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OBI Reduction in SCM/WDMA Networks Using Pseudorandom Optical Frequency Hopping

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Abstract:- Optical frequency hopping (OFH) is demonstrated to reduce optical beat interference (OBI) in subcarrier multiplexed wavelength division multiplexing (SCM/WDMA) networks. OFH is performed through the use of wide-range tunable lasers controlled by PN waveforms. Simulation results of signal and OBI spectra are presented.

Summary

Optical beat interference (OBI) is due to the square law characteristics of photodetection, It results from the detection of a sum of optical fields by a single photodetector. When a sum of fields is applied to a photodetector, the output consists of terms proportional to the intensities of the individual fields, as well as other cross terms. OBI is caused by spectral overlapping between cross terms and field intensities.

In this paper, we propose optical frequency hopping (OFH) as a solution to the OBI in subcarrier multiplexed wavelength division multiple access (SCM/WDMA) optical networks [1]. This is a very simple multiple access scheme that can offer high network throughputs. Figure 1 shows the hierarchy of multiplexing schemes used in such an SCM/WDMA network [1]. Figure 2 shows a block diagram of the network [2].

As a worst case assumption, laser fields in one optical channel are assumed to have identical polarizations. Each of these fields can be represented by:

$$e_i(t) = \left[S_i(t)\right]^{1/2} \cos\left[\varphi_i(t)\right] \quad (1)$$

where the intensity modulation by an RF subcarrier of center frequency f_i is represented by:

$$S_i(t) = S_0\left\{1 + m\cos(2\pi f_i t)\right\} \quad (2)$$

and the phase is represented by

$$\varphi_i(t) = 2\pi F_i t + \varphi_{in}(t) \quad (3)$$

The phase noise component $\varphi_{in}(t)$ was shown in [3] to be of small effect compared to OBI, hence, it will be neglected.

Analysis of Simulation Results

The system simulated to produce the results below has the following description: Two subrarriers centered at 4 and 5 GHz are PSK modulated by 200 Mb/s data signals. The modulated subcarriers then intensity modulate two lasers each using a modulation index of $\sqrt{2}$. Lasers are assumed to be tunable over a range of 1000 GHz. Detection is performed through the arrangement shown in Figure 3. The optical filter at the receiver front end passes only the fields in one optical channel. As a result, the photodetector has at its input a sum of two optical fields. After photodetection, an electric BPF passes only the signal intended for its corresponding subcarrier. Two signal terms and a cross terms are present at the input of the BPF.

Figures 4 and 5 show subcarrier and OBI spectra for laser tuning ranges of 100 and 1000 GHz, respectively. In the following, we estimate the best tuning range such that the maximum network throughput can be achieved.

The objective is a probability of error less than or equal to 10^{-9}. It was shown in [2] that this can be satisfied when the carrier-to-interference ratio is at least 18. The signal power at the BPF output is given by [2]

$$P_{sig} = \frac{S_0^2 m^2}{8} \tag{4}$$

Substituting the modulation index in eq. (4), the signal power at the electric BPF output is

$$P_{sig} = 0.0625 \text{ W}$$

Note that, S_0 is set to unity. From Figures 4 and 5, and noting that the OBI PSD is almost constant in the range of interest, the OBI power at the BPF output is:

$$P_{obi,100} = 0.00148 \text{ W}$$
$$P_{obi,1000} = 0.000148 \text{ W}$$

In case we have M subcarriers per optical channel, the total OBI power is $M(M-1)/2$ times the numbers above. Hence,

$$\frac{P_{sig}}{P_{obi,R} \cdot M(M-1)/2} \geq 18 \tag{5}$$

$P_{obi,R}$ denotes either $P_{obi,100}$ or $P_{obi,1000}$ above. Rearranging eq. (5), we get:

$$M_R(M_R-1)\leq\frac{P_{sig}}{9P_{obi,R}} \tag{6}$$

Adding the subscript R to M denotes a specific tuning range. Substituting the signal and interference power values in eq. (6), we get:

$$M_{100}\leq 2$$
$$M_{1000}\leq 7$$

Obviously, there is no point in using OFH to support just two users per optical channel. On the other hand, increasing the tuning range above 1 THz is practically difficult, besides, it results in a small number of allowable WDMA channels. Assuming a total optical bandwidth of about 30 THz, the total network throughput in the case of 1 THz tuning range is:

$$C_{tot}=30\cdot 7\cdot 0.2=42\ \mathrm{Gb/s}$$

Increasing the subcarrier data rate to 400 Mb/s allows 5 subcarriers per optical channel, which results in a total network throughput of:

$$C_{tot}=30\cdot 5\cdot 0.4=60\ \mathrm{Gb/s}$$

Concluding Remarks

A simple method has been proposed for effective reduction of OBI. Using optical frequency hopping, a total network throughput as high as 60 Gb/s was shown to be achievable. The proposed method makes use of tunable laser diodes, does not need high-rate PN signals, and does not need frequency dehopping at the receiver. Lasers are only required to provide randomly varying operating frequencies within the tuning range.

References

[1] N. K. Shankaranarayanan, S. D. Elby, and K. Y. Lau, "WDMA/subcarrier-FDMA lightwave networks: limitations due to optical beat interference,", *J. Lightwave Tech.*, Vol. 9, No. 7, pp. 931-943, Jul. 1991

[2] M. M. Banat and Mohsen Kavehrad, "Reduction of Optical Beat Interference in SCM/WDMA Networks using Pseudorandom Phase Modulation,", Submitted for publication.

[3] M. M. Banat and Mohsen Kavehrad, "Effects of laser direct intensity modulation index on optical interference in subcarrier multiplexed wavelength division multiple access networks,", Submitted for publication.

Figure Captions

Figure 1: A Hierarchy of the Multiplexing Schemes in an SCM/WDMA network

Figure 2: An SCM/WDMA network block diagram

Figure 3: Reference user receiver

Figure 4: Subcarrier and OBI spectra under 100 GHz frequency tuning range

Figure 5: Subcarrier and OBI spectra under 1000 GHz frequency tuning range

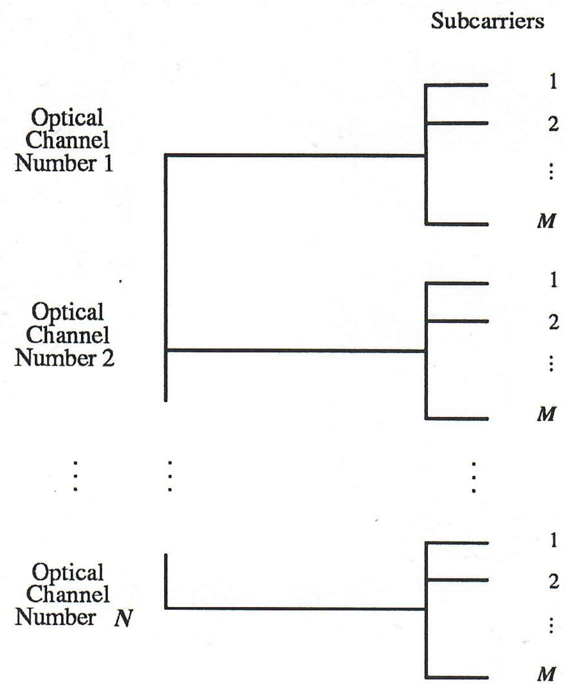

Figure 1

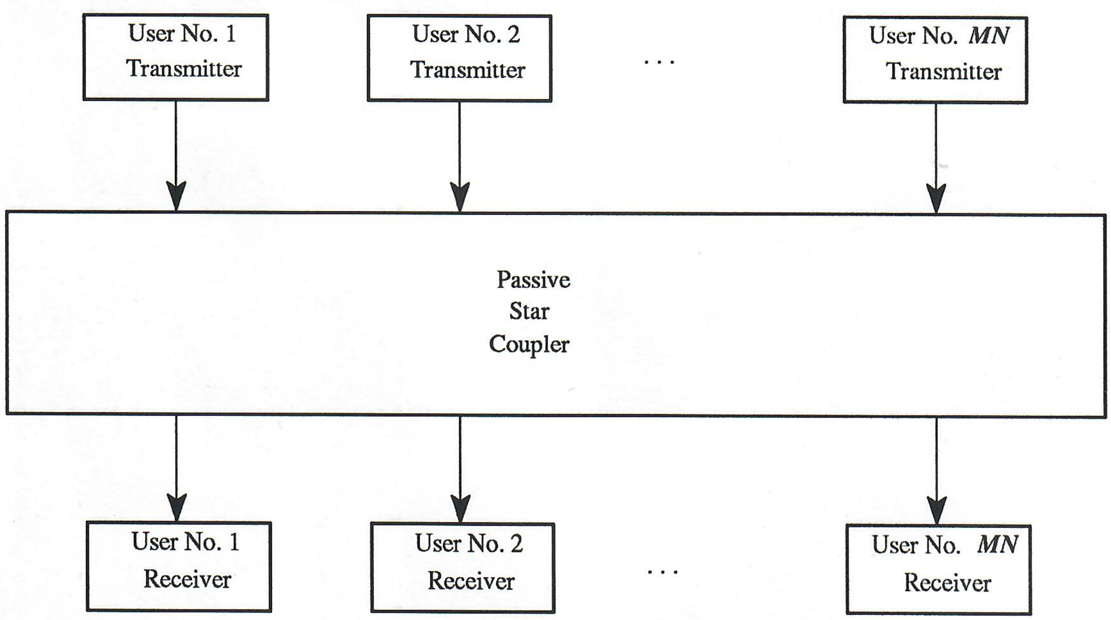

Figure 2

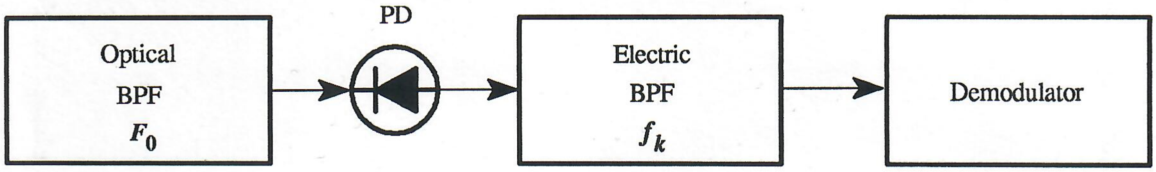

Figure 3

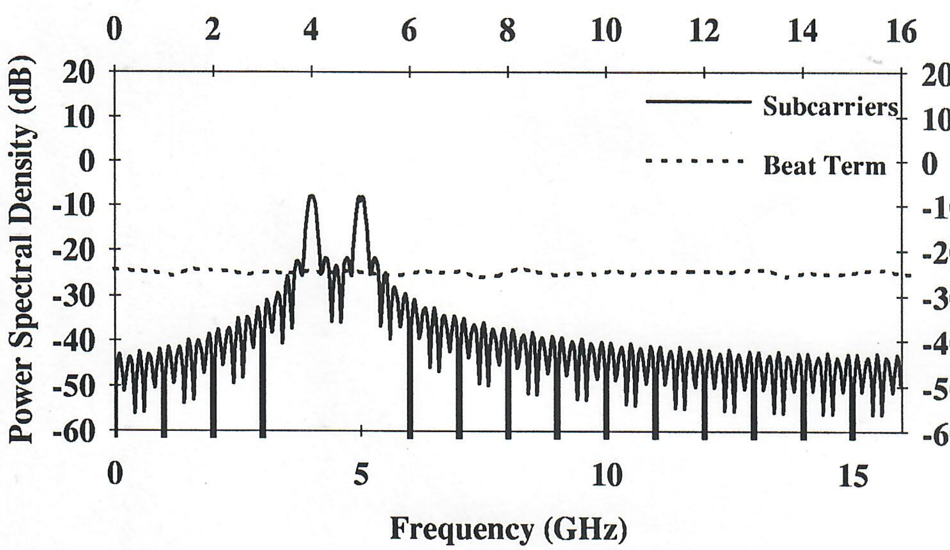

Figure 4

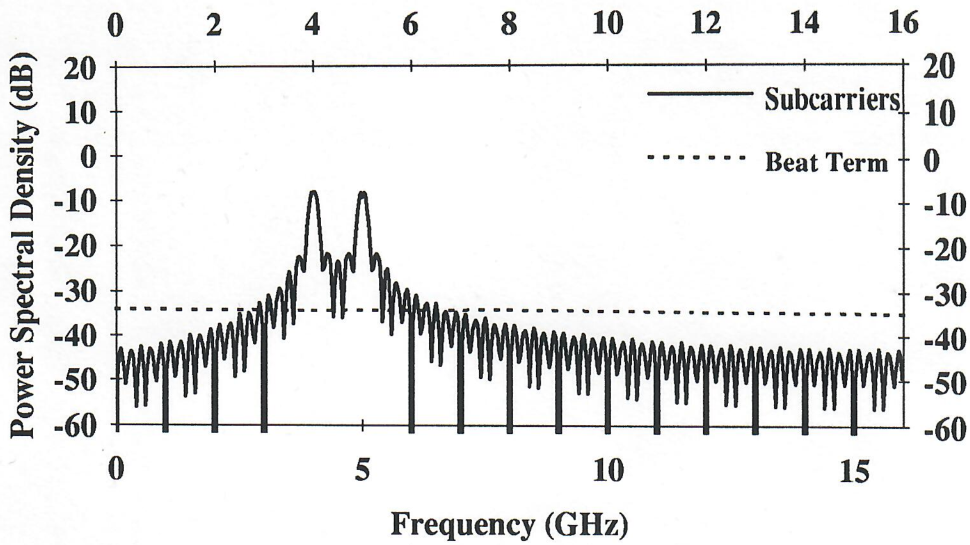
0
2
4
6
8
10
12
14
16
20
10
0
-10
-20
-30
-40
-50
-60
Subcarriers
Beat Term
Power Spectral Density (dB)
0
5
10
15
Frequency (GHz)

Figure 5