Evaluating 200G/400G solutions for practical deployments in long-haul network

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200G/400G systems based on 16QAM and 8QAM are studied over three China Telecom links with different distances and span lengths. Ultra-low loss and ultra-low loss + large Aeff fibres were shown to support high-order modulation with sufficient industrial margin.

Introduction: Many approaches have been extensively studied to increase transmission capacity, such as the use of multiple carriers and high-order modulation formats [1–4]. Industry has generally agreed on two solutions to achieve 400G: 2 × 200G PM-16QAM with 32Gbaud and 2 × 200G PM-8QAM with 43Gbaud [5]. However, there is an uncertainty about the 16QAM and 8QAM transmissions performance in real links because such systems have not yet been deployed on a mass scale. For operators, it is essential to confirm whether current links can support migration from 100G to 200G/400G without adding electrical regeneration. In the network planning, it is also important to make decisions whether new types of fibre need to be deployed to support high-density modulation format to avoid the difficulty and costs associated with building new regeneration sites.

In this Letter, we simulate 200/400G performance of three links within China Telecom's backbone network, which represent the typical links with short, medium and long reach, respectively. The performance of currently deployed G.652 fibre is first simulated, and its performance if then compared with SMF-28® ULL and Vascade® EX2000 fibres. Monte Carlo modelling based on a split-step Fourier approach is used for 32 Gbaud 16QAM transmissions and Gaussian-noise analytical model is used for 43 Gbaud 8QAM transmissions. For both 8QAM- and 16QAM-based 200G transmissions over the three links studied in this work, Vascade EX2000 and SMF-28 ULL fibres are able to support the existing span lengths with sufficient engineering and maintenance margin. The difference is that Vascade EX2000 fibre could employ hard SMF-28 ULL fibre can only use soft decision FEC (SD-FEC) or ultra-SD-FEC. Existing fibre can hardly support 16QAM and 8QAM transmissions without adding new regeneration even with ultra-SD-FEC capable equipment.

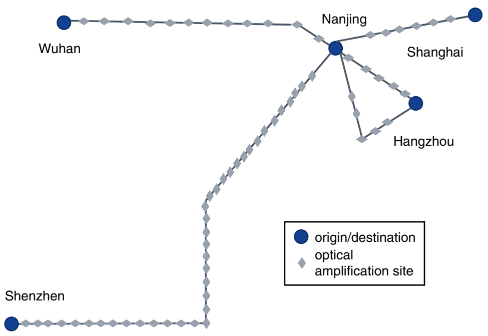

Fig. 1 *Real links with span distance and existing loss*

Table 1: Attributes of optical fibres studied in this work

	Existing fibre	SMF-28 ULL fibre	Vascade EX2000 fibre
Attenuation (dB/km)	Varies	0.162	0.156
Aeff (μm^2)	82	82	112
n2 (×10–20, m^2/W)	2.3	2.1	2.1
Dispersion (ps/nm/km)	16.5	16.5	20.2
Splicing to G.652 fibre (dB)	Already spliced	0.03	0.1
Splicing to itself (dB)	Already spliced	0.03	0.02

Modelling setup: A 16QAM-based 200G optical fibre link schematic diagram is established. At the transmitter end, electrical fifth-order Bessel filtering with 35 GHz half-width half-maximum (HWHM) bandwidth and an optical third-order Butterworth filter with 50 GHz bandwidth were applied for 50 GHz spaced channels. For 37.5 GHz spaced channels, a matched raised cosine filter was used.

The symbol rate for both configurations was 32 Gbaud, and the linewidth of the laser was 100 kHz. A total of 20 WDM channels were modelled – our previous studies showed that such number of channels provides good balance between the computational time and modelling precision.

At the receiver end, electrical fifth-order Bessel filter with 20 GHz HWHM bandwidth and an optical third-order Butterworth filter with 50 GHz bandwidth were used for 50 GHz spaced channels. For 37.5 GHz spaced channels, the filtering was the same as the one used at the transmitter. The linewidth of the local oscillator was 100 kHz and the limited analogue-to-digital converter quantisation was not included in the model. For chromatic dispersion compensation, we used a finite-impulse-response filter with 15.625 ps tap spacing (half symbol period). For PMD compensation we used 2-stage constant-modulus 16QAM equalisers with 15 taps.

To model the performance of PM-8QAM based 200 Gbit/s transmission (at 43 Gbaud) we used Gaussian-noise analytical model [6]. Linear and non-linear interference noises were calculated per each span, and then added together to determine the equivalent linear and non-linear interference noises.

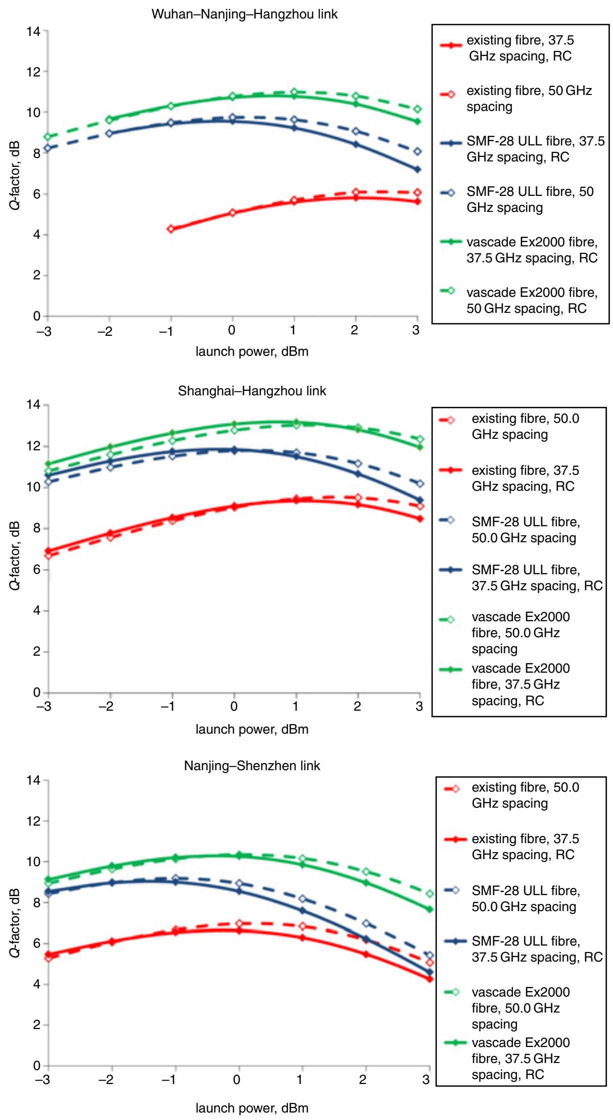

Fig. 2 *200G 16QAM-based transmission comparison for different fibres*

We first modelled the existing China Telecom links with lengths and span losses as shown in Fig. 1. For Wuhan–Nanjing–Hangzhou 1287 km link the average span length was 67.7 km with the largest span length of 100.4 km and the largest span loss of 30.4 dB. While for Shanghai–Hangzhou 795 km (via the lower route from Hangzhou to Nanjing) link the average span length was 61.2 km with the largest span length of 91.7 km and the largest span loss of 20.4 dB. We also modelled a link between Nanjing and Shenzhen, and the total length is 1977 km and the average span length is 50.7 km with the largest span length of 77.3 km and the largest span loss of 16.4 dB. The span length and loss are real including necessary margins for long term operation and maintenance. We then evaluated options to improve transmission performance by using SMF-28 ULL and Vascade EX2000 fibres with the parameters given in Table 1. Erbium doped fiber amplifiers (EDFAs) noise figure was assumed to be 5 dB, and the ROADMs were modelled as a static block with an insertion loss of 10 dB (and a subsequent EDFA to compensate for this loss). For links with 20 spans or less, we assumed the presence of ROADM at each amplifier site. For links with more than 20 spans, we assumed the maximum of 20 ROADMs, spaced as uniformly as possible across the link. The spectral shape of ROADMs was neglected in this modelling.

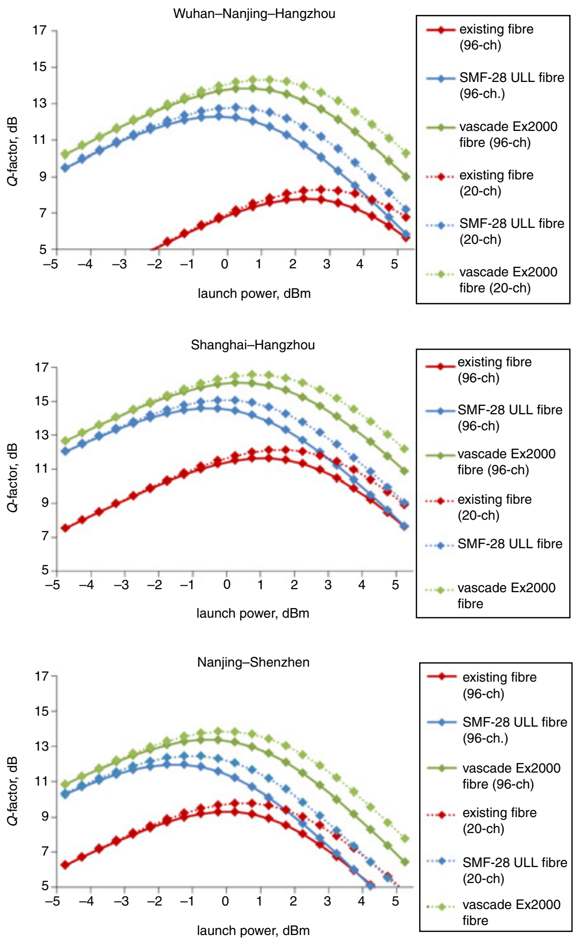

Fig. 3 *200G 8QAM-based transmission comparison for different fibres*

For network design rules, we assumed 3 dB of optical margin (provisioned for repairing the cable cuts) for spans with the length of 75 km or less (for both existing and new fibres). For the longest span, 5 dB of optical margin was added. For spans with intermediate span length, the margin was calculated as: (span length–75)/(longest span length–75)*(5–3 dB)+3 dB. We also assumed that splicing between fibre cable sections occurs every 4 km.

Simulation results: Fig. 2 shows the performance of 16QAM with three real links over existing fibre, SMF-28 ULL fibre and Vascade EX2000 fibre. Commercial FEC threshold is provided with Q value of 5.5 dB for ultra-SD-FEC, 6.25 dB for SD-FEC and 8.5 dB for HD-FEC.

For the busiest Wuhan to Hangzhou link, the use of existing fibre will not provide sufficient Q-margin (needed when active equipment is commissioned for the deployment), even when ultra-SD-FEC is used. SMF-28 ULL fibre will have sufficient margin with ultra-SD-FEC, while Vascade EX2000 fibre will have sufficient margin also with SD-FEC. For the longest Nanjing to Shenzhen link, Vascade EX2000 will provide sufficient Q-margin with ultra-SD-FEC, while SMF-28 ULL fibre has borderline margin with ultra-SD-FEC and existing fibre cannot provide sufficient margin. For the shortest Shanghai to Hangzhou link, Vascade EX2000 fibre is able to provide sufficient margin even with HD-FEC, and SMF-28 ULL fibre will have sufficient margin with SD-FEC. Existing fibre can only provide borderline margin with ultra-SD-FEC. An interesting observation from Fig. 3 is that the performance of 50 GHz spaced channels with non-raised cosine (RC) is almost equivalent to the performance of configuration with 37.5 GHz spacing with RC filtering.

200G 8QAM system performance is shown in Fig. 3 – the performance of 96 and 20 channels differ by −0.5 dB in Q-factor. The use of existing fibre will only provide an adequate Q-margin for Shanghai–Hangzhou link (and only with ultra-SD-FEC), while both SMF-28 ULL and Vascade EX2000 will have sufficient margin with all SD-FEC's for all three links. In addition, Vascade EX2000 fibre will provide sufficient margin with HD-FEC for all three links.

Conclusion: The performance of 200G/400G solutions with both 16QAM and 8QAM is evaluated with three real links. High-order modulation will bring challenges for current network to migrate to 200G/400G and the use of new fibres could enable a cost-effective transition to 200G/400G.

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One or more of the Figures in this Letter are available in colour online.

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