

Supplementary Information for Exploiting a Centrally Powered Coherent Microcomb for Lightweight Optical Transmission

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Supplementary Note 1. Energy conversion

In the field of microcavity optical frequency combs, the intrinsic energy conversion efficiency is typically defined as follows: the total power of all comb teeth in the output spectrum, excluding the pump frequency, is calculated as $(P_{\text{comb, total}} - P_{\text{comb, cw}})$. By adjusting the temperature of the DFB laser, the frequency comb is turned off. A second measurement is then performed using an optical spectrum analyzer to record the continuous-wave power P_{cw} . The conversion efficiency can thus be determined as $(P_{\text{comb, total}} - P_{\text{comb, cw}})/P_{\text{cw}}$.

The supplementary table.1 lists the wavelengths and power levels of all comb teeth. The energy conversion efficiency is calculated to be 61.50%. However, this value does not fully represent the practical performance in a communication system. Only the channels actively used for transmission hold statistical significance. Therefore, the efficiency is recalculated based on the 16 channels numbered from -8 to +7, $P_{\text{comb, total}}^{\text{communication}} = 27.598$ mW. Define the communication conversion efficiency as $(P_{\text{comb, total}}^{\text{communication}} - P_{\text{comb, cw}})/P_{\text{cw}}$. The communication conversion efficiency of our system is calculated to be 61.34%. Nearly 100% of the output energy is coupled into the communication system.

In the main text, we give the conversion efficiency as the ratio between the total power of the 15 generated comb lines to the pump laser power. Considering the 18 dBm LD power is converted to 16 >-10 dBm carriers, the “effective” conversion efficiency can be calculated as $16 \times 10^{-1} / 101.8 = 2.5\%$. After including the additional

insertion loss of the WSS (IWC), the post-equalization conversion efficiency falls to 0.8% (0.4%).

Following the wall-plug efficiency definition, we also provide the electro-optic conversion efficiency, which accounts for the generated optical power relative to the electrical power driving the optical sources. Considering the electric consumption of 0.469 W (0.3 A×1.564 V) for the laser diode, 0.587 W (0.38 A×1.545 V) for the SOA and the output optical power of 0.031 W (15 dBm), the overall electric-optic conversion efficiency is ~3.0%. This is lower than the typical wall-plug efficiency (9%~16%) of DFB laser diodes, but unlike DFB arrays, it requires no individual LD or TEC control for each laser unit.

Supplementary Table 1. Power of individual comb lines

Number	Wavelength (nm)	Power (dBm)	Power (mW)				
-12	1546.1	-32.97	0.0005	1	1556.2	7.147	5.1844
-11	1546.9	-27.82	0.0017	2	1556.9	-2.009	0.6297
-10	1547.6	-26.63	0.0022	3	1557.7	-4.629	0.3444
-9	1548.4	-21.65	0.0068	4	1558.5	0.290	1.0691
-8	1549.2	-8.076	0.1557	5	1559.3	-2.429	0.5716
-7	1549.9	-6.437	0.2271	6	1560.1	-3.501	0.4466
-6	1550.7	-3.927	0.4049	7	1560.8	-9.068	0.1239
-5	1551.5	-6.882	0.2050	8	1561.6	-15.44	0.0286
-4	1552.3	-9.309	0.1172	9	1562.4	-21.96	0.0064
-3	1553.0	-3.109	0.4888	10	1563.2	-29.08	0.0012
-2	1553.8	1.129	1.2969	11	1564	-31.66	0.0007
-1	1554.6	8.761	7.5180	12	1564.8	-36.34	0.0002
0	1555.4	9.452	8.8145	$P_{\text{comb, total}}$	-	14.42	27.646
				P_{cw}	1555.4	14.86	30.620
				$-P_{\text{comb, cw}}$	-	12.75	18.832

Supplementary Note 2. Current progress in communication

Supplementary table.2 provides an overview of current transmission systems. It serves as a detailed supplement to Fig. 5 in the main text, additionally presenting results including the Number of Lines, Summation Net Rate, and Communication Energy Conversion.

Supplementary table 2. A part of current progress in comb-based communication experiments.

Ref. In main	Number of lines & band	Symbol rate [Gbaud]	Net rate/ λ /core [Gbps]	Summation Net rate [Tbps]	Energy Conversion	Communication Energy Conversion	Conversion Loss
[1]	20 C	18	72	1.44	-	-	>80%*
[2]	179 C+L	40	307	55	0.6%	0.499%*	16.83%*
[3]	20 C	20	220	4.4	20%	17.9%*	10.5%*
[4]	160 C	23	245	39.2	42%	38%	9.5%
[5]	39 C	40	274	10.68	<0.3%*	-	63%*
[6]	80 C	10	275	661	66%	-	>70%*
[7]	223 C+L	32	223	1840	13%	2.956%*	77.25%*
This Work	16 C	70	523	200.97	61.50%	61.34%	0.26%

The data marked with an asterisk (*) in the table are derived from the spectral plots provided in the referenced paper or calculated from supplementary data.

Supplementary Note 3. Light sources in coherent transmission systems

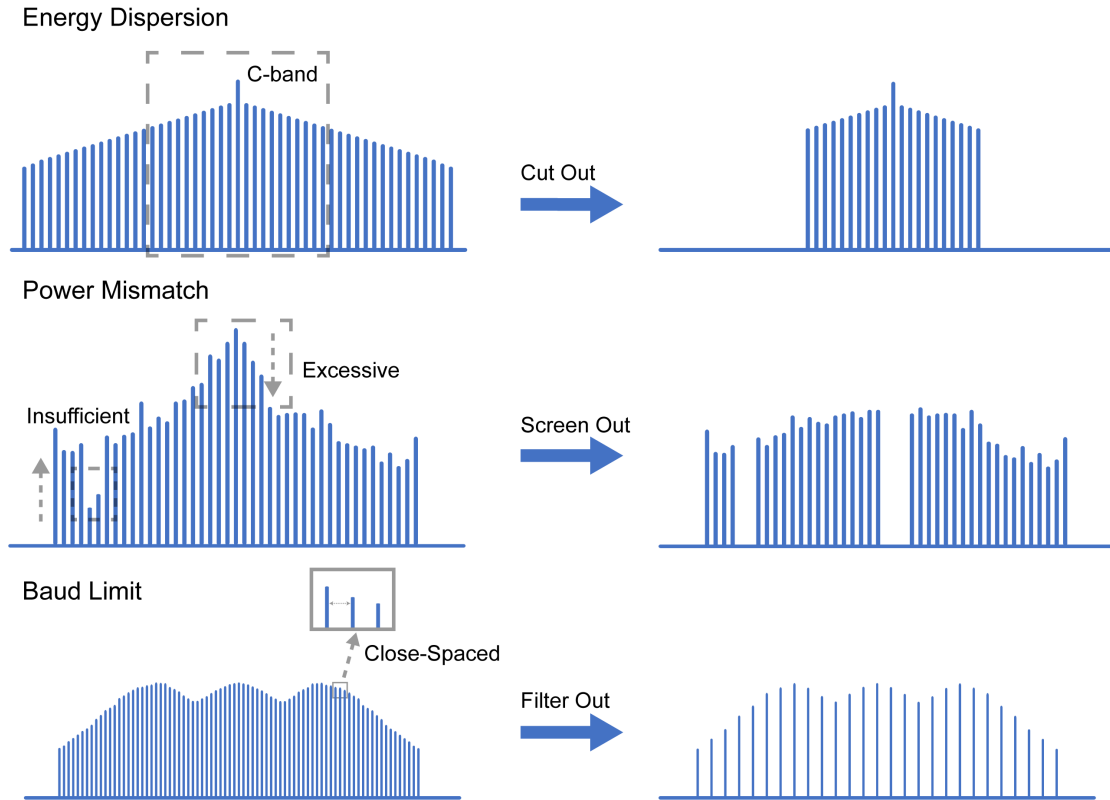
The generation and energy conversion of light sources are crucial in lightweight systems. Common conversion methods primarily include bright solitons, dark pulses, mode-locked lasers (MLL), and EO combs. In current communication systems, these light sources are subject to limitations imposed by device characteristics or their intrinsic properties, which spoil the overall transmission system.

Supplementary Fig. 1 summarizes three scenarios of light source loss in communication systems. Typically, due to the dispersion characteristics of bright solitons, their spectral width often exceeds the C-band, causing energy dispersion. Since the energy conversion efficiency of bright solitons is usually no more than 2%, this results in lower communication conversion efficiency. Additionally, the non-flatness of the generated comb spectrum introduces additional operational complexity and energy waste. Excessively high energy causes rapid saturation of EDFAs, while excessively low energy loses high-speed modulation capability, necessitating processing before the signal can be coupled into the channel. Finally, intrinsic gain requirements of devices such as MLLs limit the expansion of frequency spacing, requiring the filtering of some comb teeth to meet high baud rate transmission demands. All these factors contribute to a reduction in communication energy conversion efficiency.

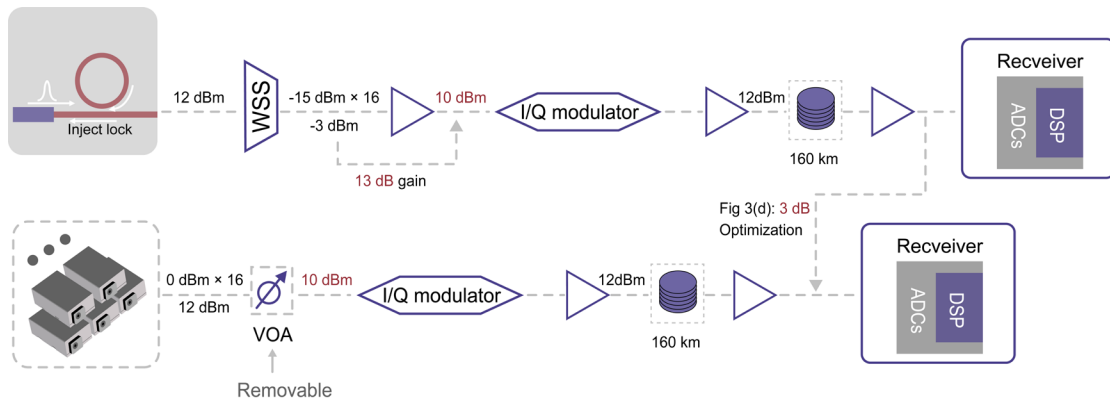
Therefore, there is an urgent need for integrated light sources with energy

concentrated entirely within the communication band, flat power distribution, and suitable frequency spacing, which offer high conversion efficiency, to be applied in coherent communication systems.

Here we present a comparative analysis of the gain requirement between the SIL microcomb and the laser-array schemes. To ensure a fair comparison, the input power to the modulator is fixed at 10 dBm (its optimal operating point) across all configurations. With higher output power, the system with laser arrays eliminates the need for the first-stage EDFA (shown in supplementary Fig.2 bottom panel). And the WSS before IQ modulators for demultiplex is not needed. For the microcomb-based approach, due to the 5 dB insertion loss introduced by the WSS, this scheme requires an additional 13 dB of first-stage gain compensation, with additional OCNR degradation. However, due to the narrow-linewidth characteristics of the self-injection-locked microcomb, the receiver achieves the same level of BER, despite remaining a 3 dB lower OSNR when compared with the bulky laser approach (main text in Fig 3(d)).



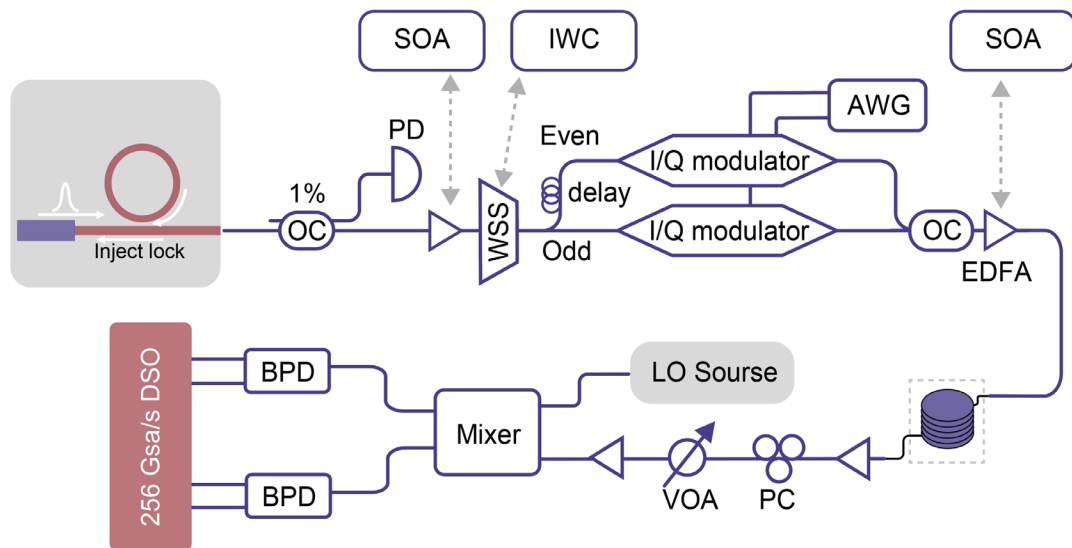
Supplementary Fig. 1 Loss mechanisms of light sources in comb-based coherent transmission systems.



Supplementary Fig. 2 Gain comparison: SIL comb vs. commercial external-cavity laser.

Supplementary Note 4. Optical communication system equipment

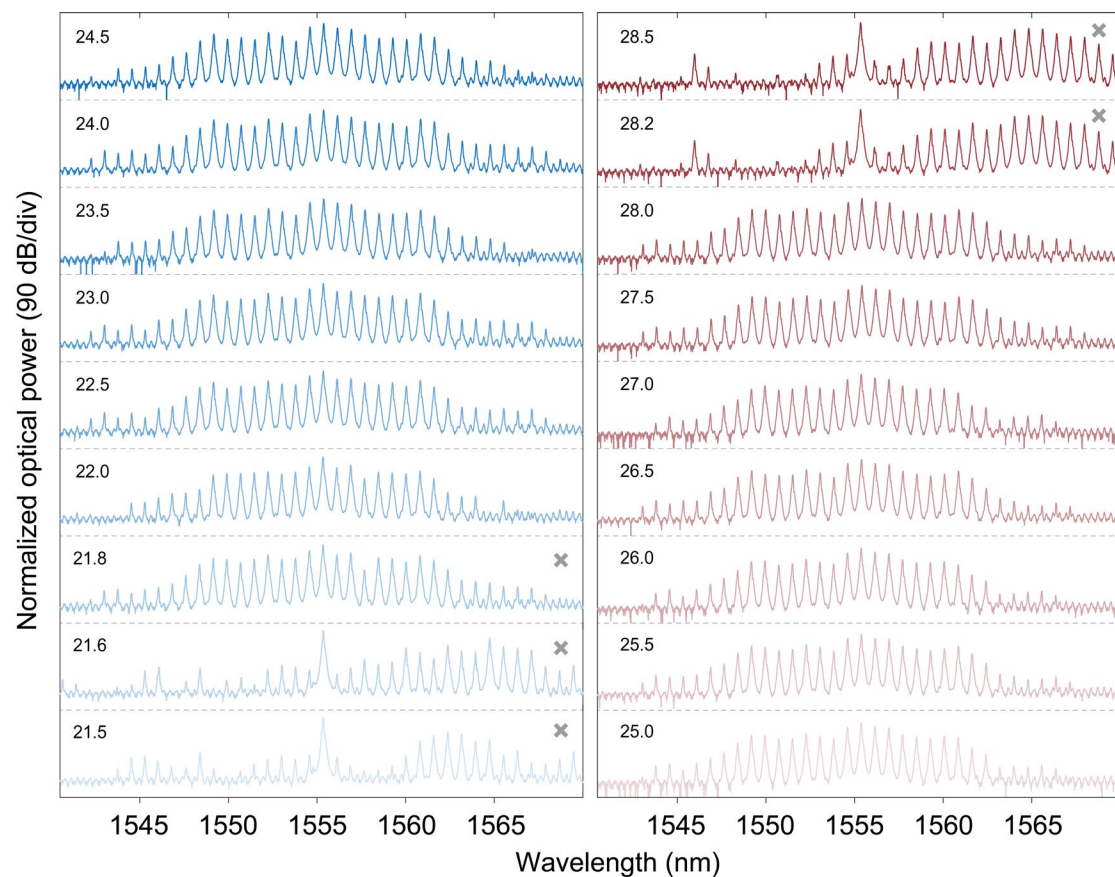
As shown in Supplementary Fig. 3, a schematic diagram of the communication experimental setup is provided. The fan-in/fan-out devices for the MCF and the multiplexers/demultiplexers required for MDM are not depicted in the figure. After generating the frequency comb, it is split into odd and even channels and decorrelated. Each channel undergoes I/Q modulation, and the signals are then coupled and transmitted through the fiber. The local oscillator at the receiver in both the EDFA-based and the SOA-based configurations is the KEYSIGHT N7714A ECL.



Supplementary Fig. 3 Detailed schematic diagram of the communication system; OC: optical coupler. PD: photodetector. WSS: wavelength selective switch. AWG: arbitrary waveform generator. LO: local oscillator (KEYSIGHT N7714A). EDFA: erbium-doped fiber amplifier. PC: polarization controller. VOA: variable optical attenuator (CETC AV6381B). BPD: balanced photodetector (Finisar BPDV3120RQ). Mixer (Optolex).

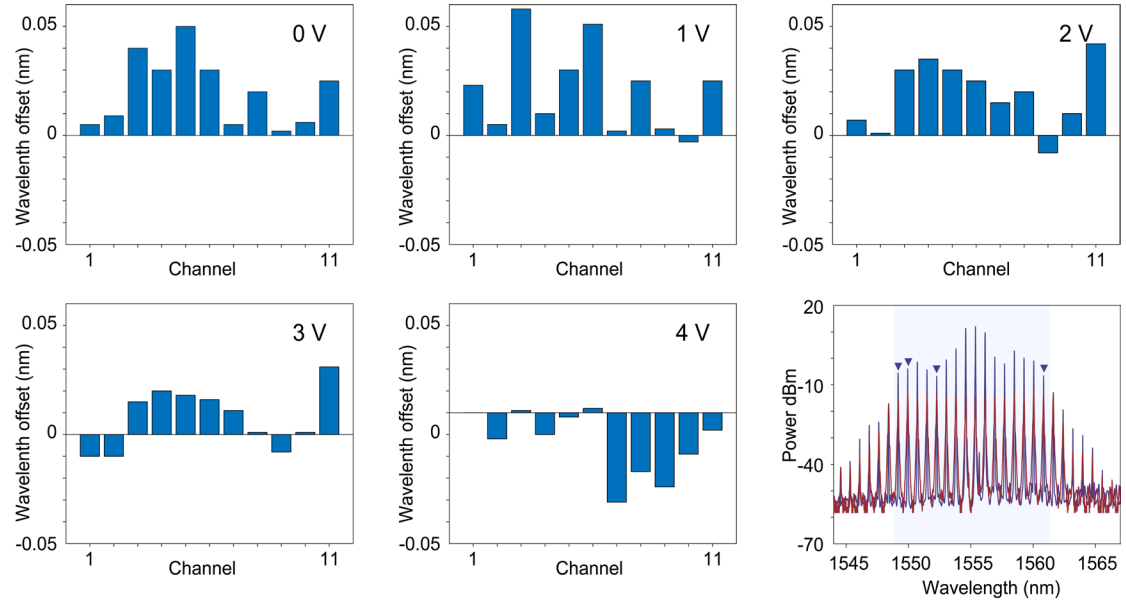
Supplementary Note 5. Component characteristics

In integrated WDM transmission systems, light sources exhibit the most significant susceptibility to temperature fluctuations. By adjusting the TEC temperature of the silicon nitride microring, we simulated real-world environmental temperature variations. The system maintains normal operation within a 22-28°C range (6°C operational window). In practical transmission scenarios, each component can be thermally stabilized by individual TEC controllers, enabling reliable performance across wider ambient temperature fluctuations.



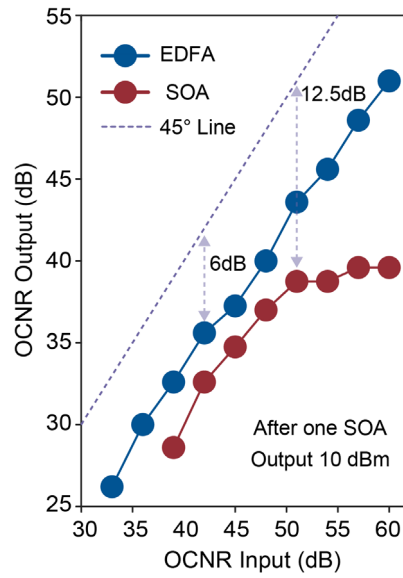
Supplementary Fig. 4 Temperature sensitivity of SIL light sources. The optical spectrum varies with ambient temperature from 21.5°C to 28.5°C, where cross markers in the figure indicate failure conditions.

Thermal crosstalk in the IWC has been characterized within the 0-4V operating range. The impact is more pronounced on microrings in closer proximity, exhibiting stronger interference effects. The wavelength drift is less than 0.06 nm.



Supplementary Fig. 5 Thermal crosstalk in IWC. The voltage applied to the outermost microring (Channel 12) was adjusted and the resulting wavelength offsets across the remaining 11 channels were measured. The post-equalization optical spectrum is shown in the lower-right inset, where the marked wavelengths indicate components that did not pass through the filtering structure.

We present the degradation of the input OCNR by a single SOA at an output power of 10 dBm using a single wavelength laser, which is caused by the introduction of ASE noise. In comparison, EDFAs introduce lower ASE noise, which results in a 4 dB higher final OCNR output. Additionally, EDFAs offer superior linearity, broader span range, higher saturation power, and lower input power requirements.



Supplementary Fig. 6 OCNR degradation. The blue curve represents the EDFA, and the red curve represents the SOA, both at an output power of 10 dBm. The EDFA shows a degradation of approximately 6 dB, while the SOA exhibits about 10 dB.

Supplementary Note 7. Lightweight transmitter component sizes

We present the volume and quantity of all components in the transmitter. For our long-haul, high-speed demonstration, the transmitter assembly features a footprint of 2374 cm² and a height of 12 cm. In the more lightweight transmitter demonstration, our system occupies an area of 89 cm² with a height of 3 cm. This results in a volume reduction of more than a hundred-fold ($2374 \times 12 / 89 / 3 = 106$).

It is noteworthy that in our experiment, two DP-IQ modulators were used to separate the odd and even channels to simulate a real world transmission system. In an actual communication node deployment, each carrier channel requires an individual modulator for signal loading. Consequently, we have re-evaluated the size here in supplementary table.5. In a practical deployment scenario using commercially available EDFAs and WSSs, the overall footprint is 2546 cm² with a height of 12 cm. By adopting a more lightweight SOA system and on-chip DEMUX/MUX components⁸, the overall required footprint is further reduced to 208 cm² with a height of 1 cm. This results in a volume reduction by a factor of approximately 150 ($2546 \times 12 / 208 / 1 = 147$). Furthermore, the use of on-chip IQ modulators holds the promise of achieving a volume reduction of more than a thousand-fold⁹.

Supplementary table 4. Experimental system component sizes.

EDFA-WSS-based		
Component	Number	Volume (cm*cm*cm)
SIL Comb	1	2.8*1.2*1
EDFA	2	32*25*10
WSS	1	31*24*12
DP-IQM	2	8.8*1.4*1
2x1 Optical Coupler	1	0.3*6*0.3
SOA-IWC-based		
Component	Number	Volume (cm*cm*cm)
SIL Comb	1	2.8*1.2*1
SOA	2	3*1.27*1
IWC	2	5.2*4.8*3
DP-IQM	2	8.8*1.4*1
2x1 Optical Coupler	1	0.3*6*0.3

Supplementary table 5. Real deployment system component sizes.

EDFA-WSS-based		
Component	Number	Volume (cm*cm*cm)
SIL Comb	1	2.8*1.2*1
EDFA	2	32*25*10
WSS	1	31*24*12
DP-IQM	16	8.8*1.4*1
16x1 Optical Coupler	1	0.7*5*0.4
SOA-AWG-based		
Component	Number	Volume (cm*cm*cm)
SIL Comb	1	2.8*1.2*1
SOA	2	3*1.27*1
AWG (DEMUX/MUX)	2	~0.11*0.07
DP-IQM	16	8.8*1.4*1

Supplementary Note 8. Experimental results

To better present the experimental results and conceptual framework, we have tabulated the obtained data. Experiments 1 and 2 primarily demonstrate transmission in short-range campus/edge networks and metropolitan area networks. Experiments 3–5 employ SDM to showcase multi-point aggregated data transmission. Experiment 6 achieves more integrated lightweight transmission through the use of highly integrated components such as SOA and IWC.

Supplementary table 6. Tabulation of experimental results.

	Symbol rate [Gbaud]	Signal format	Raw capacity [Tbps]	Summation Net rate [Tbps]	Net rate/ λ /core [Gbps]	Multiplexing scheme	Local oscillator
1	110	DP-32QAM	8.38	8.064	1008	1 km-SMF	SIL-Comb
2	70	DP-16QAM	8.96	8.374	523	160 km-SMF	ECL
3	70	DP-16QAM	215.04	200.97	523	2 km-24MCF	ECL
4	40	DP-16QAM	10.24	9.57	598	25 km-FMF	ECL
5	70	SP-16QAM	8.96	8.37	523.	50 m-RCF	ECL
6	40	DP-16QAM	5.12	5.015	313	10 km-SMF	ECL

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