Gain Flattening of EDFA using Hybrid EDFA/Raman Amplifier with Reduced Channel Spacing

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***Abstract* - In this paper, the hybrid optical amplifier composed of single erbium doped fiber amplifier and a Raman amplifier is proposed for wavelength division multiplexed system and also investigates the impact of reduced channel spacing. The performance has been evaluated in terms of gain and noise figure. Gain and noise figure are important characteristics of the optical amplifier to evaluate the performance. There are various parameters on which the gain spectrum of EDFA and Raman amplifier depends. The effort has been made to optimize these parameters by simulating the system of 16 channels in Opti system software. In this paper the length, pumping wavelength, pumping power of EDFA/Raman is optimized. After the analysis the reduction in gain is about 2.7dB and the noise figure is about6.86dB.**

***Keywords* - EDFA, Raman amplifier, HOA, WDM, Gain, Gain flatness and Noise figure.**

I. INTRODUCTION

Optical fiber communication is seen as one of the most reliable telecommunication technologies to achieve consumer's need for present and future applications. Optical transmission systems are based on the principle that light can carry more information over longer distances. Information revolution implies that multimedia networks need high bandwidth and low loss communication links, which can be achieved with optical fiber as transmission medium. In fiber optic communications, WDM is a technology which multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths at speed in Gbps [1-2].WDM of optical signals is a promising way to increase transmission capacity of a fiber. The development of WDM has allowed us to exploit large amount of bandwidth available in optical fiber as low capacity channels [3]. In optical fiber network, amplifiers are used to regenerate an optical signal, amplify and then retransmitting an optical signal. In long-haul optical systems, many amplifiers are needed to prevent the output of signal seriously attenuated. EDFAs are widely used in comparison to other similar amplifiers and optical devices for larger wavelength optical communication system because of its advantages of high gain, large bandwidth, less noise figure (NF), polarization insensitivity, low pump powers and better performance. One difficulty in implementing a WDM system including EDFA's is that the EDFA gain spectrum is wavelength dependent and it doesn't necessarily amplify the wavelength of the channels equally. Bandwidth of EDFA can be increased to more than 30nm with appropriate gain flattening in the third transmission window for future development of WDM long-haul optical fiber communication systems. Moreover, the noise performance of EDFA is characterized by its NF which is signal to noise ratio reduction ratio of input to output of the amplifier and should have a low value. Gain is the main characteristic to evaluate the performance of an optical amplifier. The gain spectrum must be uniform for the long distance transmission, but EDFA cannot amplify all the wavelengths equally [4]. Hence the gain flatness is important for EDFA's wavelength division multiplexing (WDM) which is important technique for long haul optical transmission link system. Different compensation methods were studied in past and based on these methods efforts were made to increase the gain flatness of EDFA. Methods such as hybrid Al-co doped &Al/P co doped EDFAs [1]**,** hybrid EDFA/RFA amplifiers, erbium doped waveguide amplifiers (EDWA) having gain flattened and gain clamped functions simultaneously [4], the usage of the gain flattening filters (GFF) such as, thin film dielectric filters, sinusoidal filters [4], chirped fiber brag gratings [5], acousto-optic tunable filter [6]. The combination of distributed Raman amplifier and EDFA present better performance than conventional EDFA [1].

Hiroji. Masuda et al. [7] demonstrated a wideband and finely gain flattened hybrid fiber amplifier. The amplifier consists of an erbium doped fiber amplifier and a discrete Raman amplifier, which has two, isolated Raman fibers pumped simultaneously at three wavelengths. Here the amplifier yields optical noise under 6dBand total output power13.8dB. The relative gain variation is 11.3dB.

C.H.Yeh et al. [8] proposed the design of simple erbium doped fiber amplifier and erbium doped waveguide amplifier having gain flattened functions. The results showed that the maximum gain variations of 2.5dB with the signal input power 30dBm.

Hyo Sang Kim et al. [9] proposed a Gain flattened erbium doped fiber amplifier by using acoustooptic tunable filters. The gain flatness of < 0.7dB is achieved and the noise figure is about 5dB.

M.M. Martini et al. [10] presented a new technique to optimize the gain profile of broadband hybrid amplifiers under pump residual cycling. 32 channels are transmitted along the fiber, multi pumping technique is used for the Raman amplifier, the gain variations is above 1dB and noise figure is 2.6B.

Liu Kaixian et al. [11] theoretically analyzed the basic characteristics of chirped fiber grating. The design of uniform chirped fiber brag grating with modulation depth changing along vertical direction of FBG Have the distribution characteristics with

EDFA. The transmission spectrum of gratings and the ASE spectrum of EDFA is complementary and the output becomes flattening after transmission by gratings. The unevenness of gain a spectrum is 0.2dB in the range of 1525-1560nm.

II. OPTICAL AMPLIFIERS

When a signal travels in an optical fiber it suffers from various losses like fiber attenuation losses, fiber tap losses and fiber splice losses. Due to these losses it is difficult to detect the signal at the receiver side. So in order to transmit signal over a long distance in a fiber, it is necessary to boost up the signal within the fiber [12]. The block diagram of optical amplifier is shown below:

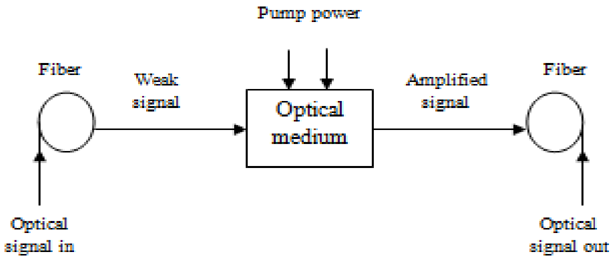


Figure 1 Block diagram of optical amplifier

Initially the optical signals were converted to electrical signal then amplified and then reconverted to optical signal. But it was a complex and costly procedure. The introduction of optical amplifiers allowed the signal amplification in optical domain. There are mainly two types of optical amplifiers: semiconductor optical amplifier and fiber amplifiers. Optical amplifiers were again divided into travelling wave semiconductor optical amplifier and Fabry-perot semiconductor optical amplifier. Fiber amplifiers are divided into Erbium doped fiber amplifier, Raman amplifier and Brillion amplifier [13].

III. ERBIUM DOPED FIBER AMPLIFIER

These fiber amplifiers are the ones normally deployed in WDM fiber –optic communication systems today. EDFA have the gift of nature that the give the output in the vicinity of 1550nm, where silica fiber exhibits minimum attenuation. This fortunate coincidence is why erbium doped fiber amplifiers are so widely used.

In EDFAs pumping is done with a laser diode radiating powerful light in a wavelength other than the information signals wavelength. Specifically, an information signal is transmitted around 1550 nm but pump laser radiate either at 980nm or at 1480 nm, or both. Both the optical information and optical pumping beams are put in the same fiber by a coupler. These beams propagate together along the doped section of fiber where information signal is amplified while the pumping signal loses its power. In a sense, then pumping light gives its power to an information signal and “dies”. The following figure shows the basic diagram of EDFA. Gain of EDFA can be calculated as:

$$G_{EDFA}= G_{max}(\mathrm{L}, \lambda_p,\lambda_s)=exp\left[L\frac{r_p(\lambda_p)-r(\lambda_p)}{1+r_p(\lambda_p)}\right] \quad (1)$$

Where λ_p= pump wavelength, λ_s= signal wavelength, r_p- is the ratio of pump absorption and pump emission $(\sigma_{pa}/\sigma_{pe})$, r = the ratio of signal absorption and signal emission$(\sigma_{sa}/\sigma_{se})$. The gain of EDFA is largely dependent on the parameters explained above. The diagram shown below is the schematic representation of EDFA.

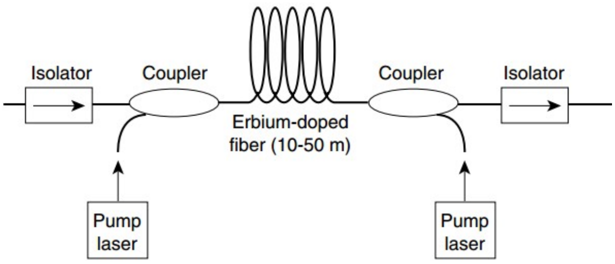


Figure 2: Schematic of EDFA

Gain flattening means achieving a spectrally uniform gain bandwidth. We have seen in EDFA gain spectrum the gain fluctuates between 1530 and 1560nm.There should no fluctuations in the gain spectrum. It is very difficult to work with this type of amplifier whose gain spectrum is not uniform. We need to have a flat gain over its range of operating wavelengths. This characteristic of an EDFA is called Gain Flattening. There are various methods to achieve gain flatness [15].

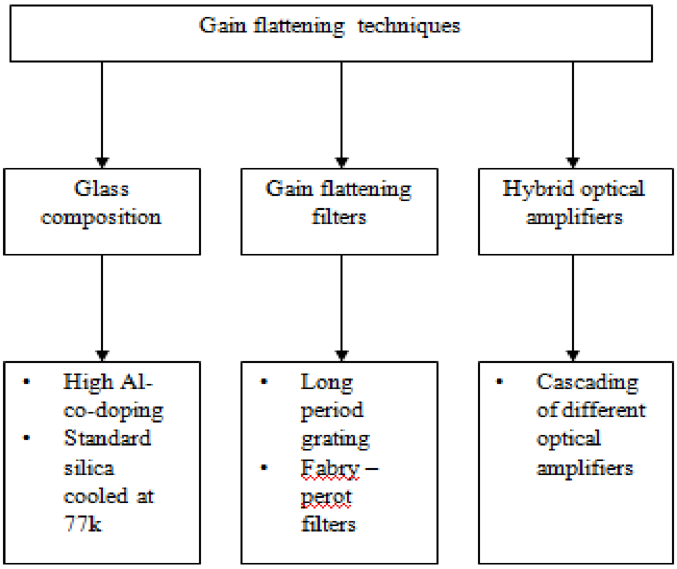


Figure 3.Gain flattening techniques

IV. HYBRID OPTICAL AMPLIFIER

The increasing demand for bandwidth in today's backbone networks makes it increasingly necessary to extend the effective transmission bandwidth of the deployed fibers beyond the widely used C-band (1530 nm to 1610nm) [14]. As the transmission bandwidth is mainly limited by today's amplifier-of choice, the EDFA, new ways of extending the amplifier bandwidth must be pursued. As an example, hybrid combinations of EDFA and Raman amplifier have been used to extend the seamless bandwidth of discrete amplifiers up to 80nm, 100 nm and so on. In general, the combination of more than one optical amplifier in any configuration is called hybrid optical amplifier (HOA). EDFA amplifies the signal but the gain spectrum is not uniform. To reduce the gain variations hybrid combination of EDFA and Raman amplifier is the best choice [16].

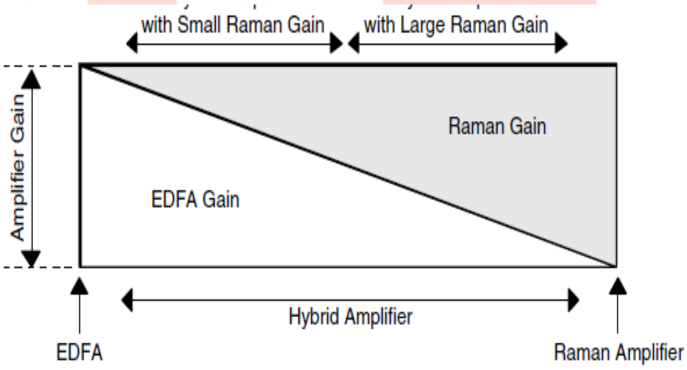


Figure 4.Gain profile of hybrid optical amplifier

V. SIMULATION MODEL

The basic configuration consists of 16 channels with 50GHz channel spacing, the system has a WDM transmitter with first channel is at 193.5THz and increases as the number of channels increases, the input power of WDM transmitter is 20dBm. All the channels are transmitted into the WDM multiplexer with zero insertion loss, here all the light signals are combined and transmitted over the erbium doped fiber of length 9m.The erbium doped fiber amplifier is counter pumped at 1480nm.The counter pumping scheme gives more gain than that of co-propagating pumping scheme. The pump power at which the EDFA pumped is 130Mw.The output of EDFA is then passed through the optical isolator. Optical Isolators are used to protect a source from back reflections or signals that may occur after the isolator. The output after the isolator then fed into the Raman amplifier of length 11m which is counter pumped at 1450, 1452, 1454, 1456nm with constant pump power of 450mW.The over all amplified signal is fed into the optical spectrum analyzer to analyze the optical spectrum. The dual port WDM analyzer is placed after the Raman amplifier which gives the values of gain and noise figure. The gain variations and the noise figure variations are noted down for different frequencies. At the end, it passes through the photo detector to convert the optical signal into electrical signal to note down the bit error rate value. The bit error value should be less than 10^{-6} dB. The simulation setup of hybrid optical is shown in the given figure 5.

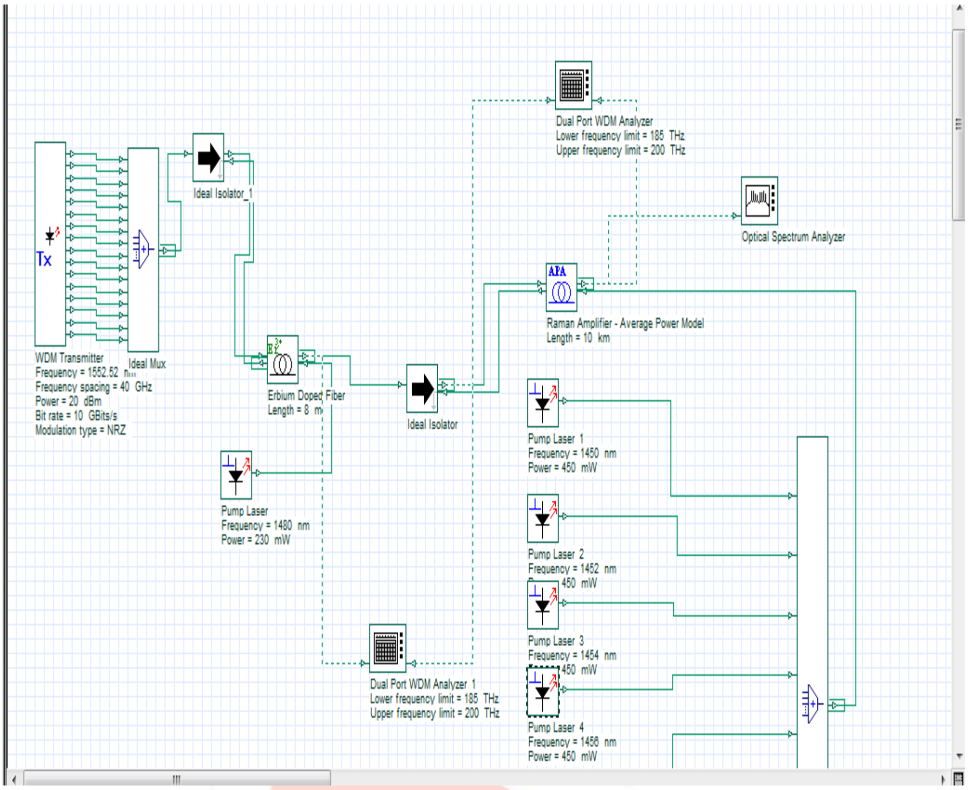


Figure5.Schematic of Hybrid optical amplifier of 16 channels

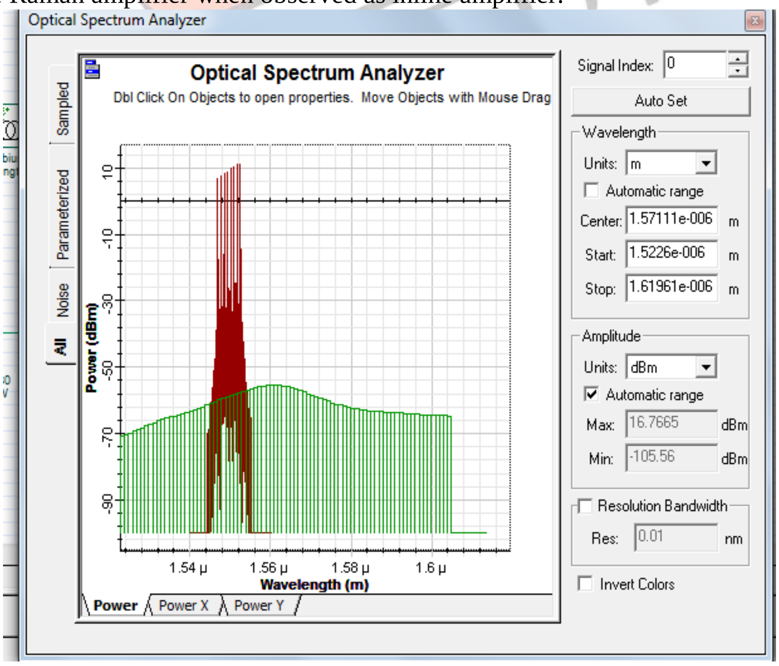
VI. RESULTS AND DISCUSSIONS

First of all the Raman fiber amplifier and EDFA as inline amplifier is observed individually. The amplification done by EDFA is about 13dB, but the gain spectrum is not uniform and the noise figure is about 13dB. After EDFA Raman amplifier is observed, in which the amplification done by Raman is about 10dB but the gain spectrum is flat and noise variations is about 6dB.The results are tabulated in table 1.

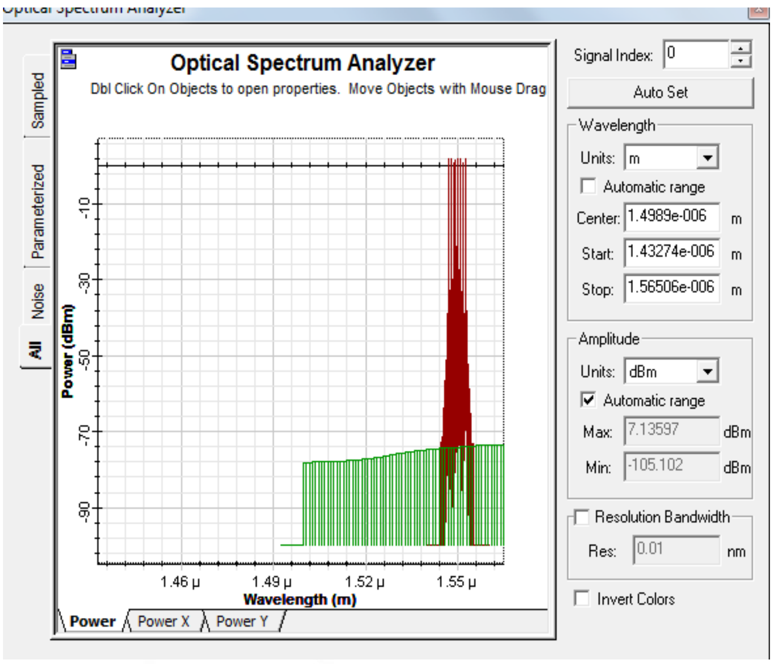
Table1 Comparison of gain and noise figure of EDFA and RAMAN as inline amplifier

Inline amplifier used	Pump wavelength	Pump power	Gain variations	Noise figure variation
EDFA	1480(nm)	130mW	3.95dB	2.94dB
RFA	1460(nm)	200mW	0.161dB	0.09dB

Figure 6 shows the results viewed from spectrum analyzer in the Opti-system software. These are power spectrum of Erbium doped fiber amplifier and the Raman amplifier when observed as inline amplifier.



a) for EDFA



b) for Raman

Figure6. Output power spectrum (red) noise spectrum (green)

After the analysis, RFA as an inline amplifier at pump power of 200mW provides lesser gain variations than the EDFA. Moreover the gain response of RFA shows opposite characteristics than EDFA and hence this property of RFA can be exploited for gain flattening. As the HOA is placed in the network system with reduced channel spacing, the different gain and noise figure is recorded at every step. It is found that the gain of HOA is almost flat after the observation. The maximum gain is achieved after the hybrid optical amplifier. It means that the combination of EDFA and Raman is responsible to increase the gain. To illustrate the performance of this hybrid optical amplifier, gain and noise figure is recorded after HOA incorporated. Figure 7 shows gain as a function of frequency. The overall gain for given frequency band is increased from 12.41dB to 16.21dB. Figure 8 shows the characteristic in terms of noise figure as a function of input signal frequency. The overall noise figure is maintained below 6dB.

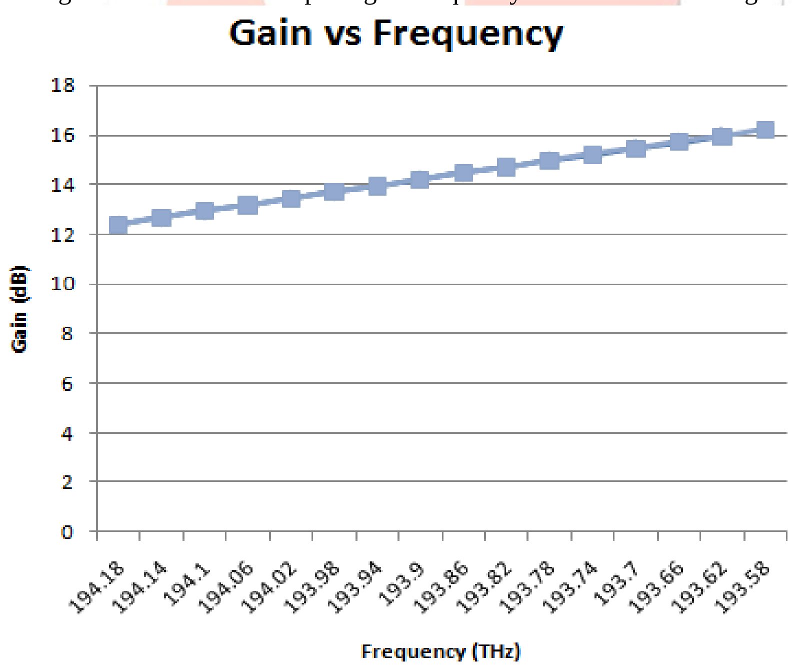


Figure7. Flattened gain response

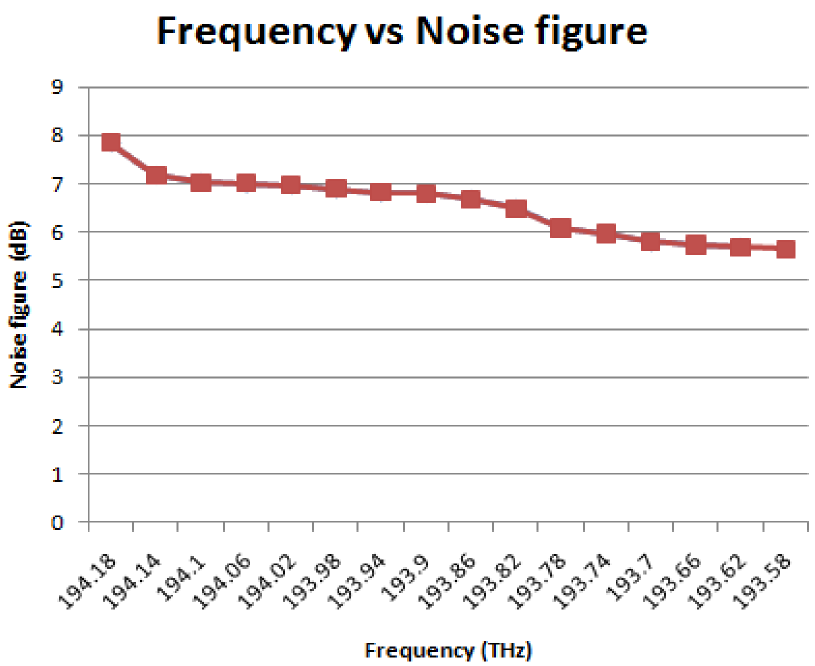


Figure8. Noise figure variations

VII. CONCLUSION AND FUTURE SCOPE

The erbium doped fiber amplifier has very high gain and can be made suitable for optical transmission systems for long haul communications by employing appropriate gain flattening technique. In this paper a system of 16-channels was designed in the range of 1532-1547nm, which lies in C-band. In the hybrid configuration of EDFA/Raman, it is possible to reduce gain variations by optimizing erbium fiber length which is 8m in the proposed model and proper choosing of pump wavelengths and injected pump powers to Raman fiber amplifier. By applying this gain equalization technique, the hybrid optical amplifier has gain value of 15 dB. The gain variations are reduced to 2.7dB and noise figure is obtained below 6 dB. In future more the 16 channels can be transmitted with reduced channel spacing by incorporating different co doping concentration, multiple pumping schemes, where the pump wavelengths and pump powers can be chosen carefully to ensure a good performance.

VIII. ACKNOWLEDGEMENT

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