Transport network support for clients beyond 400G

Joint IEEE 802 and ITU-T SG15 workshop

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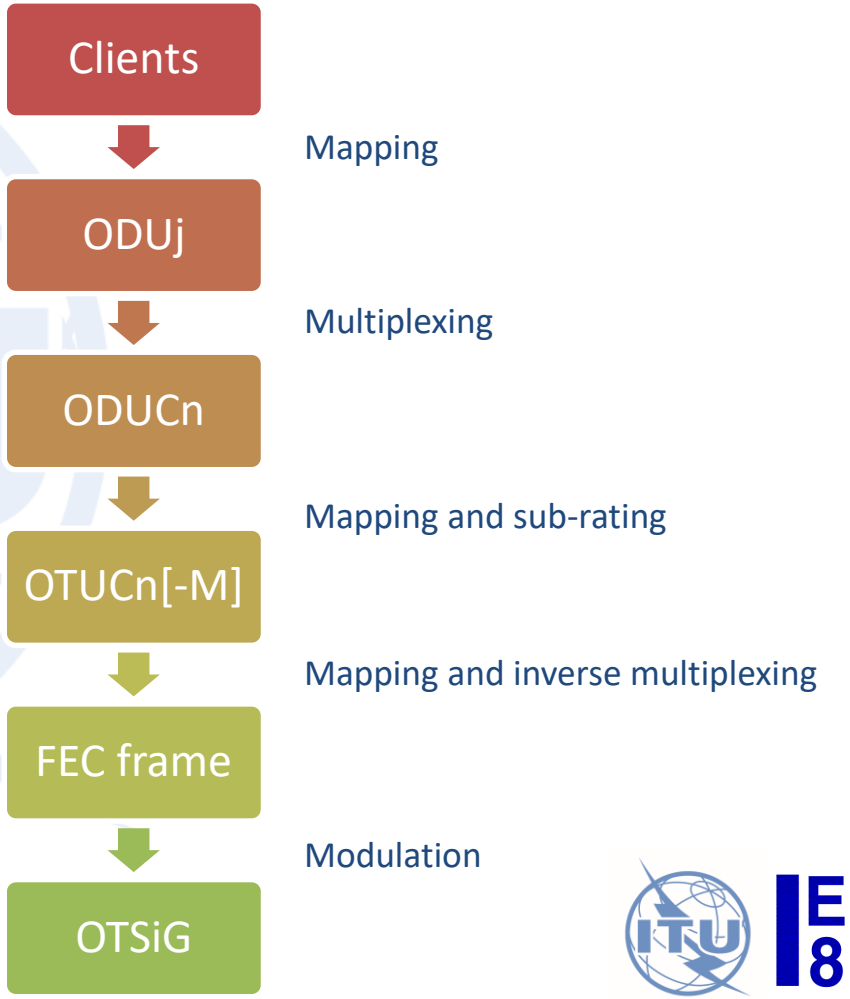
OTN Beyond 100G

Basic concepts

- Based on 100G slices – ODUCn/OTUCn
  - The ODUCn is organized into *n* × 20 5G tributary slots
  - Clients are mapped into ODU2, ODUflex, or ODU4 which are multiplexed into the ODUCn
- OTUCn is mapped into a FEC frame
  - The structure of the FEC frame and the number of lanes depends on the modulation scheme that will be used
  - Inverse multiplexing may be used
- FEC frame is modulated onto a group of one or more optical signals – OTSiG
- Some modulation schemes produce wavelengths that are not multiples of 100G
  - E.g., 8QAM at 30 Gbaud is 150G
- To enable use of such optical interfaces, OTUCn can be sub-rated - OTUCn-M
  - M of the tributary slots are available to carry traffic, the rest are unavailable and contain a fixed pattern
  - Unavailable slots are discarded and regenerated



Transport network challenges as bit rates increase

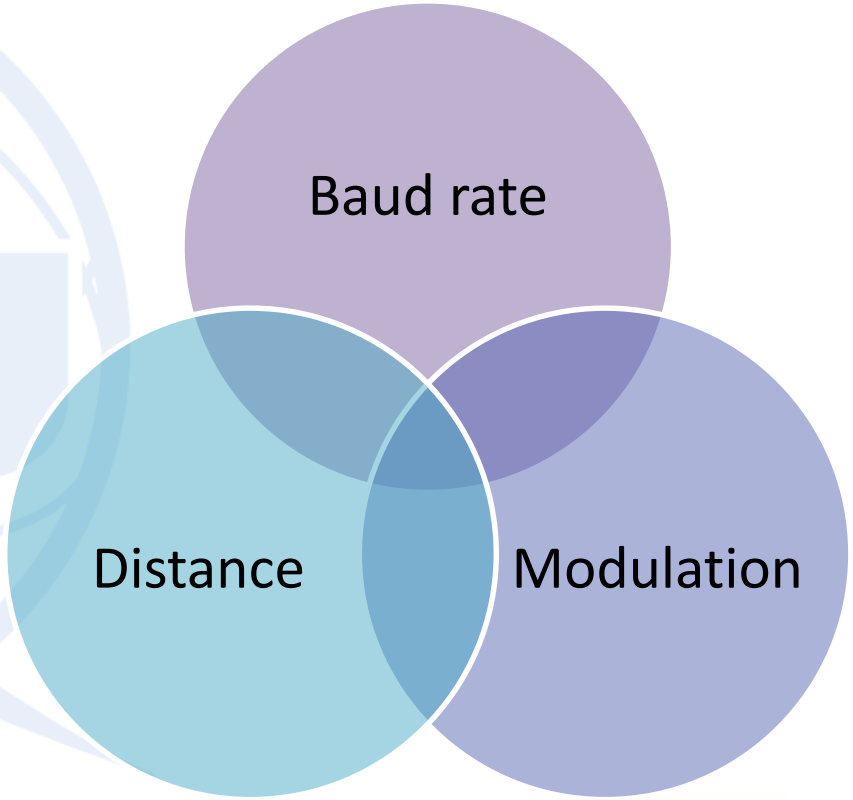
Channel bandwidth

- Limits the baud rate
- Higher-order modulation enables more bits per symbol
- Higher baud rate reduces the number of channels per fiber

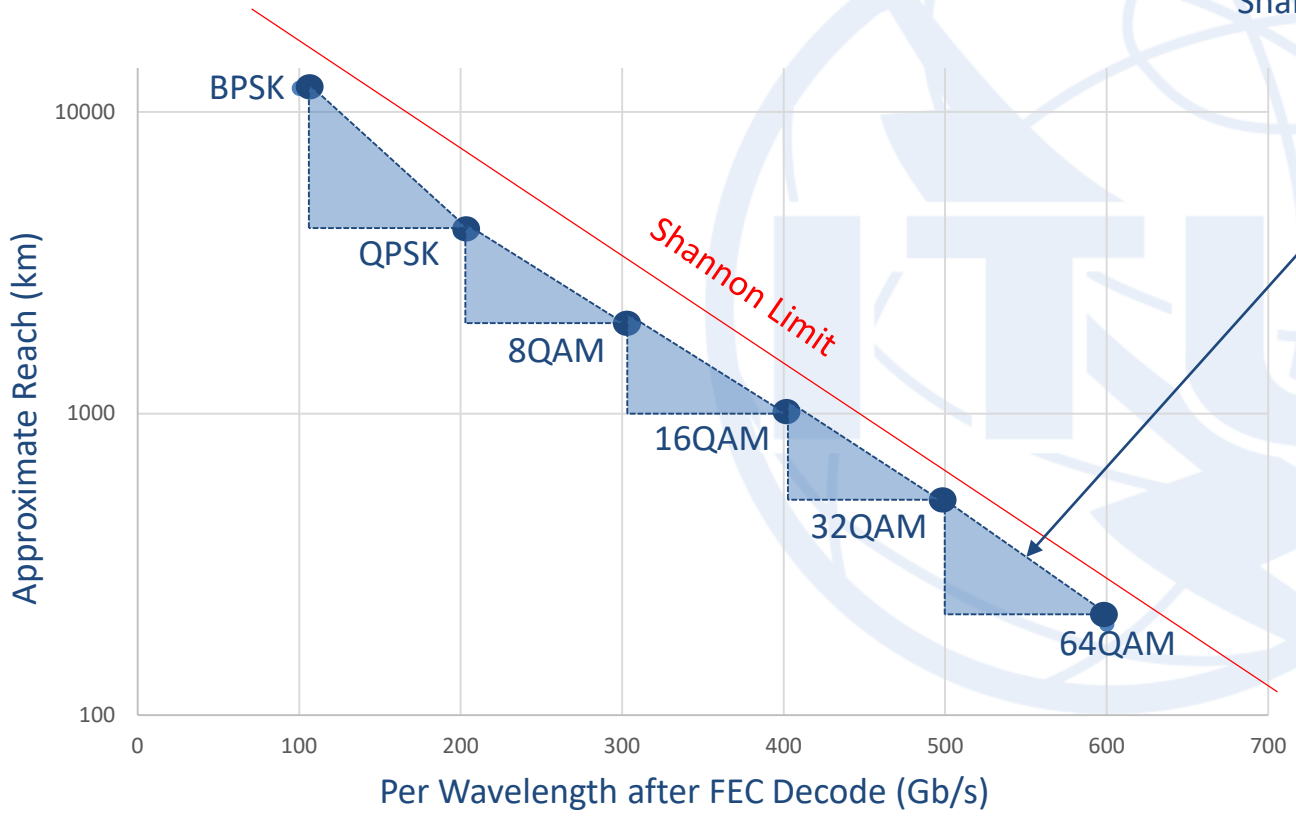
Shannon limit

- Relates capacity to bandwidth and signal-to-noise ratio
- Limits achievable distance at a given bit rate

$$C = B \log_2 \frac{S}{N}$$



Approaching the Shannon limit



Higher order modulation enables higher bit rates in discrete steps
Shannon limits the distance these signals can be transmitted

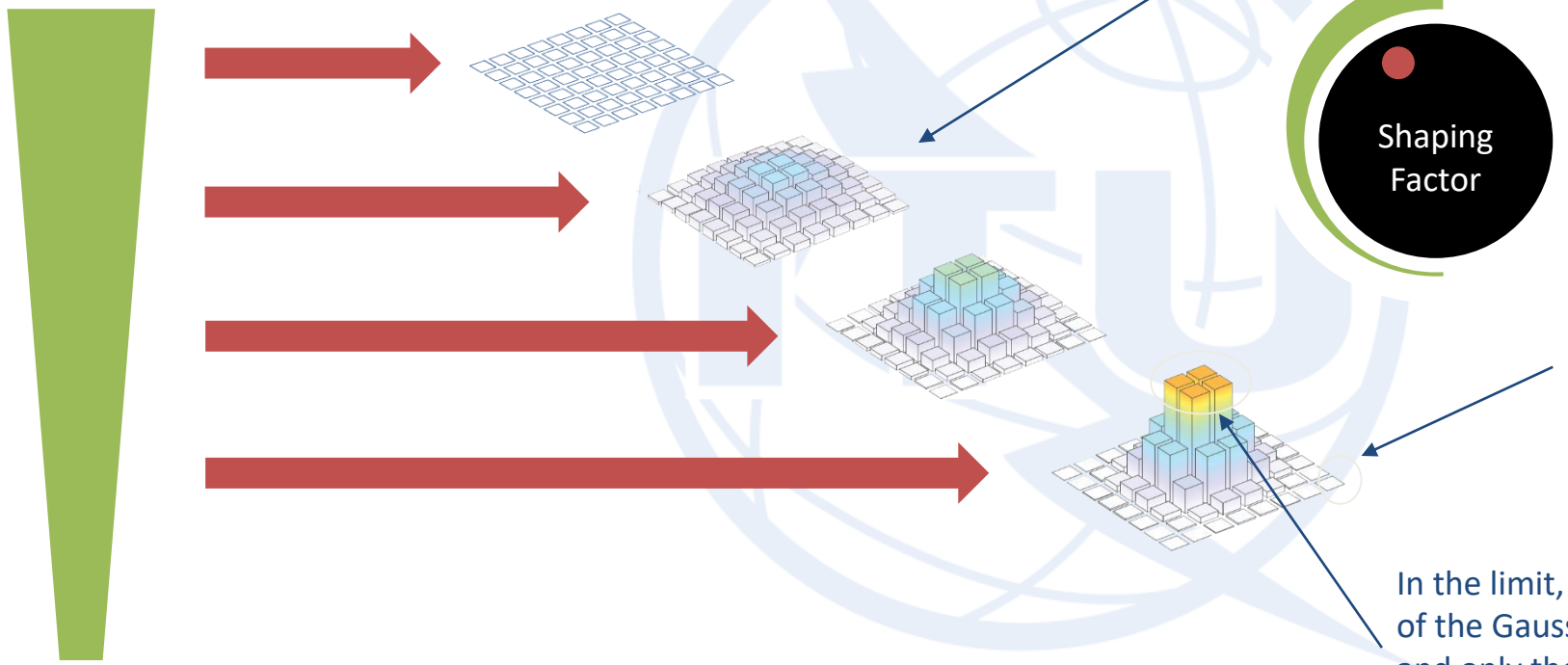
Lost bandwidth due to discrete constellations

Constellation	Both Polarizations	Baud Rate Including FEC		
	Bits/Symbol	30 Gbaud	60 Gbaud	90 Gbaud
BPSK	2	50 Gb/s	100 Gb/s	150 Gb/s
QPSK	4	100 Gb/s	200 Gb/s	300 Gb/s
8QAM	6	150 Gb/s	300 Gb/s	450 Gb/s
16QAM	8	200 Gb/s	400 Gb/s	600 Gb/s
32QAM	10	250 Gb/s	500 Gb/s	750 Gb/s
64QAM	12	300 Gb/s	600 Gb/s	900 Gb/s

Using higher baud rates increases spectrum required

Probabilistic constellation shaping smooths out the staircase

Enables variable tradeoff between bit rate and reach



2-dimensional Gaussian probability distribution of how frequently different symbol values are used decreases average Bits represented per symbol

Using the outer (highest power) constellation points less frequently Improves OSNR

In the limit, xQAM degenerates to QPSK as σ of the Gaussian distribution approaches zero and only the inner four constellation points are used

Transport network considerations for beyond 400G Ethernet

Inverse multiplexing will be needed

Probable next Ethernet rate is 1.6Tbps

Even at 90 Gbaud, 64QAM cannot provide this bit rate

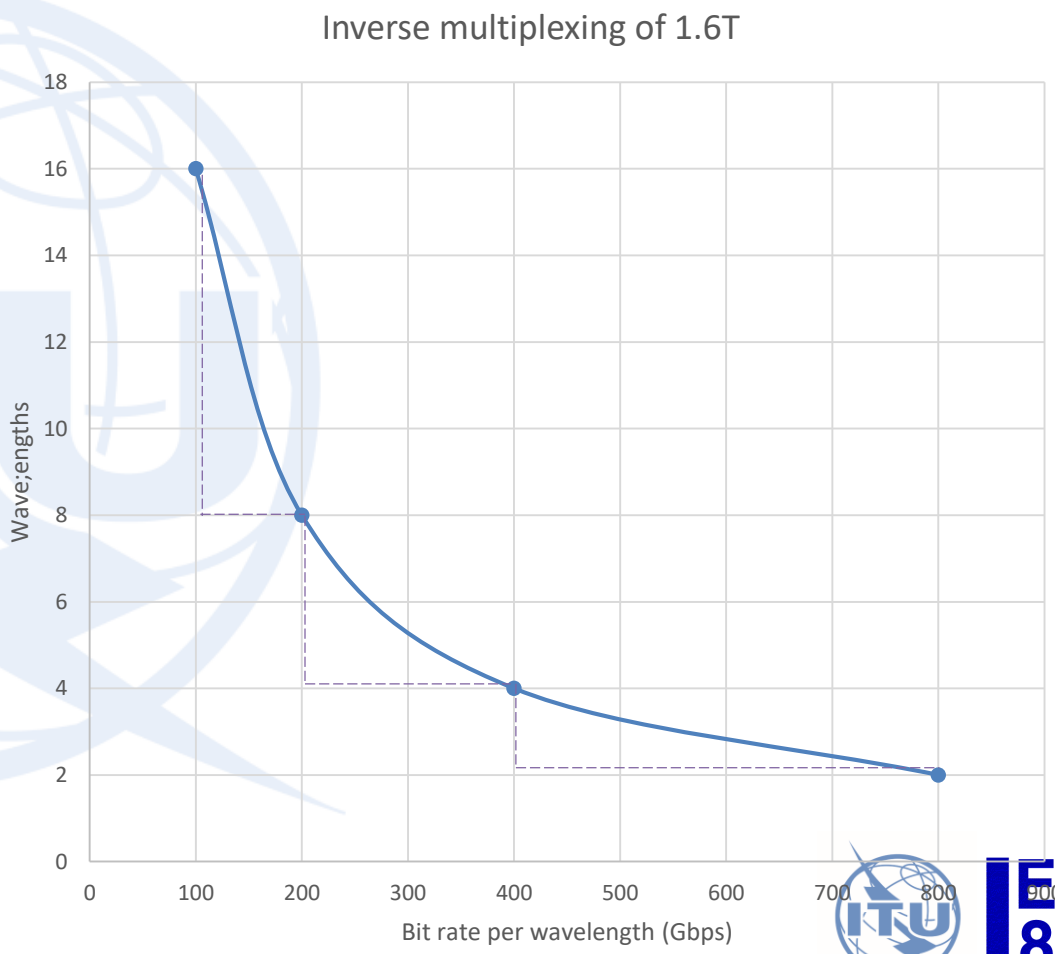
Inverse multiplexing over multiple wavelengths will be needed

A small discrete set of inverse multiplexing options with different formats will create another staircase

ITU IEEE 802 NOKIA

Inverse multiplexing

- Inverse multiplexing divides the signal across multiple wavelengths
  - Familiar concept in Ethernet interfaces and in transport networks
- Using only a small number of discrete steps creates another staircase and eliminates the spectral efficiency gains from probabilistic shaping
  - If the required reach is too far to use 4x400G, the next option is 8x200G, even if 6 wavelengths at ~267 G would work at the required distance
- A more flexible approach to inverse multiplexing is needed



Brainstorming about criteria for a flexible inverse multiplexing approach

- Number of lanes has to be small enough to be manageable
- Granularity must be small enough to support from 1 to 16 wavelengths
- Probabilistic shaping should be possible even without changing the number of wavelengths
- In order to satisfy those criteria, the inverse multiplexing mechanism must tolerate non-integer number of lanes per wavelength and/or lane rates that are not an integer number of Gbps
  - 320 5G lanes seems like a nice choice, but has many cases of non-integer number of lanes per wavelength
  - Other options with non-integer lane rates can reduce the number of cases with non-integer number of lanes per wavelength
  - Completely eliminating non-integer number of lanes per wavelength requires far too many lanes

	# of lanes per wavelength for given lane size (in Gbps)		
λ	**5**	**6.666667**	**0.952381**
1	320	240	1680
2	160	120	840
3	106.667	80	560
4	80	60	420
5	64	48	336
6	53.3333	40	280
7	45.7143	34.28571	240
8	40	30	210
9	35.5556	26.66667	186.6667
10	32	24	168
11	29.0909	21.81818	152.7273
12	26.6667	20	140
13	24.6154	18.46154	129.2308
14	22.8571	17.14286	120
15	21.3333	16	112
16	20	15	105