Journal of King Saud University – Computer and Information Sciences (2015) 27, 430–436

King Saud University

Journal of King Saud University – Computer and Information Sciences

www.ksu.edu.sa
www.sciencedirect.com

A low complexity based spectrum management algorithm for 'Near–Far' problem in VDSL environment

Sunil Sharma *, **O.P. Sahu**

ECE Department, NIT, Kurukshetra, Haryana, India

Received 18 April 2014; revised 1 October 2014; accepted 9 December 2014
Available online 26 September 2015

KEYWORDS

Digital subscriber line;
Discrete multi-tone;
Iterative water-filling;
Optimal spectrum balancing;
Dynamic spectrum management

Abstract In digital subscriber line (DSL) system, crosstalk created by electromagnetic interference among twisted pairs degrades the system performance. Very high bit rate DSL (VDSL), utilizes higher bandwidth of copper cable for data transmission. During upstream transmission, a 'Near–Far' problem occurs in VDSL system. In this problem the far end crosstalk (FEXT) is produced from near end user degrades the data rate achieved at the far end user. The effect of FEXT can be reduced by properly managing power spectral densities (PSD) of transmitters of near and far users. This kind of power allocation is called dynamic spectrum management (DSM). In this paper, a new distributed DSM algorithm is proposed in which power from only those sub channels of near end user are reduced which create interference to far end user. This power back off strategy takes place with the help of power spectral density (PSD) masks at interference creating sub channels of near end user. The simulation results of the proposed algorithm show an improvement in terms of data rate and approaches near to that of optimal spectrum balancing (OSB) algorithm.

1. Introduction

The 3 kHz bandwidth of copper wire was earlier utilized in plain old telephone service. During 1980's the efforts of researchers made it possible to utilize higher bandwidth of copper wire with DSL technology. The VDSL technology for broadband access utilized bandwidth of copper wire up to 12 MHz with the help of advancement in signal processing techniques (Starr et al., 2003; ETSI, 2003). In DSL loop layout as shown in Fig. 1, modems are installed at customer premises (CP) as well as at central office (CO) sides. In DSL technology, investment is only on modems by utilizing already existing infrastructure of Plain old telephone service. The data transmission up to maximum channel capacity of copper cable is the main goal for DSL technology. When a large number of users share the same bundle for data transmission up to a certain distance then an interference is created among the users. The interference is commonly referred as crosstalk

* Corresponding author.
E-mail addresses: ersunil0@gmail.com (S. Sharma), OPS_nitk@yahoo.co.in (O.P. Sahu).

Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jksuci.2014.12.005
1319-1578

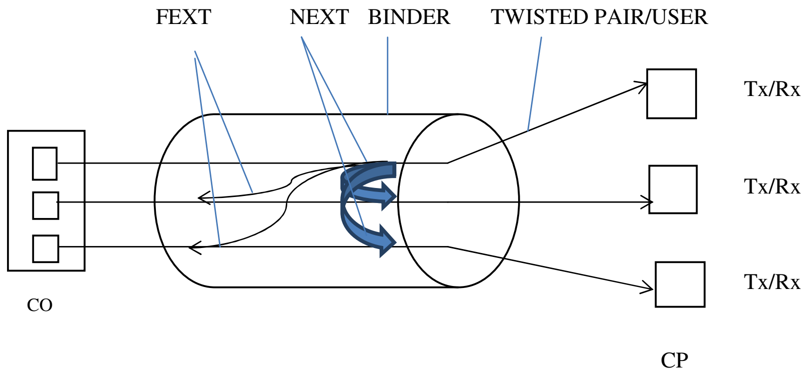

Figure 1 Loop plant environment.

(Zeng et al., 2001). The crosstalk is of two types- Near End Crosstalk (NEXT) and Far End Crosstalk (FEXT).

NEXT is an electromagnetic interference that exists when the transmitter and the disturbed receiver are present on the same end of communication network. In contradiction to NEXT, FEXT is an electromagnetic interference that exists when the transmitter and the disturbed receiver are present on opposite ends of communication network as shown in Fig. 1.

One of the techniques to control crosstalk among the users is to manage their power spectral densities (PSD) at their respective transmitters. When modems are operated in this mode called power adaptive mode. In this mode the power to maintain a predefined bit rate is transmitted. Power back off (PBO) techniques are used to implement this kind of adaptive mode. In PBO the minimization of power transmission is done on near end user where contributing excessive power creates strong crosstalk and reduces capacity of the nearby user (Jacobsen, 2001; Schelstraete, 2002). The adaptive power allocation at each modem depending on channel characteristics improves the capacities of near and far end users. This kind of adaptive power allocation is known as dynamic spectrum management (DSM) (Huberman et al., 2012; Chen et al., 2012; Biyani et al., 2013). The categorization of DSM with increasing complexity is done at different levels. At Level 1, all management of power is done in a distributive manner. At this level the power management algorithm gives near optimal result. One of the first DSM Level 1 algorithms is iterative water-filling (IWF) (Yu et al., 2002). The complexity of IWF algorithm scales linearly with the number of users in the binder. This algorithm is a greedy algorithm which converges to the selfish optimum. At level 2, all management of power between different users is done with the help of centralized spectrum management center (SMC). In this, the information regarding crosstalk among different users is collected by SMC and then all users transmit PSD with a power allocation coordination scheme for joint optimization of transmitted spectrum. In this way the management of power distribution is in a centralized manner. The centralized DSM level 2 algorithm named optimal spectrum balancing (OSB) uses a weighted rate sum method to find the theoretical optimal transmit spectra (Cendrillon et al., 2006). The complexity of OSB scales exponentially with the number of users. Due to the hardware implementation problem of centralized systems, distributed algorithms are gaining popularity. In this paper a new algorithm is proposed whose performance approaches the optimal performance of OSB algorithm in terms of data rate while maintaining low complexity and distributed implementation. In the proposed algorithm the data rate of each user in the binder increases by applying a new PBO technique at crosstalk creating sub channels using spectral masks (UK NICC ND 1602, 2011).

2. Channel capacity

In information theory, Claude Shannon's formula represented by Eq. (1) shows the channel capacity in terms of bits per second (Cover and Thomas, 1991; Shannon, 1948):

$$\mathrm{C} = \mathrm{W}\log_2\left(1+\frac{\mathrm{P}}{\mathrm{N_0 W}}\right) \quad \text{bits per second} \tag{1}$$

where P and $\mathrm{N_0}/2$ represent transmitted signal power in watts and white noise power spectral density in watts/Hz, respectively. W denotes the channel bandwidth. Quadrature amplitude modulation (QAM) is used in discrete multi-tone (DMT) systems as modulation method for mapping information in digital form to complex numbers (Chow et al., 1995). So, the channel capacity in a QAM–DMT system is given by Eq. (2):

$$\mathrm{C}_k = \log_2(1+\mathrm{SNR}_k) \tag{2}$$

where SNR_k and C_k represent signal to noise ratio and capacity of sub channel k, respectively. Theoretically channel capacity gives the upper limit of data rate that can be achieved but practically there is some probability of error always present. The reduced channel capacity is due to the introduction of SNR gap Γ:

$$\mathrm{b}_k = \log_2\left(1+\frac{\mathrm{SNR}_k}{\Gamma}\right) \tag{3}$$

At $\Gamma = 1$, b_k is the same as the channel capacity. SNR gap Γ selection depends on coding scheme and the error probability. The SNR gap is calculated for a two dimensional QAM system having bit error rate (BER) at 10^{-7} Chow et al., 1995:

$$\Gamma = 9.8 + \gamma_m - \gamma_c(\mathrm{dB}) \tag{4}$$

where γ_m and γ_c represent performance margin and coding gain, respectively. The total bit rate for user n can be calculated by summing the bit rate of each sub channel:

$$\mathrm{R}^n = \frac{1}{\mathrm{T_{symbol}}}\sum_{k=1}^{\mathrm{K}} \mathrm{b}_k^n \tag{5}$$

where T_{symbol} represents period of sub channel bandwidth. In two user environments the bit rates of user 1 and user 2 depend on channel transfer functions. P_k^1 and N_k^1 denote signal power allocation and background noise power for user 1 at sub channel k. P_k^2 and N_k^2 denote signal power allocation and background noise power for user 2 at sub channel k. The user 1 and user 2 data rates are given by Eqs. (6) and (7):

$$R^1 = \frac{1}{T_{symbol}} \sum_{k=1}^{K} \log_2\left(1 + \frac{|h_k^{11}|^2 P_k^1}{\Gamma_1(|h_k^{12}|^2 P_k^2 + N_k^1)}\right) \tag{6}$$

$$R^2 = \frac{1}{T_{symbol}} \sum_{k=1}^{K} \log_2\left(1 + \frac{|h_k^{22}|^2 P_k^2}{\Gamma_2(|h_k^{21}|^2 P_k^1 + N_k^2)}\right) \tag{7}$$

The direct channel transfer functions of user 1 and user 2 are calculated by:

$$|h_k^{11}|^2 = L_1.\alpha.\sqrt{f_k} \tag{8}$$

$$|h_k^{22}|^2 = L_2.\alpha.\sqrt{f_k} \tag{9}$$

The crosstalk channel transfer functions of user 1 and user 2 are calculated by:

$$|h_k^{21}|^2 = K_{FEXT} \cdot f_k^2.L_{2,1}.|h_k^{11}|^2 \tag{10}$$

$$|h_k^{12}|^2 = K_{FEXT}.f_k^2.L_{1,2}.|h_k^{22}|^2 \tag{11}$$

where K_{FEXT} represents crosstalk coupling coefficient and the value is taken as $10^{-4.5}/\text{MHz}^2$ Km. f_k denotes the central frequency at subcarrier k in MHz. L_1 and L_2 are twisted pairs lengths of user 1 and user 2 while α represents attenuation at 1 MHz which is taken as 22.5 dB/km/MHz. $|h_k^{11}|^2$ and $|h_k^{22}|^2$ represent direct channel transfer functions of user 1 and user 2 while $|h_k^{21}|^2$ and $|h_k^{12}|^2$ represent crosstalk channel transfer function from user 1 to user 2 and from user 2 to user 1, respectively, as shown in Fig 2.

$L_{2,1}$ and $L_{1,2}$ represent binder length which is common for both users. In two user test case, the SNR of a user not only depends on user's own PSD but also on the PSD of the adjacent user in the same binder. Eqs. (12) and (13) represent crosstalk PSD for user 1 and user 2:

$$FE_1 = |h_k^{12}|^2 P_k^2 \tag{12}$$

$$FE_2 = |h_k^{21}|^2 P_k^1 \tag{13}$$

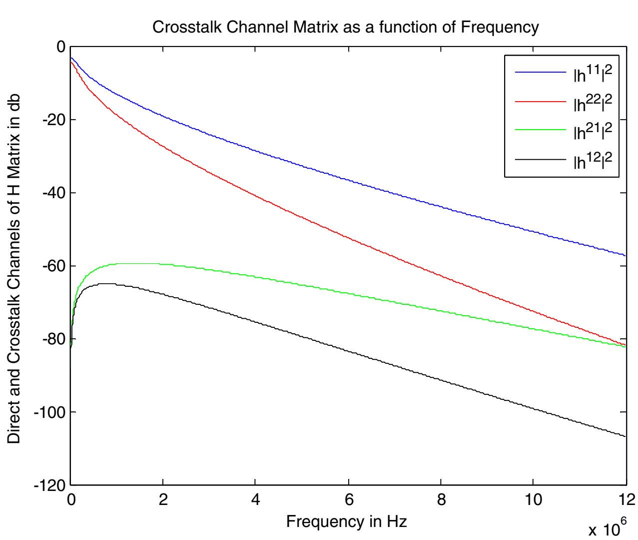

Figure 2 Direct and crosstalk channel transfer functions of two user case.

3. Water-filling method

In water filling method, DMT modems adaptively distribute power and information according to the channel conditions. In this method, the curve of inverse of channel's SNR is obtained and fills that like a bowl with power until the whole available power is consumed. In a two user case, the optimal power allocation is obtained by using the cost function (Bogaert et al., 2004) and represented by the following formula:

$$\begin{aligned} J(P_k^1 P_k^2) = &\sum_k \log_2\left(1 + \frac{|h_k^{11}|^2 P_k^1}{\Gamma_1(|h_k^{12}|^2 P_k^2 + N_k^1)}\right) \\ &+ \sum_k \log_2\left(1 + \frac{|h_k^{22}|^2 P_k^2}{\Gamma_2(|h_k^{21}|^2 P_k^1 + N_k^2)}\right) \\ &+ \lambda_1\left(P_{budget}^1 - \sum_k P_k^1\right) + \lambda_2\left(P_{budget}^2 - \sum_k P_k^2\right) \end{aligned} \tag{14}$$

P_K^n and N_k^n denote signal power allocation and background noise power for user n at sub channel k. λ_1 and λ_2 are the constants known as Lagrange multipliers which are used for solving the equation by taking power constraints P_{budget}^1 and P_{budget}^2 for user 1 and user 2. By dual decomposition the largest performance gain is achieved (Bogaert et al., 2004). As compared to background noise power, if the crosstalk power is very small i.e., $\check{N}_k^n = N_k^n$, then Eq. (15) simplifies the cost function:

$$\begin{aligned} J(P_k^1 P_k^2) = &\sum_k \log_2\left(1 + \frac{|h_k^{11}|^2 P_k^1}{\Gamma_1 + \check{N}_k^1}\right) + \sum_k \log_2\left(1 + \frac{|h_k^{22}|^2 P_k^2}{\Gamma_2 + \check{N}_k^2}\right) \\ &+ \lambda_1\left(P_{budget}^1 - \sum_k P_k^1\right) + \lambda_2\left(P_{budget}^2 - \sum_k P_k^2\right) \end{aligned} \tag{15}$$

The derivative of cost function with respect to P_k^n and by setting this equal to zero gives optimal solution for user n:

$$\frac{\partial J}{\partial (P_k^n)} = \frac{1}{P_k^n + \frac{\Gamma_n \check{N}_k^n}{|h_k^{nn}|^2}} - \lambda_n = 0 \tag{16}$$

Eq. (17) gives the water filling solution by rewriting the above equation:

$$P_k^n = \frac{1}{\lambda_n} - \frac{\Gamma_n \check{N}_k^n}{|h_k^{nn}|^2} \tag{17}$$

Now by including interfering crosstalk, the power allocation for user 1 in case of two user environments is given by Eq. (18):

$$P_k^1 = K_1 - \frac{\Gamma_1(|h_k^{12}|^2 P_k^2 + N_k^1)}{|h_k^{11}|^2 P_k^1} \tag{18}$$

where K_1 represents highest limit of transmit power in each sub channel k and can be called the water level.

4. Multi-user bit loading problem

In DSL multiuser environment, N users transmit data over K parallel sub channels, where $(1 \leqslant n \leqslant N)$ and $(1 \leqslant k \leqslant K)$. Discrete multi-tone (DMT) is used to divide selective channel into sub channels. In DMT the optimal performance is obtained by choosing PSDs of transmitted signal according to SNR of sub channel. The optimal power allocation problem is same as that of optimal bit allocation on sub channels. In multi-user environment the problem is of optimization of bit allocation. The maximization of data rate of all users in a binder is the main objective which is given in Eq. (19):

$$\text{Maximize } R_{total} = \sum_{n=1}^{N} R^n = \frac{1}{T_{symbol}} \sum_{n=1}^{N} \sum_{k=1}^{K} b_k^n \tag{19}$$

The PSD mask constraint on sub channel k of user n and PSD constraint of user n are given in Eqs. (20) and (21):

$$0 \leqslant P_k^n \leqslant P_{mask}^n \tag{20}$$

$$\sum_{k=1}^{K} P_k^n \leqslant P^{n,total} \tag{21}$$

The bit constraint on sub channel k of user n is given in Eq. (22):

$$b_{min} \leqslant b_k^n \leqslant b_{max}, \text{ and } b_k^n \text{ is integer} \tag{22}$$

In real networks, users in the binder are having equal priority as each one pays the same fee for getting broadband services. The bit loading should be done in such a way on each sub channel so that the service quality should be same for equal length users. The bit loading becomes the major concern in multi user environment.

5. Rate region

Rate Region is the combinations of data rates of all users in the bundle and shown in the form of a picture. When any user gets its own data rate high by increasing the PSD on its sub channels then it affects other users by creating crosstalk. This crosstalk can be reduced by successively reducing power from crosstalk creating user. In the next step the water filling is done on each user with the remaining power. The power reduction continues until data rate on the crosstalk creating user becomes zero. Rate Region shows the picture of data rate combinations that can be achieved on each pair of users in the binder.

6. Iterative water-filling (IWF) algorithm

In IWF, power allocation is done by each user one by one with water filling process. The power allocation through water filling continues until each user achieves the desired target rate. The desired target rate for each user is set by choosing one of the optimal points inside the Rate Region. If the target rate of any user is below that of achieved rate then the power of that user is decreased by a constant δ. On the other hand power is increased by the same constant δ in that user which does not achieve the target data rate (Yu et al., 2002). In Fig. 3, two user's test case is taken and IWF algorithm converges until the target rates of both the users are not achieved.

Algorithm 1: IWF
procedure $(R^n, P_{e,k}^n) = IWF(P_{in,k}^n, T^n, P^{n,total})$
Initialize $P^{n,max} > 0, \delta > 0, \varepsilon > 0, p_k^n = 0, \forall k, \forall n$
For each *n* do
Do water-filling by taking noise $\Gamma(\sum_{m \neq n}^{N} |h_k^{n,m}|^2 p_k^m + \sigma_k^n)$, maximum power $P^{n,total}$ and initial PSD mask $P_{in,k}^n$ and then get value of R^n and resultant PSD mask $P_{e,k}^n$
  While $R^n > T^n \; \forall n$ **do**
    for $n = 1, \ldots, N$ **do**
      If $R^n > T^n + \varepsilon$ **set** $P^{n,total} = P^{n,total} - \delta$
      If $R^n < T^n$ **set** $P^{n,total} = P^{n,total} + \delta$
      If $P^{n,total} > P^{n,max}$ **set** $P^{n,total} = P^{n,max}$
    end for
  end while
end for
end procedure

Fig. 4 shows the PSDs of near and far end users of two users having length 1500 feet and 3000 feet, respectively. It is clear from above Fig. 4 that the most of the power is consumed at low frequency sub channels because the channel gain is high at lower frequencies as shown in Fig. 2.

7. OSB algorithm

OSB algorithm finds the theoretical values of optimal power allocation of a communication system. The technique named dual decomposition technique (Cendrillon et al., 2006) and optimization theory help in getting an optimal point (Cendrillon et al., 2006). In a two user case, the maximization of Lagrangian on sub channel k is defined as:

$$L_k = w b_k^1(P_k^1, P_k^2) + (1 - w) b_k^2(P_k^1, P_k^2) - \lambda_1 P_k^1 - \lambda_2 P_k^2 \tag{23}$$

where $b_k^n(P_k^1, P_k^2)$ represents achieved bit loading on sub channel k of user n when transmitted PSDs are P_k^1 and P_k^2, respectively. The optimal power allocation on sub channel k is found out by maximization of L_k:

$$P_k^{1,opt}, P_k^{2,opt} = \arg\max_{P_k^1, P_k^2} L_k \tag{24}$$

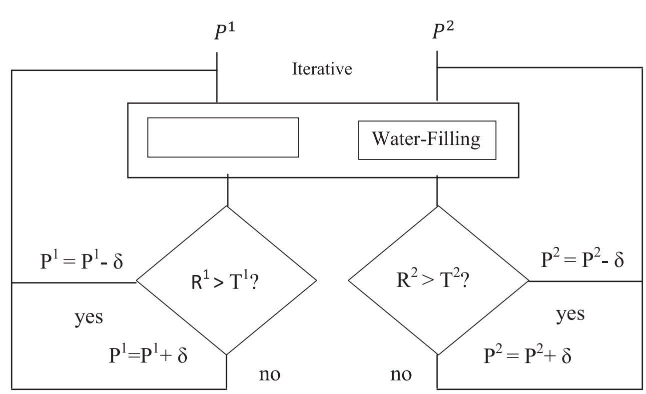

Figure 3 Flow chart of IWF algorithm for two user case.

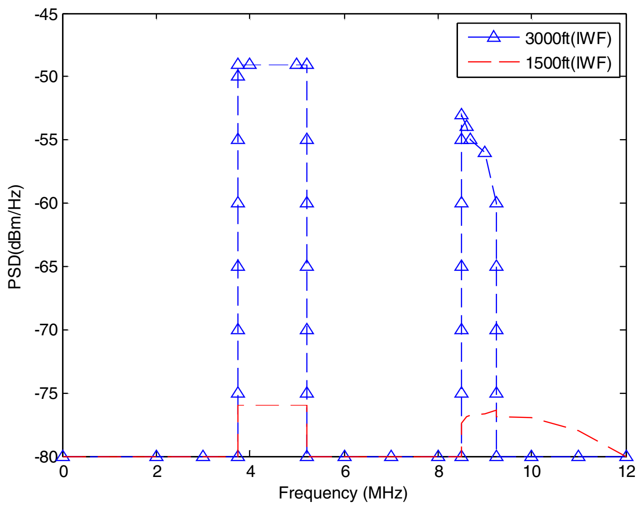

Figure 4 PSDs for near end user (1500 feet) and far end user (3000 feet).

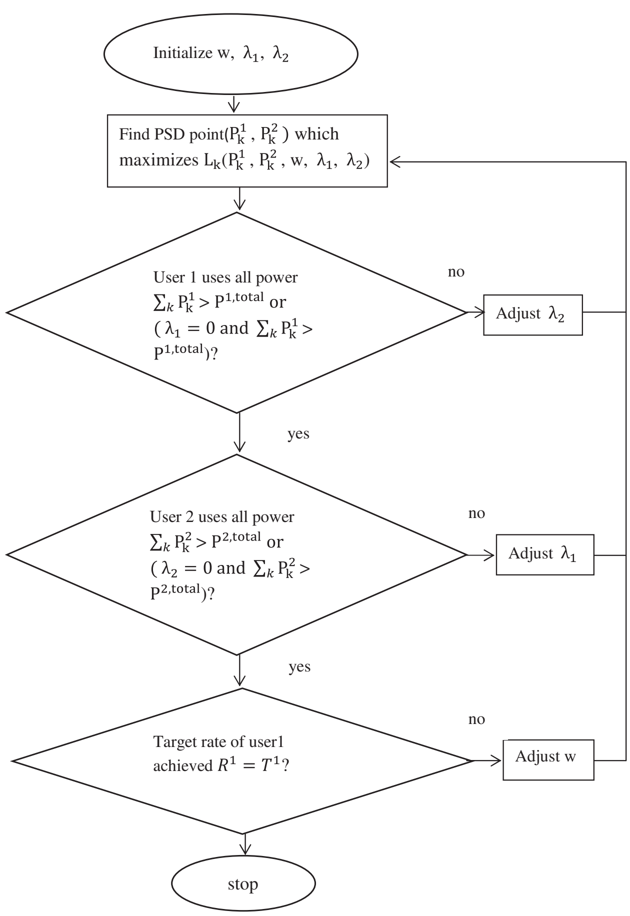

Figure 5 Flow chart of OSB algorithm.

w represents weight which decides the data rate trade off among user 1 and 2. When $w = 0$, then the full priority is for user 2 and the user 1 is in switch off mode. Lagrangian multipliers λ_1 and λ_2 are the power constraints for user 1 and 2, respectively. In OSB algorithm the value of w is adjusted in such a way that user 1 is able to achieve its target rate. The priority is given to user 2's data rate maximization while user 1 should necessarily achieve the target data rate. In OSB algorithm as shown in Fig. 5, three loops exist. The outer loop varies w, whereas other two loops search for λ_1 and λ_2. In every search bisection method (Cendrillon et al.. 2006) is used.

Algorithm 2: OSB
Main Function
For $w = 0,\ldots 1$
P^1, P^2 = optimize_λ_1 (w)
End
Function P^1, P^2 = optimize_λ_1(w)
$\lambda_1^{max} = 1, \lambda_1^{min} = 0$
While $\sum_k P_k^1 > P^{1,total}$
$\lambda_1^{max} = 2\lambda_1^{max}$
P^1, P^2 = optimize_λ_2(w, λ_1^{max})
End
Repeat
$\lambda_1 = (\lambda_1^{max} + \lambda_1^{min})/2$
P^1, P^2 = optimize_λ_2(w, λ_1)
If $\sum_k P_k^1 > P^{1,total}$ then $\lambda_1^{min} = \lambda_1$, else $\lambda_1^{max} = \lambda_1$
Until convergence
Function P^1, P^2 = optimize_λ_2(w, λ_1)
$\lambda_2^{max} = 1, \lambda_2^{min} = 0$
While $\sum_k P_k^2 > P^{2,total}$
$\lambda_2^{max} = 2\lambda_2^{max}$
P^1, P^2 = optimize_s (w, λ_1, λ_2^{max})
End
Repeat
$\lambda_2 = (\lambda_2^{max} + \lambda_2^{min})/2$
P^1, P^2 = optimize_s (w, λ_1, λ_2)
If $\sum_k P_k^2 > P^{2,total}$ then $\lambda_2^{min} = \lambda_2$, else $\lambda_2^{max} = \lambda_2$
Until convergence
Function P^1, P^2 = optimize_λ_2(w, λ_1, λ_2)
For $k = 1,\ldots K$
$P_k^1, P_k^2 = \arg\max_{P_k^1, P_k^2} L_k(P_k^1, P_k^2, w, \lambda_1, \lambda_2)$
(Solved by exhaustive 2-D search)
End

8. The proposed algorithm

It is clear from Fig. 4 that most of the power of far end user is consumed in lower frequencies due to high channel gain at these frequencies. There is no power consumption beyond 9.25 MHz in far end user. If the PSD of near end user is decreased by using PSD masks then the effect of crosstalk can be reduced and more number of bits can be loaded on lower sub channels. In proposed algorithm, PSD masks are controlled by two parameters 'α' and 'β' for upstream frequency bands i.e., 3.75–5.2 MHz and 8.5–12 MHz (UK NICC ND 1602, 2011). PSD mask that is allocated at sub channel k of user n can be calculated from Eq. (25):

$$p^n_{U,k} = -\alpha_n - \beta_n\sqrt{f_k} + l_n\sqrt{f_k} \quad (\text{dBm/Hz}), \tag{25}$$

where $l_n\sqrt{f_k}$ is the transmission loss compensation in which l_n represents the electrical length estimated at user n (Shannon, 1948). The parameters 'α_n' and 'β_n' are region specific parameters of user n where $40 \leqslant \alpha_n \leqslant 80.95$ and $0 \leqslant \beta_n \leqslant 40$. First of all, the PSD masks at different sub channels for each user are set. Then all users simultaneously do water filling with maximum allowable power to them. The interference is then measured at each sub channel of all users. If the interference at certain sub channel is high then it is predicted that other users allocate a large amount of power to that sub channel to enhance their data rates. The interference creating sub channels can be classified as high interference creating region denoted as F^A and non-interference creating region denoted as F^B. In the proposed algorithm, crosstalk creating users back off their power only from high interference creating region only. The back off can be done with the help of earlier calculated PSD masks at each sub channel. In test case, two users allocate their maximum power in lower frequency bands due to high channel gain at these frequencies as shown in Fig. 4. The power is back off only in high interference creating region i.e., F^A (3.75–5.2 MHz, 8.5–9.25 MHz). The PSD masks limit the transmit PSD at interference creating sub channels by the controlling parameters 'α' and 'β'. In the proposed algorithm if target data rate is lower than that of obtained data rate, the back off at only high interference creating sub channels is done for user n by factor δ, with $P^n_{U,k}$ as PSD mask till the predefined threshold τ is exceeded. The IWF algorithm does not converge until the target data rate is not achieved. The proposed algorithm works well with $\delta = 3$ dB and $\tau = -2$ dB. The obtained Nash Equilibrium (NE) point (Yu et al., 2002) is now different from that obtained from traditional IWF algorithm. The new NE point which is obtained by converging the proposed algorithm forms a better Rate Region and approaches near to that of OSB algorithm.

Algorithm 3: The Proposed Algorithm
Initialize $\tau > 0$, $\varepsilon > 0$, $\delta > 0$, $P^{n,\text{total}} = P^{n,\max}$
for $n = 1,\ldots, N$ **do**
for $k = 1,\ldots, K$ **do**
$P^n_{U,k} = -\alpha_n - \beta_n\sqrt{f_k} + l_n\sqrt{f_k}$
$P^n_{in,k} = P^n_{U,k} + \delta$
end for
end for
Do water-filling by each user using maximum allowed power $P^{n,\text{total}}$ and plot the rate region. Target data rate T^n, $\forall n$ is chosen from rate region.
$(R^n, P^n_{e,k}) = \text{IWF}(P^n_{in,k}, T^n, P^{n,\text{total}})\ \forall n$
While $10\log_{10}\left(\frac{1}{N}\left(\sum_{n=1}^{N} 10^{(P^n_{e,k}-P^n_{in,k})/10}\right)\right) > \tau$ for any k **do**
for $n = 1,\ldots, N$ **do**
If $R^n > T^n + \varepsilon$
$P^n_{in,k} = P^n_{in,k}/\delta$, $k\ \varepsilon\ F^{n,A}$
end
end for
end while
$(R^n, P^n_{e,k}) = \text{IWF}(P^n_{in,k}, T^n, P^{n,\text{total}})\ \forall n$

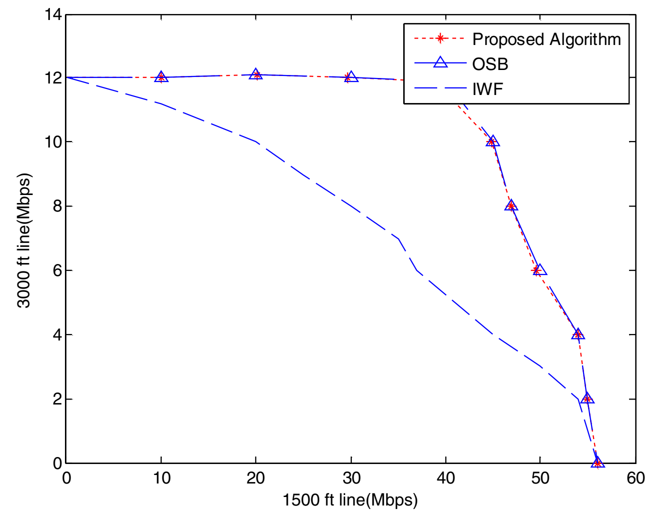

Figure 6 Rate region of two user VDSL upstream scenario.

9. Complexity

The complexity of the proposed algorithm is compared with traditional IWF and OSB algorithm. The traditional IWF algorithm does water filling over K sub channels for N users until a convergence criterion is reached. The complexity of traditional IWF algorithm is found to be in the order of O (K N). The similar operations performed the proposed algorithm which gives complexity in the same order of traditional IWF. The OSB algorithm gives an optimal result but at the cost of high complexity in the order of $O(Ke^N)$.

10. Numerical results

The FDD band plan 998 (ETSI, 2003) is adopted for VDSL upstream transmission. In test case, two users of lengths 3000 feet and 1500 feet are taken. Two separate upstream bands i.e., 3.75–5.2 MHz and 8.5–12 MHz are reserved under this plan. The 30–138 kHz band is optional to use. 26-gauge (0.4 mm) twisted cooper lines are used in VDSL upstream transmission test case. DMT symbol rate $f_s = 4$ kHz and tone spacing $\Delta_f = 4.3125$ kHz have been considered during our simulation. A noise margin of 6 dB and a coding gain of 3 dB are assumed, giving an SNR gap $\Gamma = 12.8$ dB for an error probability of 10^{-7}. Each modem is applied with a maximum transmit power of 11.5 dBm and background noise with $\sigma^n_k = -140$ dbm/Hz. The UPBO parameters are $\alpha1 = 60$, $\beta1 = 21$ for upstream band 3.75–5.2 MHz and $\alpha2 = 60$, $\beta2 = 8$ for upstream band 8.5–12 MHz, which are the default parameters for the UK access network (Bogaert et al., 2004). The Rate Region of the proposed algorithm, traditional IWF and OSB algorithm for two user test case is shown in Fig. 6.

By power back off in high interference creating sub channels, Rate Region of the proposed algorithm becomes enlarged. A service of 10 Mbps is assumed to be required on a 3000 feet line. IWF algorithm provides this service on this line but also achieves 20 Mbps data rate on 1500 feet line. With the proposed algorithm this service can be provided with a data rate of 46 Mbps on 1500 feet line.

11. Conclusion

The proposed algorithm removes crosstalk problem in VDSL upstream transmission. The PSD masks are applied at crosstalk creating sub channels of each user. In the proposed algorithm, the enhanced data rate services are provided on different length users. The simulation results show that the proposed algorithm approaches near the rate of centralized OSB algorithm and maintains distributive nature and complexity same as that of traditional IWF algorithm.

References

Biyani, P., Mahadevan, A., Prakriya, S., Duvaut, P., Prasad, S., 2013. Co-operative alien noise cancellation in upstream VDSL: a new decision directed approach. IEEE Trans. Commun. 61, 3494–3504.

Bogaert, Vanden, E., et al, 2004. DSM in Practice: Performance Results of Iterative Water-filling Implemented on ADSL Modems. IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), pp. 337–340.

Cendrillon, R., Yu, W., Moonen, M., Verlinden, J., Bostoen, T., 2006. Optimal multiuser spectrum balancing for digital subscriber lines. IEEE Trans. Commun. 54, 922–933.

Chen, M., Rhee, W., Mohseni, M., Cioffi, J.M., 2012. Distributed crosstalk management for upstream VDSL using dynamic power control. IEEE Trans. Commun. 60, 940–945.

Chow, P.S., Cioffi, J.M., Bingham, J.A., 1995. A practical discrete multitone transceiver loading algorithm for data transmission over spectrally shaped channels. IEEE Trans. Commun. 43 (234), 773–775.

Cover, T.M., Thomas, J.A., 1991. Elements of Information Theory. John Wiley & Sons.

ETSI, 2003. Transmission and Multiplexing (TM); Access Transmission Systems on Metallic Access Cables; Very High Speed Digital Subscriber Line (VDSL); Part 1: Functional Requirements, ETSI Std. TS 101 270–1, Vol. Rev. V. 1.3.1.

Huberman, S., Leung, C., Ngoc, T.L., 2012. Dynamic Spectrum Management (DSM) Algorithms for Multi-user xDSL. IEEE Commun. Surv. Tutor. 14, 109–130.

Jacobsen, K.S., 2001. Methods of upstream power back off on very high speed digital subscriber lines. IEEE Commun. Mag. 39, 210–216.

Schelstraete, S., 2002. Defining upstream power back off for VDSL. IEEE J. Sel. Areas Commun. 20, 1064–1074.

Shannon, C.E., 1948. A mathematical theory of communication. Bell Syst. Tech. J. 27, 379–423, 623–656.

Starr, T., Sorbara, M., Cioffi, J.M., Silverman, P.J., 2003. DSL Advances. Prentice-Hall.

Specification of the Access Network Frequency Plan applicable to transmission systems connected to the BT Access Network, UK NICC ND 1602 (2011–09).

Yu, W., Ginis, G., Cioffi, J.M., 2002. Distributed multiuser power control for digital subscriber lines. IEEE J. Select. Areas Commun. 20, 1105–1115.

Zeng, C., Aldana, C., Salvekar, A.A., Cioffi, J.M., 2001. Crosstalk identification in xDSL systems. IEEE J. Select. Areas Commun. 19, 1488–1496.