Power budget analysis of dual/single feeder fiber WDM-PON

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This paper investigates how to reduce the cost of wavelength division multiplexing passive optical network (WDM-PON) by comparing the transmission performance of bidirectional single feeder fiber and dual feeder fiber. Comparison is performed on the basis of power budgeting and cost of both arrangements. Simulation results using Optisystem show that the performance of a single feeder fiber is almost equivalent to that of a dual feeder fiber. Therefore, the single feeder fiber WDM-PON can efficiently replace the dual feeder fiber WDM-PON with the minimum deterioration in system performance and reduction in cost.
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Passive optical network (PON)[1] is a high bandwidth system, where an optical transceiver at central office (CO) called optical line terminal (OLT) is shared among 128 customers, and a stable reliable system is constructed with passive devices outside CO and customer's home. Different multiplexing techniques are used in PONs to achieve multiple access capability because many optical network units (ONUs) are fed by a single OLT. Some service providers use the time division multiple access (TDMA) technique to provide baseband services like gigabit PON (GPON) and ethernet PON (EPON). Although TDMA-PON is a mature technology, its use is constrained by some limitations, such as bandwidth, flexible scalability, protocol transparency, security and link reach. This has given rise to the use of next generation PON architectures, among which wavelength division multiplexing (WDM)-PON is considered as the best for satisfying the future bandwidth requirements in access networks[2-4]. However, the deployment of wavelength specific transmitters and wavelength selective components at OLT and each ONU in WDM-PON has limited the application of this technology in the current optical transport market due to the high capital expenditure (CAPEX). Hence, it is necessary to provide a cost-effective architecture for the next generation of WDM-PONs[5].

Using a single feeder fiber for both downstream and upstream transmissions in a full duplex arrangement can significantly reduce the cost of WDM-PON[6,7]. However, the performance of a single feeder fiber system suffers from the transmission power penalties and power budget losses in the system[8]. The dual feeder fiber can efficiently solve the problem of power losses, but it causes the additional cost of installation and operation. Therefore, it is necessary to select a suitable arrangement which is economical and efficient.

This paper investigates and compares the feasibility of single and dual feeder fibers on the basis of cost and performance, i.e., power budgeting, and determines a suitable cost-effective scheme for next generation WDM-PONs. Simulation analysis in Optisystem is performed to investigate the power budgeting of both single and dual feeder fibers. Simulation results show that the performance of single feeder fiber architecture is almost equivalent to that of dual feeder fiber architecture.

The purpose of power budgeting in optical communication is to make sure that enough power will be obtained from OLT to ONU in order to maintain consistent performance during the entire system life span. The power budget in PON is the sum of the losses of all individual components between transmitter and receiver, including fiber, splices, couplers and other optical devices.

Various possible losses in PON are shown in Fig.1, where optical signal power is decreased along the length of fiber because of the losses mentioned above. Therefore, it is necessary to determine both input and output power at OLT and ONU or determine all kinds of losses occurring in the network to conclude the power budget of PON. For a system to perform efficiently, the power of the signal arriving at ONU should be greater than the minimum power level required by ONU which is called as receiver sensitivity.

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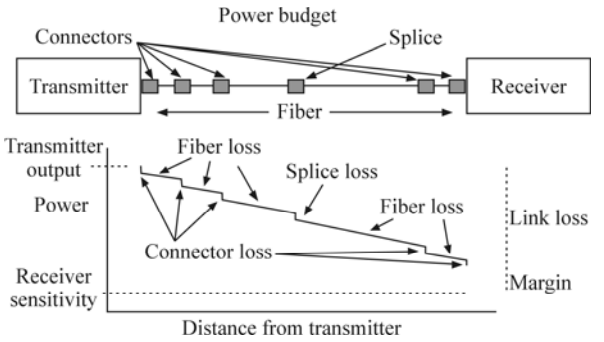


Fig.1 Graphical representation of power budget

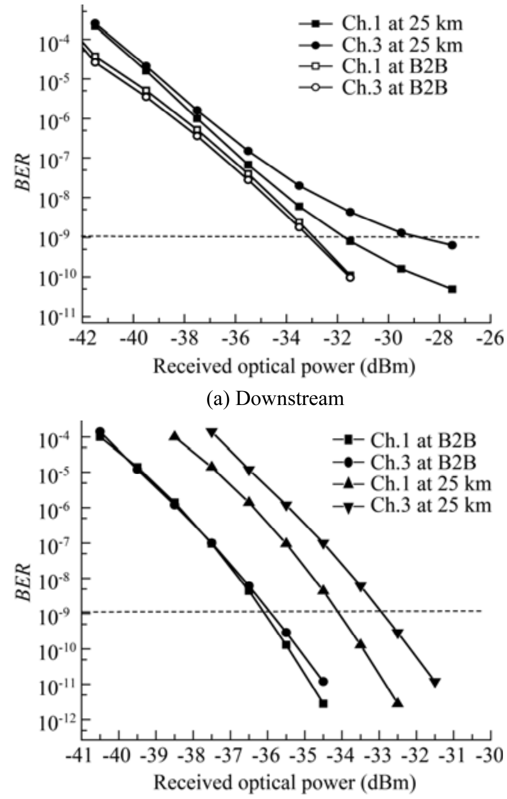
The WDM-PON architectures for single and dual feeder fibers are shown in Ref.[5]. An OLT in the single fiber setup consists of distributed feedback laser diode (DFB-LD) arrays which offer the wavelengths from λ_1 to λ_4 for downstream data. By choosing an appropriate biased voltage for $LiNbO_3$ Mach-Zehnder modulator (MZM) and applying a super imposed electrical signal of clock and data, the $LiNbO_3$-MZM can generate an optical signal which is return-to-zero (RZ)-shaped data modulated by a single modulator. The generated downstream differential phase shift keying (DPSK) signals are multiplexed and transmitted over 25 km standard single mode fiber (SSMF) using a single feeder fiber configuration. On the other end, the demultiplexer is used to demultiplex the downstream signal and send them to each ONU. At ONU, a portion of the received downstream optical signal is tapped off by a half power splitter. The downstream DPSK signal with constant intensity is demodulated by a 1 bit delayed interferometer (DI) and balanced photo diodes. The rest of the downstream optical signal is remodulated by an intensity modulation technique of 10 Gbit/s RZ on-off keying (OOK). The generated upstream signal is transmitted back to the OLT by SMF through a complete path. However, at the typical OLT configurations, the uplink and downlink paths merge by means of an optical circulator in single feeder fiber, so the possible reflection is strongly attenuated.

In order to calculate and compare the power budgets for single and dual feeder fibers using WDM-PON scheme, we establish simulation models in Optisystem software. The comparison is made between the situations at back to back (B2B) and after 25 km of transmission. A 10 Gbit/s pseudorandom bit stream (PRBS) data signal with order of 2^7-1 is used to generate four downstream data signals, using ITU-T grid of 100 GHz channel spacing. Four continuous light waves with launch power of 0 dBm are generated using DFB lasers at wavelengths of 1552.52 nm, 1552.12 nm, 1551.72 nm and 1551.32 nm for four different channels, respectively. They are multiplexed and transmitted to ONU using 25 km SMF. Each wavelength is broadcast using a 1×N power splitter, and each signal is shared by N ONUs in WDM-PON scheme. At ONU, a 3 dB optical splitter divides the downstream signal into two parts. An intensity modulation technique of 10 Gbit/s OOK is used to remodulate the first half to generate the upstream data signal. However, at the typical OLT configurations, the uplink and downlink paths merge by means of optical circulators. The parameters of the fiber used in our simulation are given in Tab.1.

Tab.1 Parameters of the fiber used in simulation

Parameters	Values
Dispersion parameter of SMF	17 ps/(nm·km)
Dispersion slope of SMF	0.075 ps/(nm^2·km)
Attenuation coefficient of SMF	0.2 dB/km
Effective core area of SMF	80 μm^2
Nonlinear index-coefficient of SMF	2.6×10^{-20}
Responsitivity of photodetector	1 A/W
Dark current of photodetector	10 nA
Rayleigh backscattering	5×10^{-5} km^{-1}

Transmission performance of single and dual feeder fibers using WDM-PON scheme is analyzed and compared in Optisystem[9]. For convenience, the performance of channel.1 (Ch.1) and channel.3 (Ch.3) is investigated by measuring bit error rate (BER) with respect to received optical power of downstream and upstream data signals. Fig.2 shows BER versus the received optical power of selected channels using dual feeder fiber WDM-PON scheme. The downstream transmission power penalties after 25 km at BER of 10^{-9} for Ch.1 and Ch.3 are found to be 2.0 dB and 3.0 dB, respectively, while the upstream transmission power penalties are found to be 2.5 dB and 3.0 dB, respectively.

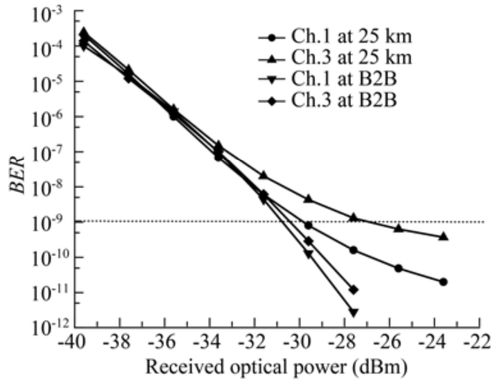


(b) Upstream

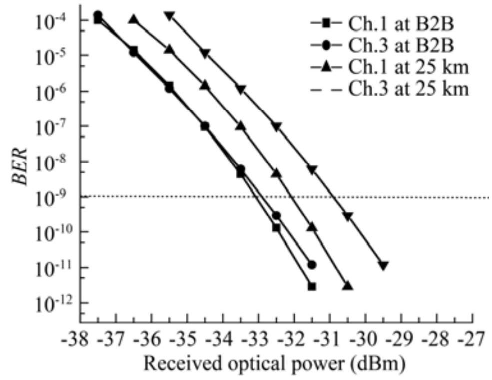
Fig.2 Downstream and upstream BER versus received optical power for dual feeder fiber WDM-PON scheme

Fig.3 shows BER versus the received optical power of selected channels using single feeder fiber WDM-PON scheme. The downstream transmission power penalties after 25 km at BER of 10^{-9} for Ch.1 and Ch.3 are found to be 1.8 dB and 2.5 dB, respectively, while the upstream transmission power penalties are found to be 2.0 dB and 2.5 dB, respectively.

After carefully analyzing the simulation results, it can be observed that the performance of single feeder fiber WDM-PON scheme is almost equivalent to that of dual feeder fiber WDM-PON scheme. It is also evident from Tab.2 that in dual feeder fiber WDM-PON scheme, the available power budgets for downstream DPSK data signal and upstream OOK data signal are 22 dB and 7.5 dB, respectively, while in single feeder fiber WDM-PON scheme, the available power budgets for the downstream DPSK data signal and upstream OOK data signal are 22 dB and 8.1 dB, respectively. Thus the available power budget in single feeder fiber is sufficient to provide an error free transmission in WDM-PON with the minimum CAPEX as compared with the dual feeder fiber.



(a) Downstream



(b) Upstream

Fig.3 Downstream and upstream BER versus received optical power for single feeder fiber WDM-PON scheme

Tab.2 Downstream and upstream power budget analysis of the two WDM-PON schemes

	Dual feeder fiber WDM-PON		Single feeder fiber WDM-PON	
	Downstream	Upstream	Downstream	Upstream
Minimum launch power (dBm)	0	–13.5	0	–12.9
SMF attenuation (dB)	5.0 (0.2 dB/km over 25 km of SMF)			
Coupler/ Mux/Demux (dBm)	2	2	2	2
Optical splitter (dBm)	3	0	3	0
Minimum receiver sensitivity (dBm)	–32	–28	–32	–28
Power budget (dB)	22	7.5	22	8.1

WDM-PON is considered as the best scheme for meeting the future bandwidth requirements in access networks, but a high CAPEX limits the applications of this technology. In order to determine an efficient and cost effective solution for WDM-PON future applications, this paper investigates the performance of single and dual feeder fiber WDM-PON schemes. Both arrangements are compared on the basis of power budget and cost. Simulation results using Optisystem show that the single feeder fiber demonstrates an adequate power budget in both downstream and upstream transmissions, and the power budget is almost equivalent to that of dual feeder fiber which is more expensive and requires high maintenance. Thus we can efficiently reduce the cost of WDM-PON systems through single feeder fiber with the minimum reduction of system's performance.

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