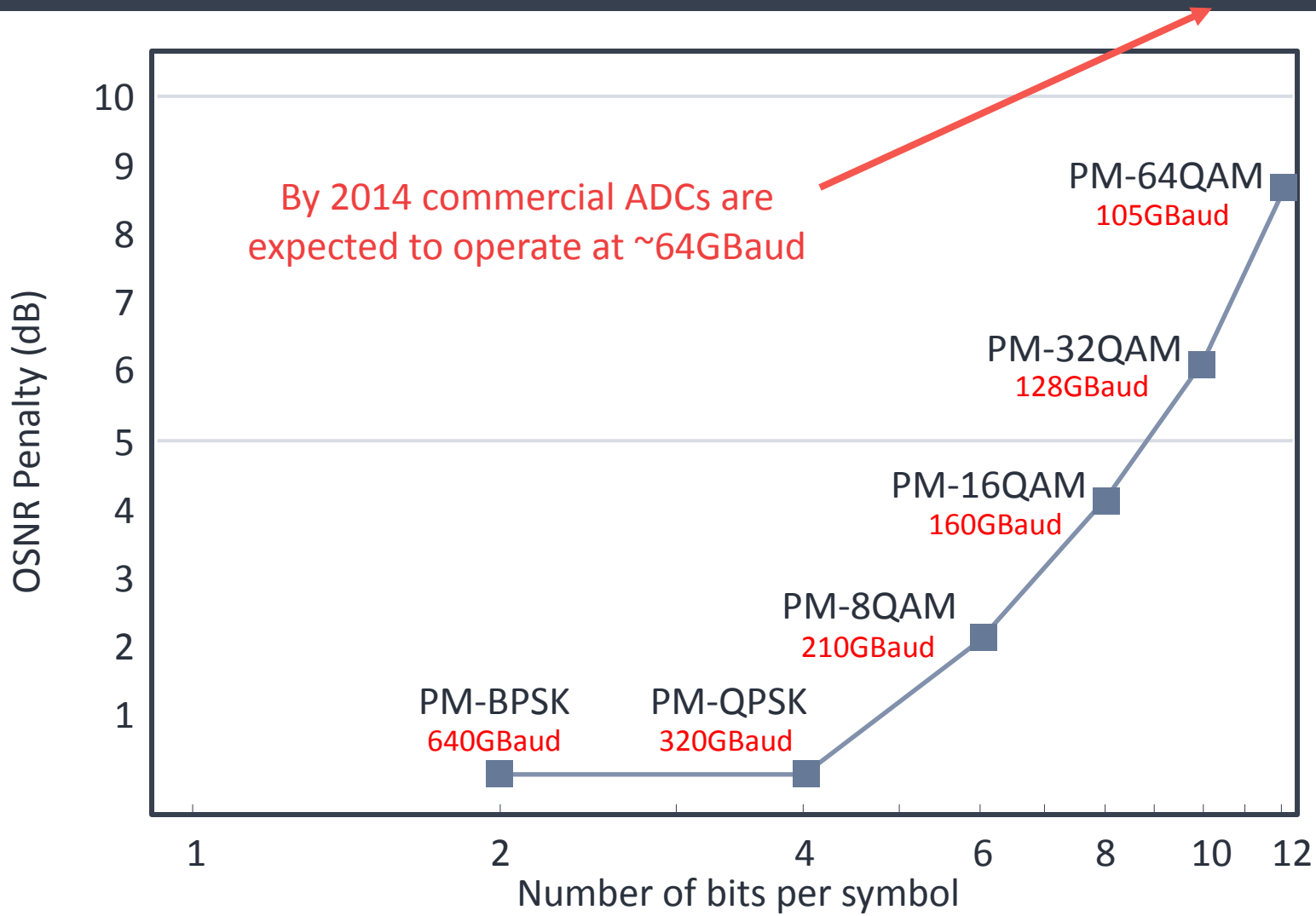
1Tb/s Single Carrier: The A/D Converter Problem



State of the art electronics are well behind the need for Tb/s carriers

Interim Conclusion

- For the foreseeable future, Terabit units of Transport Capacity will probably not be built using a single wavelength
- Given that a multi-wavelength approach is the practical option…

What technologies are needed to make practical Terabit "super-channels" possible?

What Comes Next For Terabit Transport?

Since the advent of DWDM…

- On-Off Keyed Modulation
- Direct Detection
- ITU Frequency Grid

- Quadrature Amplitude Modulation
- Coherent Wave Separation
- Grid-less Super-channels

…let's look at that evolution

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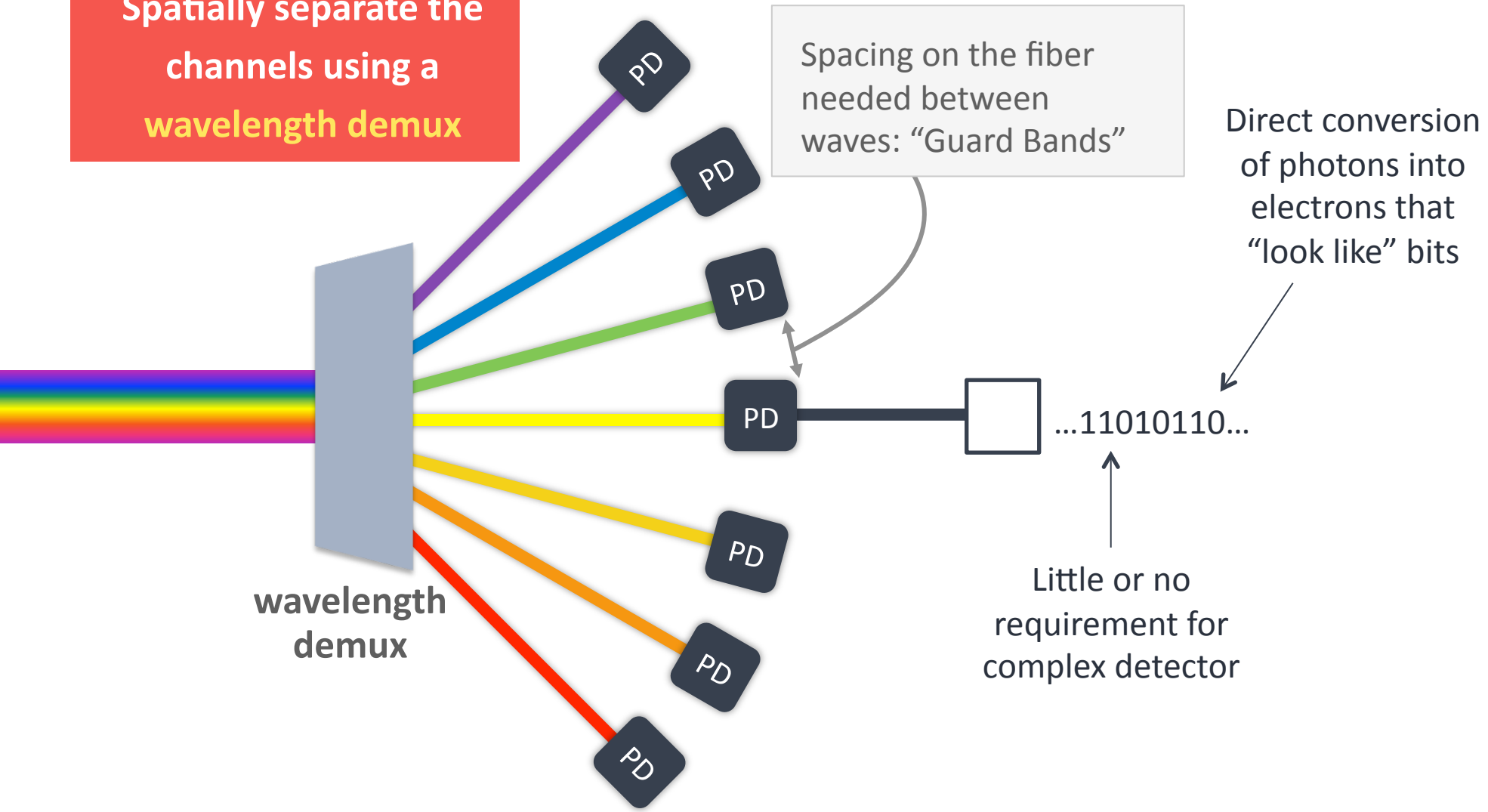
DWDM **Direct** Detection

c. 1995 – 2010
OC-1 to 10G

Spatially separate the channels using a wavelength demux



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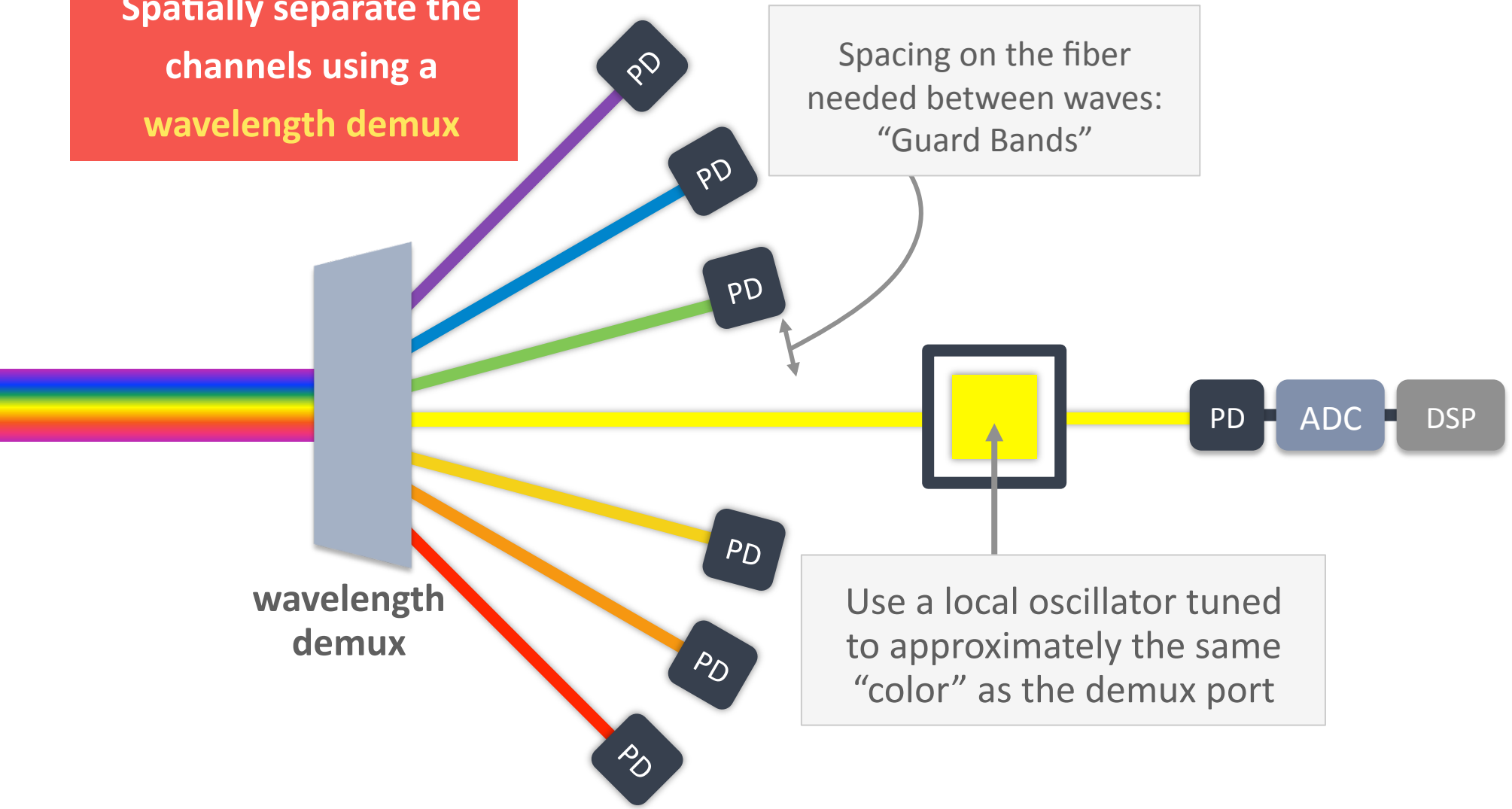
DWDM **Coherent** Detection

c. 2010 -
40G – 100G

Spatially separate the channels using a wavelength demux



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Wavelength Demux with Coherent Detection

- We use coherent detection to achieve greater reach at higher data rates (eg. 100G)
- BUT…we are still tied to a grid-based, wavelength demux architecture

- This is the current "state of the art" for 40G and 100G long haul optical transmission
  - We can run 40G and 100G on relatively poor fiber, and over even greater distances than 10G IM-DD

What Comes Next For Terabit Transport?

Since the advent of DWDM…

On-Off Keyed Modulation	Quadrature Amplitude Modulation
Direct Detection	Coherent Wave Separation
ITU Frequency Grid	Grid-less Super-channels

…so what has to change

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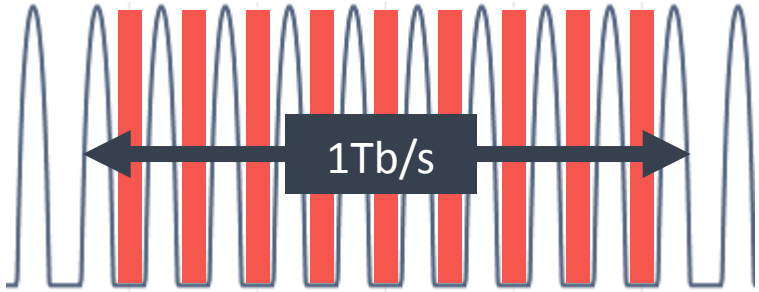
How 1Tb/s Might Look…
Conventional WDM Channels

Conventional Per-Channel WDM Filtering



- Guard bands to allow for individual *wavelength* demux

Q: Is there a wavelength separation technology that does not require these guard bands?

A: Yes, it's called *coherent wave separation*

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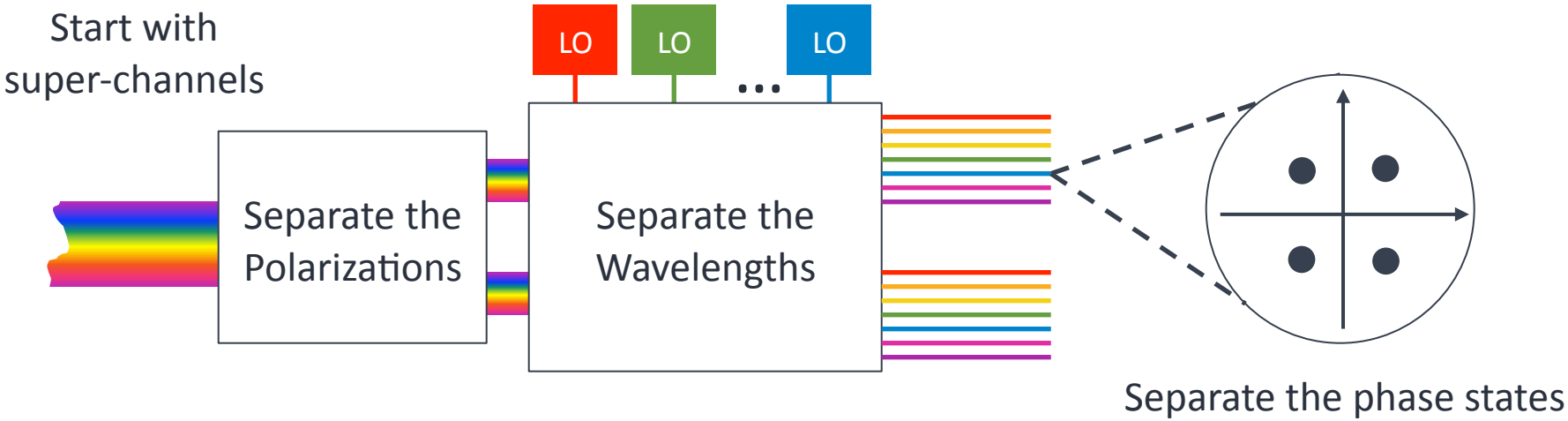
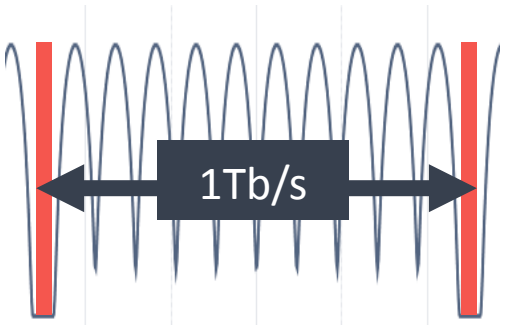
Coherent Wave Separation



Multi-Carrier Super-channel



Coherent wave separation is a complex problem

However…

The result is the ability to do this

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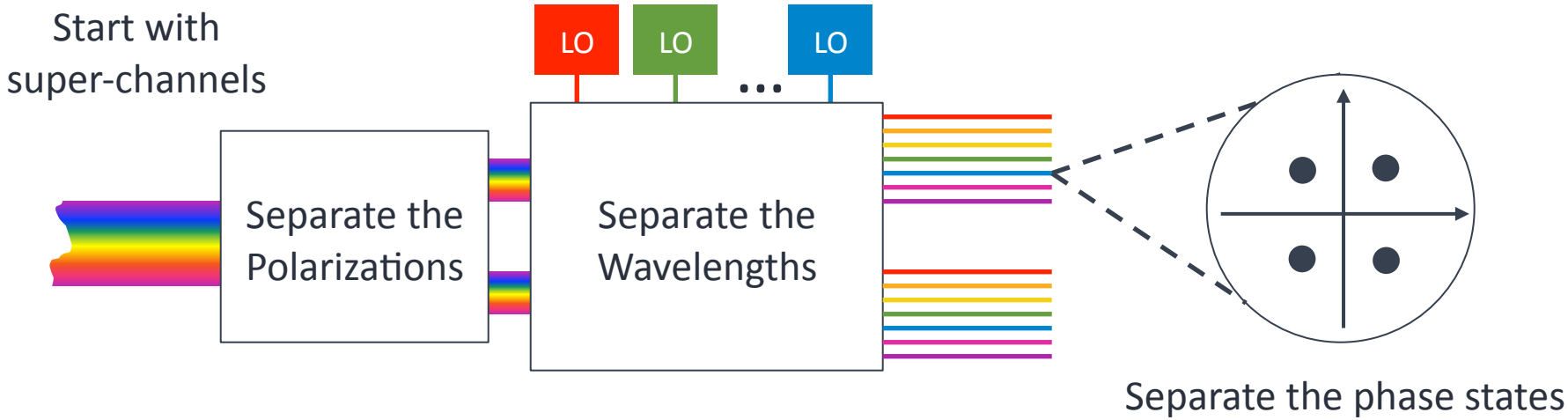
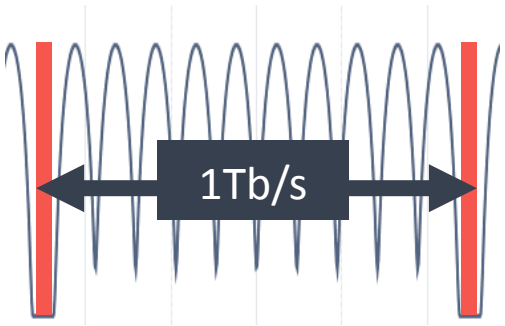
How 1Tb/s Might Look…
Super-channels



Multi-Carrier Super-channel



- Closely-packed groups of wavelengths
- Fewer guard-bands
- 25% increase in useable amplifier spectrum

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Large Scale Photonic Integration Is The Key To Economic Terabit Networking

Let's take a look at that complex optical receiver circuit…

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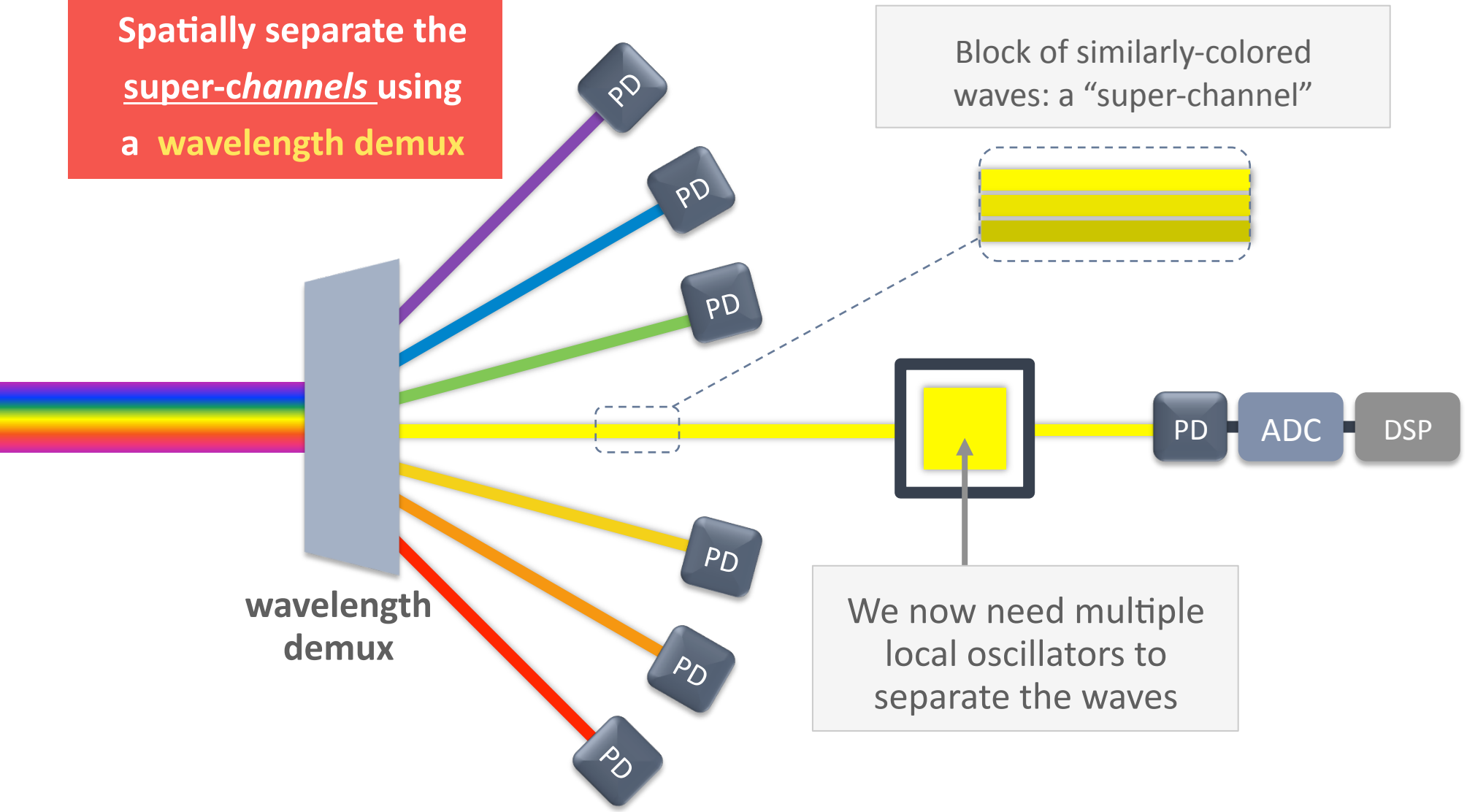
Coherent Wave Combining and Separation

Spatially separate the super-*channels* using a wavelength demux



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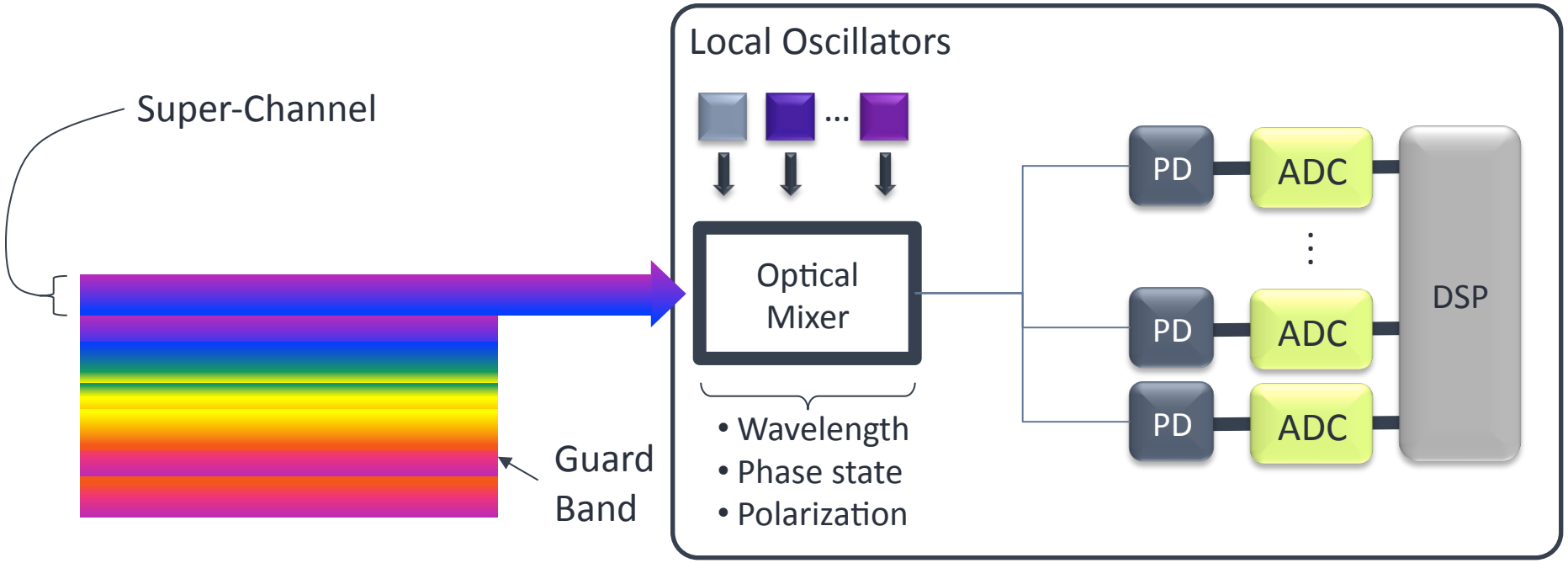
From Waves to Super-Channels



- Group waves together, into “super-channels”
- Optically separate Super-channels using guard bands
- Separate individual carriers using multiple Los
- Mitigate inter-carrier ISI, using a DSP, thus eliminating guard band

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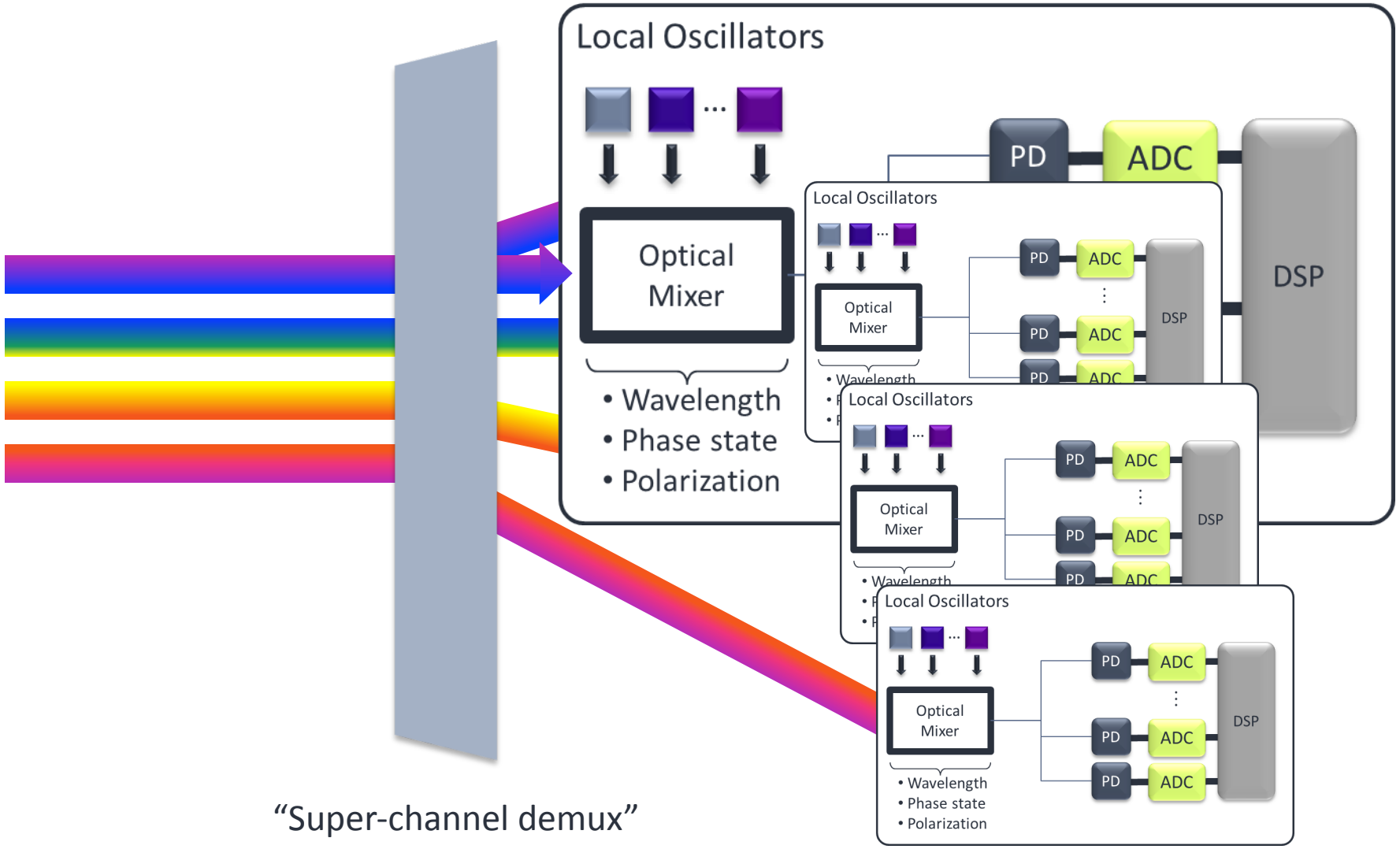
Coherent Wave Separation of Super-Channels



"Super-channel demux"

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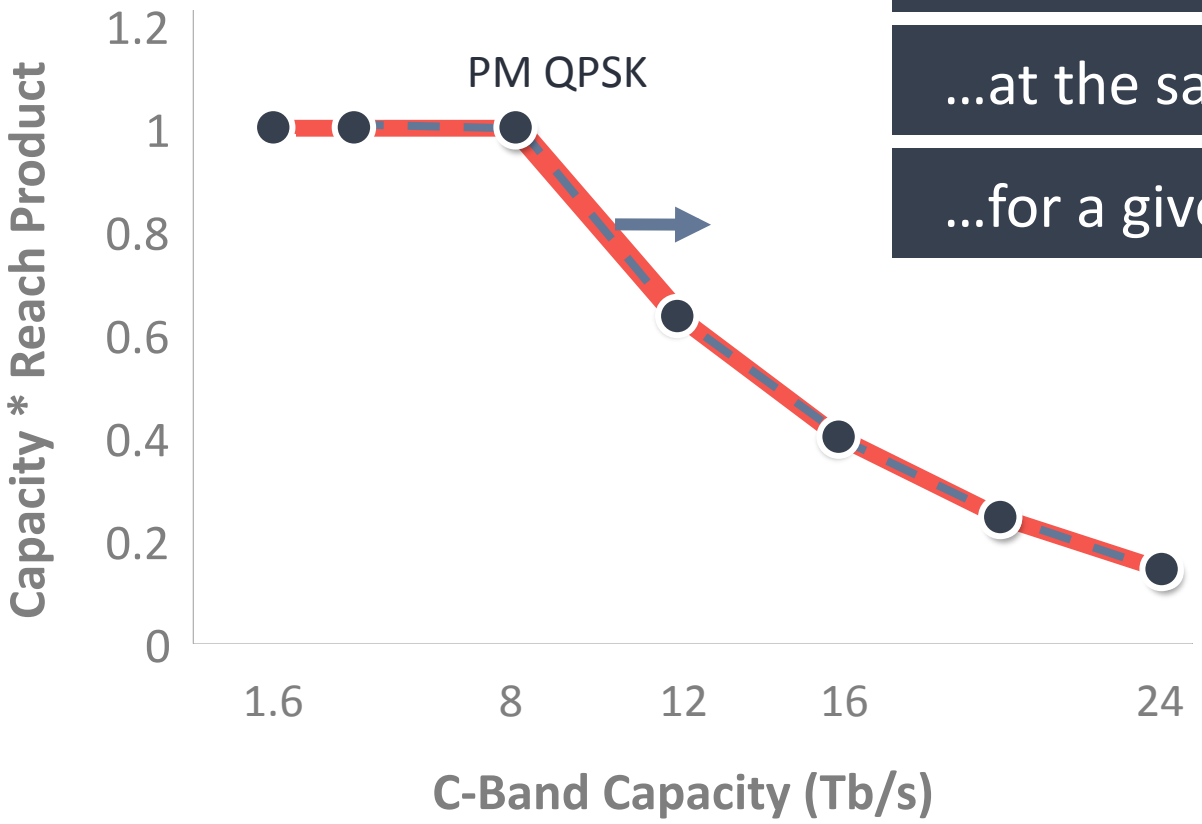
Which Modulation Technique?



The result of Super-channels:

more capacity…

…at the same reach…

…for a given modulation type

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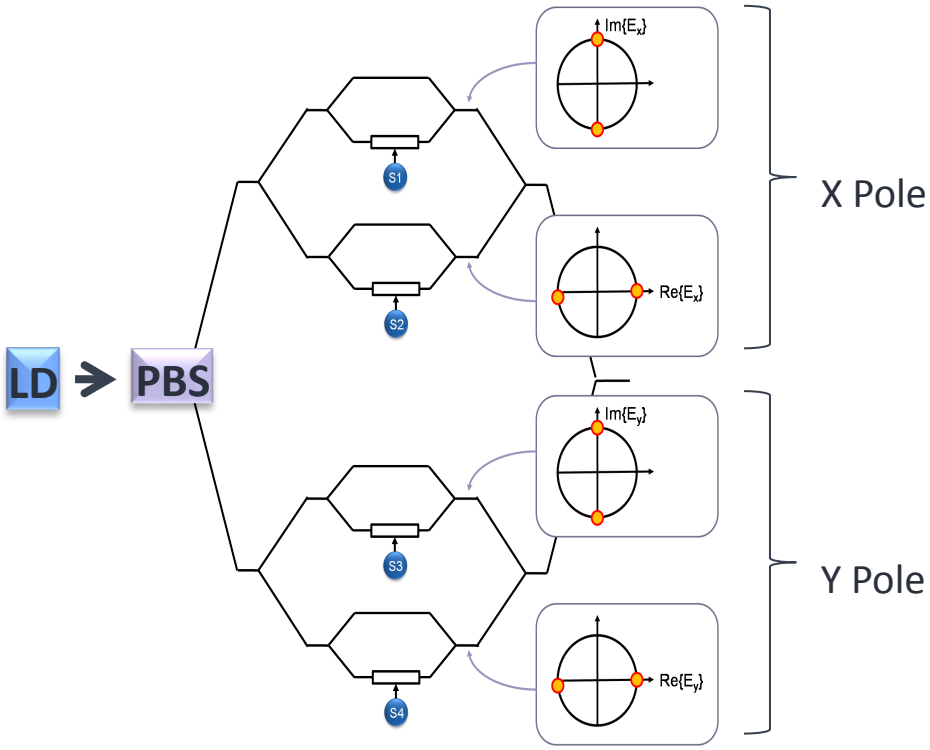
The Challenge of Building a Multi-Function Transmitter

Multiple Modulation Schemes in a Single Device

PM-QPSK Transmitter



To switch it to PM-BPSK mode, we would "switch off" half the circuit

If built with discrete optical components, it would be logical to economize, and build separate boards for PM-QPSK & PM-BPSK

A Photonic IC-based design can service multiple modulation types…

For about the same cost as one

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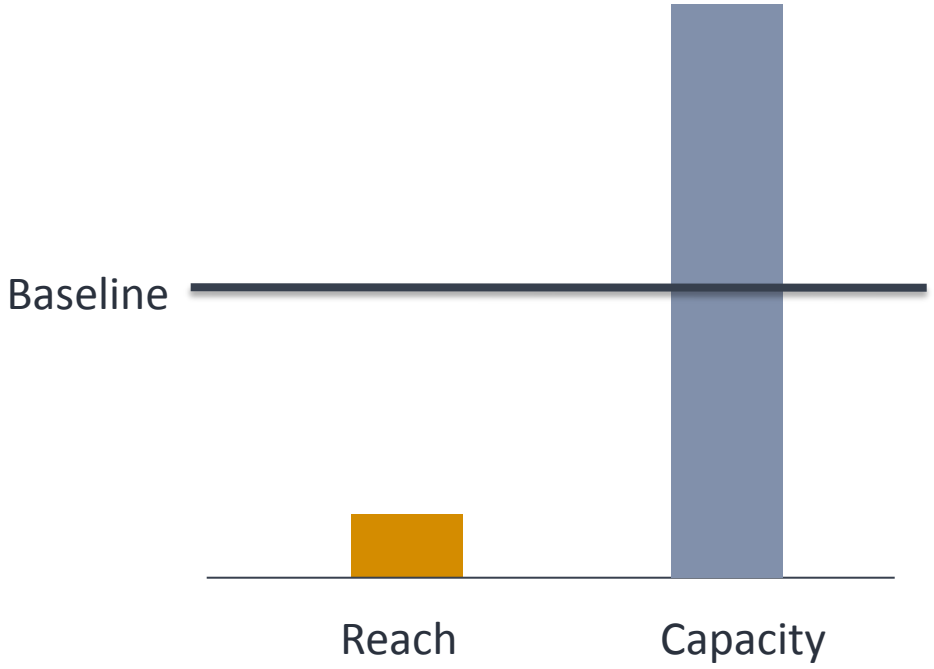
Flexible Coherent Modulation

- Flexible Coherent = “Dial-A-Reach”
  - In a *single module*
  - *Per-wavelength* selection of the optimum coherent modulation



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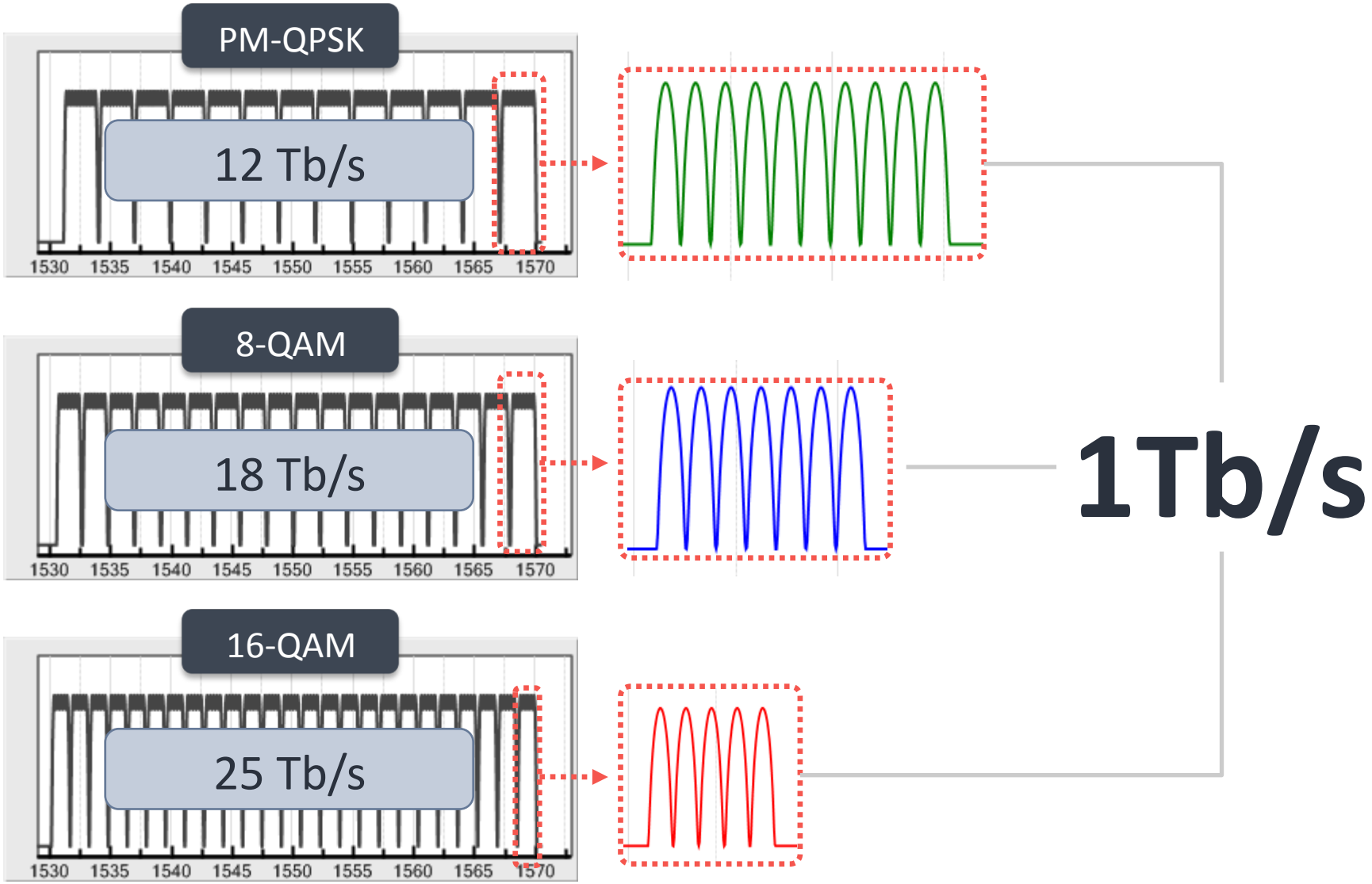
Super-channels Increase Total Fiber Capacity

More complex modulation → more capacity per fiber



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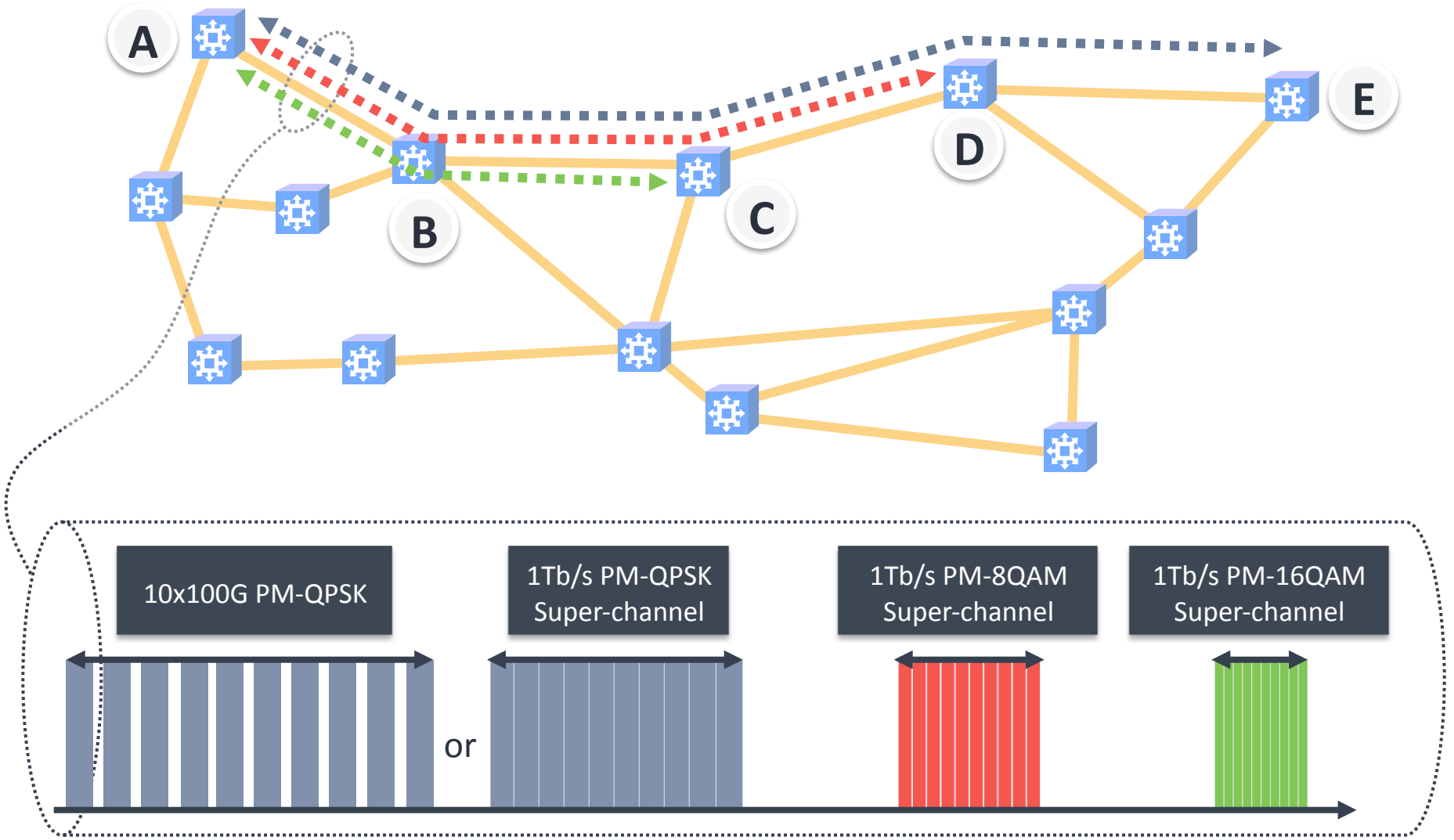
Reach, Spectral Efficiency, and Co-Existence



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Summary

- Pure “Terabit waves” are unlikely to become practical in the near to mid term technology horizon
  - Super-channels are more likely
  - Flexible modulation is essential
- Super-channels will be made up of multiple, closely packed waves that do not align on the current ITU grid
- Programmable optical circuits allow maximum super-channel flexibility & minimum spares management issues
- Large scale Photonic Integration is one way to improve super-channels economics

Thank You!

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what THE NETWORK will be