Abstract

In this paper, we propose a novel channel allocation scheme, i.e., the asymmetrically paired repeated unequally spaced (APRUS) scheme, for the dense wavelength division multiplexing (DWDM) transmission system. The APRUS scheme is capable of virtually eliminating the four-wave mixing (FWM) noise in the DWDM system, thus effectively addressing the FWM problem plaguing the conventional equally spaced (ES) channel allocation scheme. The APRUS allocation scheme was simulated and validated on four performance metrics; the number of FWM frequencies, total FWM power, total FWM efficiency and bit error rate. The simulation results revealed that the APRUS scheme outperforms the conventional ES regime on all four metrics. In addition, the FWM noise under the APRUS scheme is negligible such that no optical filters are required to filter out the noise at the DWDM’s receiving end. Moreover, an extra signal channel is accommodated under the APRUS allocation scheme, which is equivalent to a gain of 10Gbit/s data transfer rate.

Keywords: dense wavelength division multiplexing, four-wave mixing, nonlinear optics, erbium dope fiber amplifier, non-zero dispersion shift fiber

1. Introduction

The four-wave mixing (FWM) phenomenon contributes to the third-order nonlinear optical effects in the DWDM transmission system [1], and the situation is further compounded in the long-distance data transmission as the signals are significantly weakened upon arriving at the destination. To address the issue, the erbium-doped fiber amplifier (EDFA) is normally deployed to enhance the signal intensity, which in turn exacerbates the four-wave mixing effect. The optical filters are thus required to mitigate the FWM.

A typical DWDM transmission system operates based on the conventional equally spaced (ES) channel allocation scheme, which is in accordance with the ITU-T G.694.1 standard [2]. The standard specifies the use of light in the wavelength range of 1539.55-1560.61nm (192.1-196.0THz) to transmit signals along 40 channels separated by fixed 100GHz spaces. The ES channel allocation scheme nevertheless suffers from a large number of FWM light waves and, despite numerous research attempts to minimize the FWM using alternative channel allocation schemes, e.g. the unequally spaced (US) allocation schemes [3-8], the results have been less than satisfactory.

To efficiently tackle the issue of FWM, this research has thus proposed a novel channel allocation algorithmic scheme (i.e. the asymmetrical paired repeated unequally spaced (APRUS) channel allocation scheme). In fact, the APRUS scheme is an improved version of the invert repeated base-unit unequally spaced (IRBUS) channel allocation scheme [9]. In the simulations, this research assumed that the transmission was carried out via the dispersion shift fiber (DSF) which is free of the self-phase modulation (SPM) and cross phase modulation (CPM) noises and thereby only the FWM noise would be of concern [10,11]; and that the spaces between channels must be at least 50GHz, which is one of the limitations of the optical multiplexer and de-multiplexer [12].

The organization of this research is as follows: Section 1 is the introduction. Section 2 details the theoretical concepts, while Section 3 discusses the proposed APRUS channel allocation scheme. Section 4 deals with the simulation results and discussion. The concluding remarks are provided in Section 5.
The ultimate aim of the proposed APRUS channel allocation scheme is to minimize the four-wave mixing (FWM) noise. It is thus necessary to establish an understanding of the fundamental principles of nonlinear optics: the general nonlinear effects and FWM effects in optical fiber transmission.

### 2. Theoretical Concepts

The nonlinear effect in the DWDM transmission system exhibits a linear refractive index response and thus the light signal is neither affected nor weakened. On the other hand, the simultaneous transmission of high-intensity lights of multiple wavelengths from a light amplifier could induce a nonlinear refractive index response as well as nonlinear polarization. These nonlinear effects originate from two sources: the dispersion and attenuation of light in the media; and changes in the refractive index attributable to SPM, CPM or FWM noises [13].

The nonlinear effect in the DWDM transmission system, particularly those with a transfer rate above 10Gbit/s, could be attributed to the requirement for an erbium-doped fiber amplifier (EDFA) to amplify the high-intensity lights of multiple wavelengths. As seen in Figure 1, the problem develops immediately beyond the EDFA when a small amount of FWM noise associated with the output of the N-channels DWDM MUX is inadvertently amplified hundreds of times by the EDFA. This current research has thus proposed a solution to address the issue whereby the FWM is suppressed from development using the novel channel allocation algorithmic scheme (i.e. the APRUS scheme).

#### 2.1 General nonlinear effect in optical fiber transmission

The nonlinear effect pollutes the light signal in the DWDM transmission system by distorting the shape of the light signal. A normal-intensity light travelling through an optical fiber exhibits a linear refractive index response and thus the light signal is neither affected nor weakened. On the other hand, the simultaneous transmission of high-intensity lights of multiple wavelengths from a light amplifier could induce a nonlinear refractive index response as well as nonlinear polarization. These nonlinear effects originate from two sources: the dispersion and attenuation of light in the media; and changes in the refractive index attributable to SPM, CPM or FWM noises [13].

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#### 2.2 FWM effect in optical fiber transmission

The FWM phenomenon contributes to the unwanted frequencies from the interference between adjacent signal frequencies. Specifically, an FWM frequency \((f_{\text{FWM}})\) originating from the interference between three-adjacent signal frequencies \((i.e. \ f_i, f_j \text{ and } f_k)\) can be expressed as

$$f_{\text{FWM}} = f_i + f_j - f_k, \ k \neq i, j$$

(1)

Given the equation, a total of 12 FWM frequencies are generated as follows:

- \(f_1 = f_i + f_j - f_k\)
- \(f_2 = f_i + f_j - f_k\)
- \(f_3 = f_i + f_j - f_k\)
- \(f_4 = f_i + f_j - f_k\)
- \(f_5 = f_i + f_j - f_k\)
- \(f_6 = f_i + f_j - f_k\)
- \(f_7 = f_i + f_j - f_k\)
- \(f_8 = f_i + f_j - f_k\)
- \(f_9 = f_i + f_j - f_k\)
- \(f_{10} = f_i + f_j - f_k\)
- \(f_{11} = f_i + f_j - f_k\)
- \(f_{12} = f_i + f_j - f_k\)

Notably, Equation (1) is applicable to the instances with three adjacent frequencies. Meanwhile, if more light signals of multiple frequencies are being simultaneously transmitted, a larger number of FWM frequencies would be generated.

The FWM frequencies are illustrated in Figure 2 as the high baseline noise. Specifically, this noise \((f_n)\) is the summation of \(n\) FWM frequencies \((f_{\text{FWM}})\), as expressed in Equation (2)

$$f_n = \sum_{i=1}^{n} f_{\text{FWM}(i)} \quad (i = 1, 2, \ldots, m)$$

(2)

where \(m\) is a positive integer.

In this current research, the severity of the FWM effect is quantified in terms of total FWM power and total FWM efficiency. Both metrics are subsequently deployed to evaluate the performance of the proposed APRUS channel allocation scheme against other allocation schemes.

Total FWM power (TP) is the total power of all FWM frequencies generated from the interference of all adjacent signal frequencies. Typically, the lower the total FWM power is, the less severe the FWM effect and thus the higher the transmission quality. Essentially, TP can be calculated by the following equation [14,15]

$$P_{\text{FWM}}(f_m) = \sum_{f_k+f_j+f_m} \sum_{f_k} \sum_{f_j} P_{\text{FWM}}(f_{ijk})$$

(3)

where \(P_{\text{FWM}}(f_m)\) is the total power of FWM at frequency \(f_m\) and \(P_{\text{FWM}}(f_{ijk})\) is the power of FWM generated from the interference of a combination of adjacent frequencies.
\( f_{ijk} \). Specific to this current research, Equation (3) is rewritten as

\[
P_{\text{FWM}}(f_m) = \frac{1024\pi^6}{n^2\lambda^2c^2} \left( \frac{d_{ijk}\chi^{(3)}\Lambda_{\text{eff}}}{A_{\text{eff}}} \right)^2 \times P_i P_j P_k e^{-\alpha L} \eta_{ijk} \tag{4}
\]

where \( P_i, P_j, \) and \( P_k \) are the input power at \( f_i, f_j, \) and \( f_k \) respectively, \( n \) is the fiber refractive index, \( \lambda \) is the wavelength of FWM noise, \( c \) is velocity of light in vacuum, \( A_{\text{eff}} \) is the effective core area of fiber, \( \alpha \) is fiber coefficient, \( L \) is the fiber length, \( d_{ijk} \) is the degeneracy factor (\( d_{ijk} = 3 \) for \( i = j \) and \( d_{ijk} = 6 \) for \( i \neq j \)), and \( \chi^{(3)} \) is the third order nonlinear susceptibility.

Meanwhile, total FWM efficiency (TE) is the combined efficiency of all FWM sources. Similar to TP, the lower the TE, the less severe the FWM effect and thus the higher the transmission quality. In addition, TE can be calculated by the following equation [14,15]

\[
\eta_{\text{FWM}} = \sum_{i=1}^{m} \eta_{\text{FWM}(i)} \tag{5}
\]

where \( \eta_{\text{FWM}(i)} \) is TE and \( i = 1, 2, ..., m \) is the index of \( n \) sources of FWM. Specifically, the efficiency of an FWM source can be calculated by the following equation

\[
\eta_{ijk} = \frac{\alpha^2}{\alpha^2 + (\Delta \beta)^2} \left( 1 + \frac{4e^{-\alpha L} \cdot \sin^2(\Delta \beta l/2)}{(1 - e^{-\alpha L})^2} \right) \tag{6}
\]

and \( \Delta \beta \) is the sum of all different frequencies propagating in the optical fiber, i.e.

\[
\Delta \beta = \frac{2\pi\lambda^2}{c} \mid f_i - f_k \mid \mid f_j - f_k \mid \left[ D + \frac{\lambda^2}{2c} \cdot \left( \frac{dD}{d\lambda} \right) \right] \tag{7}
\]

where \( f_i, f_j, \) and \( f_k \) are any given frequencies in the transmission system, \( f_0 \) is the reference frequency, \( D \) is the chromatic dispersion, \( dD/d\lambda \) is the derivative of the dispersion coefficient of the fiber, \( \alpha \) is the fiber loss coefficient, \( \lambda \) is the wavelength of FWM noise, and \( c \) is the velocity of light in vacuum. Given the non-zero dispersion shift fiber, Equation (7) is rewritten as

\[
\Delta \beta = -\frac{\pi\lambda^4}{c^2} \cdot \frac{dD}{d\lambda} \left( \mid f_i - f_0 \mid + \mid f_j - f_0 \mid \right) \cdot \left( \mid f_i - f_k \mid \cdot \mid f_j - f_k \mid \right) \tag{8}
\]

To address the FWM noise in the DWDM system, under the conventional ES channel allocation scheme, the optical filters, one for each channel, are incorporated into the system at the input end of the N-channels De-MUX. By contrast, the proposed channel allocation scheme (APRUS) generates virtually no FWM and thereby no optical filters are required.

2.3 Bit error rate

The bit error rate (BER) is a measure of transmission quality at the receiving. Specifically, BER is the ratio of the number of erroneous bits to the total number of transmitted bits. The current standard for acceptable BER in optical fiber transmission is below \( 10^{-9} \). In a transmission simulation, BER is calculated by the Gaussian approximation (P\(_e\)) of the probability that the signal is affected by FWM in a transmission modulated by on-off keying (OOK). In other words, BER can be calculated by the following equation [14,15]

\[
P_e = \frac{1}{2\pi} \int_{-\infty}^{\infty} \exp \left( -\frac{t^2}{2} \right) dt \tag{9}
\]

where \( t \) is time, \( Q \) is the quality factor, and \( \alpha \) is the fiber coefficient. \( Q \), in turn, can be calculated by the equation below

\[
Q = \frac{bP_s}{\sqrt{N_{th} + N_{sh} + \sqrt{N_{th}\lambda}}} \tag{10}
\]

Since the thermal noise (\( N_{th} \)) and the shot noise (\( N_{sh} \)) are low relative to \( N_{\text{FWM}} \) in a DWDM setting, Equation (10) can be approximated as

\[
Q = \frac{bP_s}{\sqrt{N_{\text{FWM}}} \sqrt{b^2P_sP_{\text{FWM}}}} = \frac{2bP_s}{\sqrt{P_sP_{\text{FWM}}}} = \frac{2\sqrt{P_s}}{\sqrt{P_{\text{FWM}}}} \tag{11}
\]

where \( P_s \) is the received optical signal strength, \( N_{\text{FWM}} \) is the power of FWM noise, i.e.

\[
N_{\text{FWM}} = 2b^2P_s (\frac{P_{\text{FWM}}}{8}) \tag{12}
\]

and \( b \) is the responsivity that can be calculated by the following equation

\[
b = \frac{\eta e}{h\lambda} = \frac{\eta e\lambda}{hc} \tag{13}
\]

where \( \eta \) is the quantum efficiency of detector, \( e \) is the elementary electric charge, \( \lambda \) is the wavelength of the FWM noise, and \( h \) is Planck’s constant (6.626\times10^{-34} J.s). In the simulation, this current research assumes an avalanche photo diode detector, for which \( \eta = 80\% \) [16,17].

3. APRUS Channel Allocation Scheme

Channel allocation exerts a direct influence on the optical transmission of the DWDM system. Under the conventional ES allocation scheme, the FWM noise
Fig. 3 The optimal configuration given the APRUS channel allocation scheme

is inevitable, and numerous attempts have been made to mitigate or address the FWM issue. To this end, this current research has proposed the APRUS channel allocation scheme that is capable of virtually eliminating the FWM noise.

In fact, the proposed APRUS channel allocation scheme is an improved version of the paired URAUS and IRBUS channel allocation schemes [9,18]. Specifically, the APRUS scheme is expected to satisfy the following performance metrics [6-8]: the number of FWM less than 4,211, the total FWM power less than -28.6dBm, the total FWM efficiency less than 1.4dB and the bit error rate below -16.3dBm.

The working principle of the APRUS scheme is first to divide the bandwidth of ITU-T G.694.1 standard into two bands, each consisting of four base units of two types (RUS1 × 2 and RUS2 × 2), each base unit of which has five fixed unequal channel spaces (f1, f2, f3, f4, f5), acceptable in [8]; and then allocate two empirically determined unequal spaces (Δf1 and Δf2) between the four base units of each band. The two arrangements of all five-factorial arrangements of the five fixed unequal channel spaces (50, 75, 100, 125 and 150GHz) in a given base unit whose FWM noise is the lowest are subsequently determined [9,18], as tabulated in Table 1.

Table 1 All possible five-factorial arrangements associated with the five fixed unequal spaces in a given base unit

| No. | f1 | f2 | f3 | f4 | f5 | Number of FWM |
|-----|----|----|----|----|----|---------------|
| 1.  | 50 | 75 | 100| 125| 150| 4             |
| 2.  | 50 | 75 | 100| 125| 150| 4             |
| 3.  | 50 | 75 | 100| 125| 150| 10            |
| 24. | 50 | 150| 125| 100| 75 | 0             |
| 34. | 75 | 100| 125| 150| 50 | 0             |
| 120.| 150| 125| 100| 75 | 50 | 4             |

The values of Δf1 and Δf2 with the lowest FWM noise are then empirically determined under two constraints: first, Δf1 cannot be smaller than the smallest space of the five fixed unequal channel spaces in a base unit (RUS) due to the limitation of DWDM De-MUX, and, second, Δf2 cannot be larger than the next smallest space. The optimal arrangements of all possible arrangements associated with four base units and Δf1 and Δf2, given half the entire bandwidth, whose FWM noise is the lowest are determined.

Table 2 Possible arrangements of unequal spaces between base units

| No. | Arrangement | Number of FWM |
|-----|-------------|---------------|
| 1.  | RUS1 Δf1 RUS1 Δf2 RUS2 RUS2 | 345.9 |
| 2.  | RUS1 Δf2 RUS1 Δf1 RUS2 RUS2 | 248.5 |
| 3.  | RUS1 Δf1 RUS2 Δf2 RUS1 RUS2 | 402.5 |
| 4.  | RUS1 Δf2 RUS2 Δf1 RUS1 RUS2 | 316.5 |
| 5.  | RUS1 Δf1 RUS2 Δf2 RUS2 RUS1 | 461.5 |
| 6.  | RUS1 Δf2 RUS2 Δf1 RUS2 RUS1 | 370.5 |
| 7.  | RUS2 Δf1 RUS2 Δf2 RUS1 RUS1 | 369.5 |
| 8.  | RUS2 Δf2 RUS2 Δf1 RUS1 RUS1 | 242.5 |
| 23. | RUS2 RUS1 Δf1 Δf2 RUS1 RUS2 | 564.5 |
| 24. | RUS2 RUS1 Δf2 Δf1 RUS1 RUS2 | 564.5 |
| 35. | RUS2 RUS1 Δf1 RUS1 Δf2 RUS2 | 400.0 |
| 36. | RUS2 RUS1 Δf2 RUS1 Δf1 RUS2 | 418.0 |
| 47. | RUS2 Δf1 RUS1 RUS1 Δf2 RUS2 | 465.5 |
| 48. | RUS2 Δf2 RUS1 RUS1 Δf1 RUS2 | 676.0 |
| 95. | RUS2 Δf1 RUS1 RUS1 Δf2 RUS2 | 368.0 |
| 96. | RUS2 Δf2 RUS1 RUS1 Δf1 RUS2 | 338.0 |
| 155.| Δf1 Δf2 RUS2 RUS1 RUS1 RUS2 | 715.5 |
| 156.| Δf2 Δf1 RUS2 RUS1 RUS1 RUS2 | 715.5 |

Table 2 presents a total of 156 possible arrangements and the two arrangements with the least numbers of FWM, i.e. arrangements #2 (248.5) and #8 (242.5). Both arrangements are individually applied to the first and second halves of the bandwidth and then subsequently alternated to identify the configuration with the lower FWM noise.

Table 3 Two possible configurations associated with two optimal base unit arrangements

| Type | Configuration | Number of FWM |
|------|--------------|---------------|
| 1.   | No.2 No.8    | 594           |
| 2.   | No.8 No.2    | 569           |

In Table 3, the minimum FWM noise is achieved under the condition that arrangement #8 is applied to the first half of the bandwidth.
Table 4 Channel frequencies and space allocation under the APRUS channel allocation scheme

| Channels | 1   | 2   | 3   | 4   | 5   | 6   |
|----------|-----|-----|-----|-----|-----|-----|
| \(\Delta f_c\) (GHz) | 75  | 100 | 125 | 150 | 50  | 62.5|
| \(f_c\) (THz)  | 192.10 | 192.17 | 192.27 | 192.40 | 192.55 | 192.60 |

| Channels | 7   | 8   | 9   | 10  | 11  | 12  |
|----------|-----|-----|-----|-----|-----|-----|
| \(\Delta f_c\) (GHz) | 75  | 100 | 125 | 150 | 50  | 58.3|
| \(f_c\) (THz)  | 192.66 | 192.73 | 192.83 | 192.96 | 193.11 | 193.16 |

| Channels | 13  | 14  | 15  | 16  | 17  | 18  |
|----------|-----|-----|-----|-----|-----|-----|
| \(\Delta f_c\) (GHz) | 50  | 150 | 125 | 100 | 75  | 50  |
| \(f_c\) (THz)  | 193.22 | 193.27 | 193.42 | 193.54 | 193.64 | 193.72 |

Table 5 The simulation parameters specific to this research

| Parameters | Specifics/Value |
|------------|----------------|
| Transmission | Dispersion shift fiber (DSF) |
| Wavelength range (\(\lambda\)) / frequency range | 1.526 - 1.560.6 nm / 192.1 - 196.0 THz |
| Input Power \(P_{in}\) | 10 dBm |
| Chromatic dispersion \(D\) | 0 ps/km/nm |
| Derivative dispersion coefficient of fiber | 0.06 ps/km/nm² |
| Fiber refractive index \((n)\) | 1.45 |
| Velocity of light in vacuum \((c)\) | 3 x 10⁸ m/s |
| Third-order nonlinearity \((\chi_3)\) | 6 x 10⁻¹⁵ |
| Degeneracy factor \((d_{ijk})\) | 3 for \(i = j\) and 6 for \(i \neq j\) |
| Fiber length \((L)\) | 80 km |
| Fiber effective length \((L_{eff})\) | 20 km |
| Fiber coefficient \(\alpha\) | 0.2 dB/km |
| Effective core area of fiber \((A_{eff})\) | 50 \(\mu m^2\) |
| Avalanche photo diode \((\eta)\) | Quantum efficiency of 80% |

Table 4 tabulates the target signal channel frequencies and the allocated spaces between the frequencies, according to the proposed APRUS channel allocation scheme. Specifically, the target frequency range of 192.1 - 196.0 THz contains 41 frequency channels. Interestingly, an additional channel is made available with the implementation of the APRUS allocation scheme, compared with the number of channels (40) allocated by the conventional ES allocation scheme. The extra channel under the APRUS scheme translates into the enhanced data transfer rate by another 10 Gbit/s, which could be regarded as a windfall in addition to the FWM noise elimination.

The following paragraphs encapsulate the steps algorithmically undertaken under the APRUS channel allocation scheme to determine the optimal allocation and arrangement of signal frequencies and interval spaces.

The first step involves identifying the two arrangements, whose FWM noises are the smallest, of all possible arrangements of the five fixed unequal channel spaces within a base unit. In this research, the results are arrangement #24 (i.e. RUS1 = 50, 150, 125, 100, 75) whose FWM is equal to 0 and arrangement #34 (i.e. RUS2 = 75, 100, 125, 150, 50) whose FWM noise is also 0 (Table 1).

The next step is to determine the arrangements of the two base units identified in the previous step and two unequal spaces \((\Delta f_1\) and \(\Delta f_2)\) between these base units, which collectively result in the least FWM numbers. The findings point to arrangement #2 (RUS1 = \(\Delta f_2\) + RUS1 + \(\Delta f_1\) + RUS2 + RUS2) whose FWM is 248.5; and arrangement #8 (RUS2 + \(\Delta f_2\) + RUS2 + \(\Delta f_1\) + RUS1 + RUS1) with the FWM number of 242.5 (Table 2).

The final step is to identify the optimal configuration of the two arrangements determined in the second step (i.e. arrangements #2 and #8) by alternating between both arrangements. The optimal result with regard to the lowest number of FWM (i.e. 569) is achieved with the application of arrangement #8 to the first half of the bandwidth and arrangement #2 to the second half (Table 3).

Figure 3 illustrates the optimal configuration subsequent to the above-stated steps, and Table 4 tabulates the channel frequencies and space allocation under such an optimal configuration.

4. Simulation Results and Discussion

The simulations were carried out on four performance metrics, i.e. the FWM number, total FWM power, total FWM efficiency and BER, under three channel allocation schemes using MATLAB. The three channel allocation schemes under investigation include the ES, IRBUS and APRUS schemes. The allocated signal channel frequencies and the spaces between channels associated with the allocation schemes were simulation inputs. The simulation results were graphically compared in Figures 4, 5, 6 and 7, corresponding to the performance metrics.

Table 5 lists the simulation parameters specific to this research.

Figure 4 compares the simulated numbers of FWM frequencies under the three channel allocation schemes (ES, IRBUS and APRUS) in relation to the number of channels (40 channels). The simulated numbers of FWM frequencies under the ES, IRBUS and APRUS channel allocation schemes were respectively 33,820; 1,658; and 569. By comparison, the number of FWM under the
proposed APRUS scheme was 60 times as few as those under the ES regime.

Figure 5 compares the total FWM power under the three allocation schemes in relation to the number of channels. The total FWM powers under the ES, IRBUS and APRUS allocation schemes at the mean number of channels (i.e. 20) were respectively -12, -28.3, and -30.2 dBm. By comparison, the APRUS scheme generated over 300 times less total FWM power than did the conventional ES scheme.

Figure 6 depicts the total FWM efficiencies under the three allocation schemes relative to the difference between the FWM frequency and the reference zero-dispersion frequency. The total efficiencies of FWM under the ES, IRBUS and APRUS allocation schemes were respectively 16.20, -0.2 and -1.7dB. The proposed APRUS scheme exhibited over 4,600,000 times less total FWM efficiency vis-à-vis the conventional ES scheme.

Figure 7 compares the bit error rates (BER) under the three allocation schemes in relation to the transmitted power at the receiver. The acceptable bit error rate for optical transmission is below $10^{-9}$. The BERs under the ES, IRBUS and APRUS allocation schemes were respectively -5, -17.8 and -20.6dBm. By comparison, the proposed APRUS scheme exhibited a BER 30 times lower than did the conventional ES regime.

Interestingly, the FWM noise and the total FWM power and efficiency under the APRUS channel allocation scheme were negligible such that no optical filter is required at the input end of the N-Channels DWDM De-MUX. In addition, with the implementation of the APRUS channel allocation scheme, an additional signal channel could be accommodated while strictly adhering to the ITU-T G.694.1 optical transmission standard.

This phenomenon is attributable to the fact that under the proposed APRUS scheme the entire allocated space is smaller than that under the conventional ES scheme. Furthermore, given the same optical fiber, the extra channel enhances the DWDM transmission rate by another 10Gbit/s.

5. Conclusion

This research has proposed the asymmetrically paired repeated unequally spaced (APRUS) channel allocation scheme to minimize the four-wave mixing (FWM) phenomenon in the DWDM transmission system. In the simulation, the APRUS allocation scheme could reduce the number of FWM frequencies by more than 30 times and the total FWM power more than 300 times, vis-à-vis the conventional ES channel allocation scheme, thereby eliminating the need for optical fibers to filter out the FWM noise at the DWDM’s receiving end. In addition, an extra signal channel could be accommodated under the APRUS scheme, leading to a gain of another 10Gbit/s in the data transfer. In fact, the decrease in the FWM noise is in large measure attributable to the asymmetrical pairing of two base units, i.e. $\Delta f_1 \neq \Delta f_2$.

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(Received March 23, 2017; revised July 12, 2017)