Partial Signal Overlap with Cancellation-based Detection for Spectrally-efficient EONs

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Abstract *The cancellation-based detection strategy is exploited to enable the partial overlap of two slightly-detuned 100G PM-QPSK signals, effectively sharing the same frequency slot. Results show benefits in overall network usage compared to fully overlapped signals and 200G 16QAM.*

1. Introduction

In Elastic Optical Networks (EONs), an optical signal occupies a dedicated frequency range, called frequency slot, with no sharing of spectrum resources with other optical signals. Recently, a novel technique called *signal overlap* has been proposed to overcome this constraint[1-3]. This technique allows the overlap of two independently-generated optical signals along the same spectrum resources (i.e., same frequency slot). The overlap technique exploits a detection strategy based on the cancellation technique typically utilized in wireless networks[4], now applied for optical communication. The technique does not require global time synchronization in the whole network and it does not exploit orthogonal codes as in Optical Code-Division Multiple-Access (O-CDMA) solutions. The feasibility of the technique has been demonstrated both theoretically[1] and experimentally[2].

As discussed in[1], the full overlap of two signals is typically less spectrally efficient and more complex to implement than increasing the constellation size with non-overlapping frequency slots. However, there are specific use cases where this technique may provide interesting benefits. For example, as shown in[3], improved spectral efficiency can be achieved in the provisioning of 1+1 protected connections.

This paper proposes to apply such detection strategy based on the cancellation technique for *partial* frequency overlap i.e., considering two independently generated signals still within the same frequency slot but having their central frequencies slightly detuned. This way, larger robustness is achieved, opening the way for additional networking applications. A specifically designed routing, modulation and spectrum assignment strategy is then presented and exploited to assess the performance for the partial overlap technique.

2. Cancellation technique for partial overlap

Fig. 1 shows a portion of EON where the partial overlap case is applied. A PM-QPSK signal S_A is generated by node *A* at central frequency f_A. A second PM-QPSK signal S_B is independently generated by node *B* at central frequency f_B. At node *B* the two signals overlap. They are then jointly propagated along *B-C*. To enable successful detection of either signal, adequate low-density parity-check (LDPC) coding rates (e.g., 100Gb/s net rate over the transmitted 112Gb/s) and proper settings of the signal power levels at the superimposition point are applied. In particular, the power of S_A is set at the superimposition point *B* to a value higher than the one of signal S_B. At the receiver at node C, after the coherent opto-electronic conversion of the signal S_A+S_B, sampling and digital processing are performed. Then, a two-step procedure is applied. First, the detection is performed as if just S_A were transmitted, i.e., considering S_B simply as noisy interference. This way, the coded signal S_A is retrieved from the acquired data. Second, the acquired data are re-elaborated to perform the cancellation of signal S_A. Once the cancellation is complete, a second detection stage is performed on the interfering coded channel S_B, successfully completing both detections. To apply this technique it is necessary to consider that: *i*) the re-modulation of S_A has necessarily a limited accuracy, as some impairments are difficult to

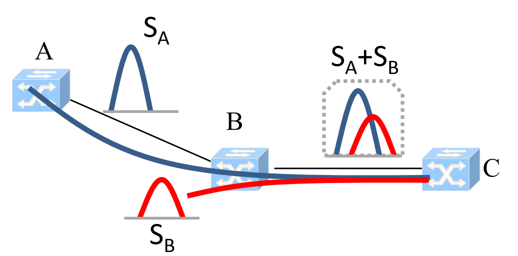

Fig. 1: partial overlap

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be estimated (e.g. non-linear effects); *ii*) the detection of S_B will be also affected by the noise from the S_A lightpath; *iii*) additional processing is required with respect to traditional detection operations. The first two points imply, as shown later, that adequate Quality of Transmission (QoT) is required to successfully detect both signals. The third point implies the availability of additional processing capabilities with respect to traditional coherent receivers. However, this last point on complexity is expected to become less critical, as occurred in the last years for cancellation in wireless or for coherent strategies in optics. We remind to[1] for additional details on the transmission technique and on the model utilized in the next section.

A detuning $D_f=f_A-f_B$ is here introduced between S_A and S_B. Note that the case of $D_f=0$ corresponds to the full frequency overlap of[1-3]. In this study, we evaluate the cases of $D_f>0$, such as $D_f=6.25$GHz and $D_f=12.5$GHz. Such values allow the two signals to still occupy a single frequency slot of 37.5 or 50GHz in the flexi-grid.

3. Transmission performance

Table I shows the simulation results for two 100G PM-QPSK signals (28GBaud). As in[1], we focus on the case $S_A/S_B=5.5$dB. Analog to digital converter with analog bandwidth of 20 GHz and a sampling rate of 56 GSample/s is assumed. In this study, to account for actual frequency slot cases, a switch and select ROADM is introduced every two 80km-spans. Each traversed ROADM encompasses two Bandwidth Variable Wavelength Selective Switches (BV-WSS), modelled as in[5]. For example, after 9 spans (720km), 8 BV-WSS are traversed.

The table reports the cases when a 3-dB margin is applied on theoretical bounds exploiting practical LDPC codes.

Results show that significant benefits can be achieved by partial overlap with respect to full overlap, and more specifically by $D_f=12.5$GHz. That is, it is more beneficial to reduce the interference between two signals while accumulating more filtering impairments, as in partial overlap, than having more interference and less filtering effects as in the full overlap. For example, around 840 km at 37.5GHz can be successfully traversed by two 100G signals partially overlapped with $D_f=12.5$GHz instead of just 560km with $D_f=6.25$GHz.

For the sake of completeness, also the PM-16QAM performance is reported, considering the transmission of a single 200G signal at 28GBaud on the same 3-dB margin (i.e., same overall net rate). In this simulative scenario, results show that slightly better performance is

Tab. 1: transmission performance of partial overlap

Format	Freq. slot [GHz]	Detuning D_f [GHz]	Reach [km]
2x100G PM-QPSK	37.5	0	280
		6.25	560
		12.5	840
	50	0	440
		6.25	880
		12.5	1080
1x200G PM-16QAM	37.5	n.a.	720
	50	n.a.	920

experienced by the two partially overlapped 100G QPSK ($D_f=12.5$GHz) with respect to a single 200G PM16QAM under same frequency slot conditions. For example, in case of 50GHz, 200G PM-16QAM reaches around 920km while two partially overlapped 100G PM-QPSK reach around 1080km.

4. RMSA with signal overlap

In this section we solve the routing, modulation format, and spectrum allocation (RMSA) problem[6] with extended capabilities for signal overlap. We aim at finding the RMSA for a set of demands that minimizes the amount of rejected demands and of used spectrum resources.

Based on the basic RMSA-based provisioning algorithm in[6], Table II introduces the proposed algorithm used to allocate a given pair of demands $<d_a,d_b>$ sharing the destination node over an EON *G*. It basically consists in finding a set of candidate paths for d_a by means of a *k*-shortest path algorithm and, for each of the paths, evaluate it as candidate to support d_b overlapping. To this aim, an auxiliary graph is created to find (if any) the shortest path for d_b that share hops with p_a i.e., from an intermediate node to the destination.

After the routing phase, the most spectrally efficient modulation format is chosen provided that it supports the distance of the found overlap. Then, an available spectrum slot is computed for all the links in the union of p_a and p_b. This procedure is repeated for all candidate paths of d_a and its respective potential overlap with d_b in order to return the minimum cost solution.

The algorithm in Table 2 is embedded into an iterative randomized heuristic[6] that process the whole set of demands and returns the best solution for the proposed optimization problem.

5. Network performance

Aiming at comparing the performance of proposed overlap techniques, the optimization problem introduced in Section 4 is solved for two different traffic scenarios based on the Telefonica national network. This network consists of 30 nodes and 56 bidirectional links

Tab. 2: RMSA with signal overlap capabilities

```
INPUT G,da,db
OUTPUT sol
sol←Ø;minC←∞
P←KSP(G,da,k)
for pa∈P do
   G'←auxiliaryGraph(G,pa)
   pb←SP(G',db)
   if pb == Ø then continue
   m←selectMF(pa,pb)
   if m == Ø then continue
   c←findSlot(G,m,pa∪pb)
   if c == Ø then continue
   cand←<pa,pb,m,c>
   if minC>cost(cand)then
      minC←cost(cand)
      sol←cand
return sol
```

creating a mesh topology of 950km of network diameter. We assume an optical spectrum of 1THz divided into 12.5GHz frequency slices.

The first traffic scenario consists in 100G demands whose source belong to a scattered, widely spread set of 11 nodes, whereas the destination belongs either to this set or to an even more reduced subset consisting of 2 gateway nodes, thus creating high traffic directionality and destination sharing. From this scenario, we aim at comparing PM-QPSK overlap techniques.

Fig 2 shows the blocking performance of full and partial PM-QPSK overlap according to the configurations of Table 1 for a detuning of 0 GHz and 12.5 GHz, respectively. A case with no overlap considering PM 16-QAM for those connections with length lower or equal than 1000 km is provided as reference. As can be observed, only partial overlap outperforms the reference no overlap case, permitting circa 25% more load for the target blocking = 1%.

A detailed analysis of the impact of overlap is provided in Table 3. Note that the strict reach limitations of full overlap reduces its applicability (only 12% of demands are overlapped) and consequently, this option provides poor performance. On the contrary, the longer reach of partial overlap is the main reason behind its good performance, since it allows overlapping a portion of traffic similar to that routed using PM 16-QAM in the absence of signal overlap.

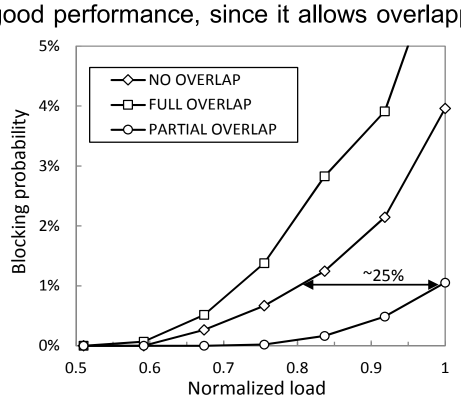

Fig. 2: performance of PM-QPSK overlap

Tab. 3: % of demands per modulation format

	PM-16QAM	PM-QPSK (no overlap)	PM-QPSK (overlap)
No Overlap	84%	16%	-
Full Overlap	-	88%	12%
Partial Overlap	-	27%	73%

In the second traffic scenario, an initial traffic matrix demanding 100G between any pair of the selected 11 nodes (i.e. 110 demands) was multiplied by a factor *k* to obtain gradual increments. Note that in case of an even *k*, we could expect optimal conditions for routing 200 Gb/s using PM-16QAM (see Table 2). However, the slightly larger reach and much more flexible spectrum exploitation of QPSK overlap (not restricted to only demands sharing source and destination) provides better overall spectrum usage results, as illustrated in Fig. 3.

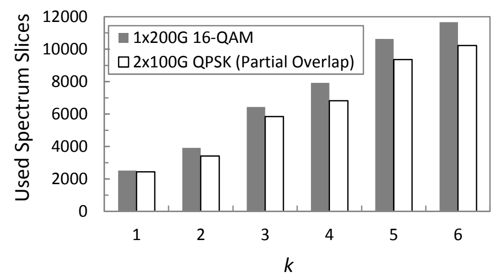

Fig. 3: capacity usage comparison

Conclusions

In this study we propose the partial overlap technique enabling two slightly-detuned 100G PM-QPSK signals to effectively share the same frequency slot. Results show remarkable benefits in the overall network usage compared to fully overlapped signals and, interestingly, also compared to 200G 16QAM.

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