Code-adaptive Transmission Accounting for Filtering Effects in EON

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• In elastic optical networks (EONs), **distance adaptation**: trade-off between spectral efficiency and the all-optical reach
  - solutions based on different modulation formats: e.g., PM-16QAM and PM-QPSK
  → such techniques may require transponders supporting multiple modulation formats
• Recently, distance adaptation through **code adaptation**: code redundancy is tuned based on the optical reach (the larger the length the more the redundancy)
  - Code adaptation can be applied with a transponder supporting a single modulation format (e.g., PM-QPSK)
Introduction

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**In this paper**

• We demonstrate the concept of code adaptation for distance adaptation considering time frequency packing transmission
• Coding is selected to satisfy quality of transmission (QoT), also considering detrimental **filtering effects**
• **High spectral-efficiency**: e.g., 6.6 b/s/Hz with PM-QPSK
• Code adaption is also hitlessy performed to re-act to the degradation without the need of any re-routing
Scenario

\[ B_i \text{ sub-carrier bandwidth} \]

Super-channel made of \( N \) PM-QPSK sub-carriers

\[ B = \text{super-channel bandwidth} \]

- \( c_i = \text{code rate} \ f/b \) where \( b - f \) bits of code are transmitted each \( f \) bits of information
  
  - Code rate (i.e., redundancy) affects the ability to correctly receive the information transmitted over an all-optical path, also traversing a certain number of nodes, thus considering filters (spectrum selective switches —SSSs).

- \( R_i = \text{sub-carrier bit rate} \): it includes information and coding

- Super-channel \textbf{information rate}: \( N \text{xc}_i \times R_i \)
Setting code, sub-carriers, and filters

$B_i$
sub-carrier bandwidth

$B$

Diagram showing sub-carrier bandwidth and overall bandwidth ($B$).
Setting code, sub-carriers, and filters

- INFORMATION RATE fixed 1Tb/s
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![Diagram showing sub-carrier bandwidth $B_i$ and total bandwidth $B$]
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• \( B_i \) Fixed

\( B_i \)  
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\( B \)
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  • increasing redundancy decreases information rate of each sub-carriers
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  → select N sub-carriers to guarantee 1Tb/s information rate
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→ select \( N \) sub-carriers to guarantee 1Tb/s information rate
- \( B = N \times B_i \)
- \( B \leq mx12.5\text{GHz} \)
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- $B=NB_i$
- $B \leq mx12.5GHz$
  - m must be selected considering filtering effects
Such code assures acceptable QoT on one hop path. ITU-T $m$ defines the switched bandwidth: $B \leq mx12.5\text{GHz}$
Example

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One hop more: → more code → higher N → higher B
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One hop more: $\rightarrow$ same code is fine
$+ \text{enlarge filters to avoid filtering effects}$
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Summary: code $\rightarrow$ number of carriers $\rightarrow$ super-channel bandwidth $\rightarrow$ ITU-T $m$
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• High spectral efficiency with PM-QPSK
• No DAC is required since we avoid multi-level formats such as PM-16QAM
• Inter-symbol interference imposes sequence detector as BCJR
• Coding is selected to account for ISI and other impairments

Experimental set up
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[Diagram of experimental setup with components labeled ECL1, ECL3, ECL5, ECL7, ECL9, ECL2, ECL4, ECL6, ECL8, OC, LPF, Q, π/2, PBC, delay, Polarization multiplexing, 2x1 OC, Coherent RX, LOI, real-time scope, DSP, 40km, programmable SSS, POL-S, OBPF, GEF.]
Experimental set up

RECIRCULATING LOOP
EMULATING INTERMEDIATE NODES
Experimental set up
Measurements

- 1Tb/s information rate
- Error-free transmission after decoding
Code adaptation to re-act against signal degradation
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- Monitoring of the super-channel
• Monitoring of the super-channel
• Super-channel QoT is degraded (e.g., due to amplifier aging) → monitoring reveals QoT degradation
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• WHAT is MONITORED?
Symbol VARIANCE
Relation between variance and OSNR

![Graph showing the relation between variance and OSNR.](image)

- **Variance** on the y-axis ranges from 0.00 to 0.16.
- **OSNR [dB]** on the x-axis ranges from 10 to 18.
- The graph indicates a linear relationship where variance decreases as OSNR increases.
- The equation $\frac{c}{i} = \frac{5}{6}$ is shown on the graph, highlighting the relationship between variance and OSNR.
Relation between variance and OSNR

\[ c_i = \frac{5}{6} \]

\[ c_i = \frac{4}{5} \]
Demonstration of code adaptation upon soft-failure
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- RX reveals OSNR degradation through variance increase and informs TX
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• TX continues to use the old code and, with a Preamble of 3 bits, informs RX of the new code
• After, TX starts transmitting with the new code
• Hitless code-adaptation without performing complex and time-consuming re-synchronization procedures (e.g., as in the case of modulation format adaptation) is demonstrated
Conclusions

• Distance adaptation is demonstrated in EONs with proper selection of code
• Filtering effects must be considered
• Hitless code adaptation is demonstrated to re-act against soft-failures:
  • no re-routing, no change of modulation format
• Failure monitoring is enabled by variance monitoring

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Optical peRformance monitoring enabling dynamic networks using a Holistic cross-layEr, Self-configurable Truly flexible appRoAch