# Simplified Han-Kobayashi Coding Strategy for Tb/s Optical Superchannel Transmissions

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**Abstract**

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# Simplified Han–Kobayashi Coding Strategy for Tb/s Optical Superchannel Transmissions

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**Abstract:** We propose a simplified strategy as a special case of Han–Kobayashi coding to handle inter-channel interference in optical superchannels. The proposed scheme achieves higher than Tb/s data rates while the complexity for superposition coding is avoided.

**OCIS codes:** (060.4510) Optical communications, (060.1660) Coherent communications, (060.4230) Multiplexing.

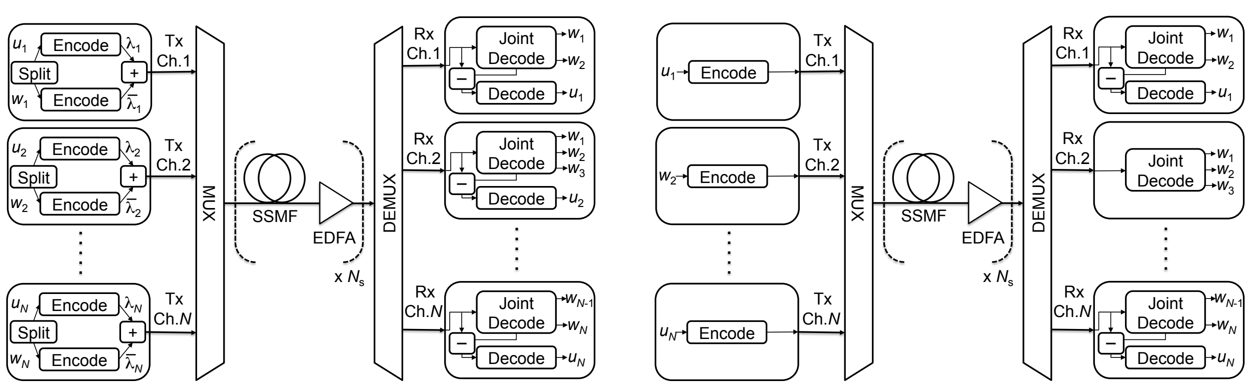
## 1. Introduction

The demand of Tb/s-class high-speed data rates in optical communications has necessitated high-throughput technologies, such as superchannel transmissions [1–9], where parallel transmitters send independent data using different wavelengths to increase total throughput. The spectral efficiency can increase as the channel spacing decreases. However, inter-channel interference (ICI) can be a major limiting factor to realize dense channel allocation.

In order to handle ICI in superchannel transmissions, we have proposed in [8, 9] to use joint decoding, Han–Kobayashi (HK) coding [10], and dirty-paper coding (DPC) [11, 12]. Through theoretical evaluations, those methods showed significant gains of up to 2.5-times higher spectral efficiency than conventional decoding in the presence of strong ICI for sub-Nyquist channel spacings. However, since HK and DPC require sophisticated methods such as superposition coding and modulo-lattice coding, a simpler method may be preferred for practical applications.

In this paper, we propose a simplified HK strategy scheme by using hybrid joint decoding. Using power splitting factors [8, 10] of either 0 or 1, we can avoid the need for superposition coding. We then show that the proposed hybrid decoding strategy can achieve Tb/s-class high-speed data rates in dense superchannel transmissions, such as 50%-Nyquist channel spacing discussed in [2, 9].

## 2. Superchannel Han–Kobayashi (HK) Coding and Joint Decoding




(a) Conventional HK Scheme

(b) Simplified HK Scheme with Hybrid Decoding

Fig. 1: Superchannel Han–Kobayashi coding for coherent optical communications.

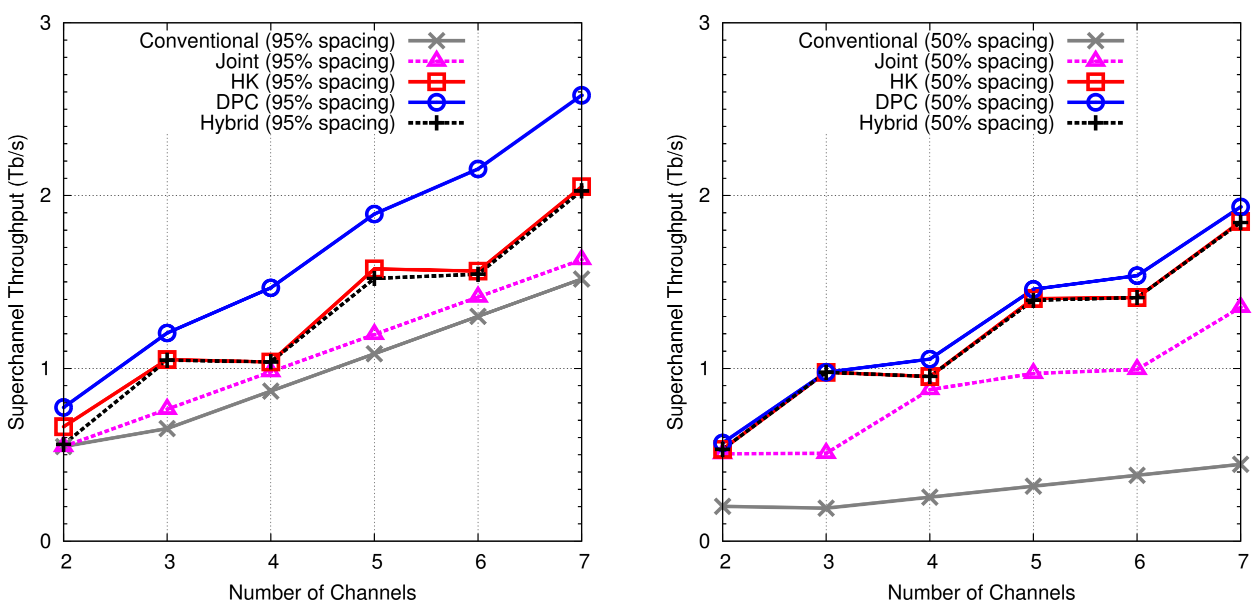
Fig. 1 shows schematics of superchannel optical transmission systems employing the HK scheme. We consider the case of sub-Nyquist channel spacing, in which ICI from adjacent subchannel transmitters is present. As shown in Fig. 1(a), the conventional HK scheme splits data at each subchannel transmitter into two portions; one is private data $u_n$ for only the intended receiver, and the other data $w_n$ is public for all receivers. These two encoded data are superimposed with a certain power splitting ratio $\lambda_n$. At each subchannel receiver, all public data including ICI are jointly decoded, and intended private data is decoded after ICI cancellation. Unintended public data, e.g., $w_2$ for the first subchannel receiver, are discarded in the end.

By controlling the power splitting ratios at all subchannel transmitters, the HK scheme can achieve joint decoding gain for public data while mitigating ICI for private data. However, optimizing the splitting ratio for each channels is cumbersome even for the 2-channel case. In [9], we have proposed a comb-like strategy for superchannel HK scheme, in which we use identical power splitting ratios at even-number channels and another identical one at odd-number channels. In particular, we have shown that setting either 1 or 0 for one of them achieves close to DPC bound, while we can reduce the number of optimization parameters to only one. However, it still requires one parameter optimization and superposition coding. We propose a more special case of $\lambda_{\text{even}} = 0$ and $\lambda_{\text{odd}} = 1$ as shown in Fig. 1(b), which we refer to as hybrid decoding since joint decoding is applied for data from even-number channels and individual decoding is applied for data from odd-number channels. Note that the hybrid decoding scheme can avoid the need of superposition coding for transmitters.

If we use $\lambda_{\text{even}} = \lambda_{\text{odd}} = 1$, all messages are private and the receiver strategy is identical to conventional decoding. If we use $\lambda_{\text{even}} = \lambda_{\text{odd}} = 0$, all messages are public to be decoded by all receivers, and the receiver strategy is identical to joint decoding. We show that our proposed hybrid decoding improves the throughput significantly, compared to those conventional decoding and joint decoding. Additionally, the hybrid decoding scheme can approach DPC performance while its complexity is lower than HK and DPC.

## 3. Performance Results

We consider two cases of sub-Nyquist channel spacing; 95% quasi-Nyquist spacing and 50% super-dense spacing. Figs. 2(a) and 2(b) show the performance curves in superchannel throughput as a function of the number of channels for a channel spacing of 95% and 50% baud rates, respectively. We assume 32 Gbaud rate per channel and root-raised-cosine filter with a roll-off factor of 0.01 for each transmitter and receiver. As in [7,9], we use the Gaussian noise (GN) model [13] to calculate nonlinear interference power after 10 spans of standard single-mode fiber (SSMF), whose span length is 80 km. The launch power is optimized at each data point around $-2.0$ dBm per channel. Amplified spontaneous emission (ASE) noise is calculated, assuming that Erbium-doped fiber amplifier (EDFA) with a noise figure of 4 dB compensates for the fiber loss every span. The theoretical analysis is carried out by assuming the use of a capacity-achieving coded modulation.




(a) Channel Spacing: 95% Nyquist Bandwidth

(b) Channel Spacing: 50% Nyquist Bandwidth

Fig. 2: Superchannel throughput of different schemes in sub-Nyquist transmission over 800 km SSMF.

It is shown in Figs. 2(b) and 2(a) that our proposed hybrid decoding achieves close to HK and DPC performance especially for very dense channel allocations of 50% baud rate. We demonstrate that the hybrid decoding at 3, 5, and 7 channels achieves 1.0, 1.5, and 2.0 Tb/s, respectively, each of which is at least 25% higher throughput than conventional decoding. Note that joint decoding has only a marginal gain over the conventional decoding for 95% spacing because ICI is weak. The conventional decoding degrades the throughput significantly when the ICI becomes stronger for 50% spacing. In contrast, the hybrid decoding can keep higher throughput even when the bandwidth consumption is reduced by half from 95% to 50% channel spacing. The proposed scheme can realize such a super-dense channel allocation even without multiple-input multiple-output (MIMO) equalization [2].

## 4. Conclusions

We proposed hybrid decoding — a simplified Han–Kobayashi scheme — to cancel ICI in sub-Nyquist superchannel transmission systems. It is shown that the hybrid decoding achieves more than 25% higher throughput than conventional decoding while the complexity is lower than joint decoding. Additionally, a very dense channel allocation with 50% spacing can be realized with almost no performance degradation.

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