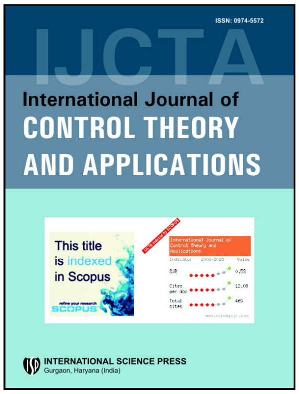

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Power Efficiency in Optical Networks with p-Cycle Protection

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Abstract: Recently the requirement of "greener" telecommunication networks gives an idea to find new area of research to cope up with power consumption and sustainability issues. With rapidly growing new technologies and network power consumption in ICT sector, power-efficient solutions have become a necessity. Optical networks are the backbone of telecom network, and a major contributor to overall power consumption. Optical networks are so huge that there are many redundant devices in active mode. There is immense amount of data transmission in network and any loss of data due to network failure can cause huge setback. There is an urgent need to consider minimization of power consumption by redundant devices while assuring survivability of networks (with redundant devices). The p-Cycles (pre-configured cycles) are one of the most promising technique for shared protection, providing both fast restoration and capacity efficiency. In this present work we have investigated the effect of power conscious routing (PCR) on the spare capacity requirement. A comparative study has been made between power efficiency and resource efficiency. It has been found that for small traffic in the network significant power saving is achieved at the cost of reduced capacity efficiency whereas for high traffic in the network the effects are relatively less pronounced. We use optical cross connect (OXC) and amplifiers (EDFA) values from the data sheets to calculate the power consumption in a network.

Keywords: Power conscious routing (PCR), Shortest path routing (SPR), Erbium Doped Fiber Amplifier (EDFA), Optical Cross Connect (OXC)

1. INTRODUCTION

ICT sector is 2% contributor in annual global greenhouse gases emissions [1]. The internet alone shares 5.5% of total energy consumption, according to a 2007 report. From a data of 2009, ICT consumes 8% of world's total electricity [1]. The amount of power consumed by core networks is huge. Optical networks are the very heart of core network. WDM networks can provide a huge amount of bandwidth for present and future Internet applications. However, current network architectures and operation schemes do not pay much attention to power efficiency. Therefore, many recent researches focus on power- efficient core network. Significant changes are occurring in the optical networks day by day with the tremendous increase in traffic because of multimedia services. The continuous demand for the increase in bandwidth goes from 10Gb/s-100Gb/s. The large requirements of information and communication technology services and high data rate applications (like videos, high definition IPTV, cloud computing etc) have increased the network capacity and forces to search the solution for the efficient use of resources as well as to manage the traffic growth. In coming years the internet traffic will be increased approximately by 40%. There will be issue of power consumption by the internet in the scenario as well. Impact of network operational expenditures (OPEX) can be reduced with the help of power consumption constraints in the network model. The major power consumption in backbone network is due to transponders, optical cross connects, optical amplifiers etc. The improvement in power efficiency of any network methods is a promising issue for the future. It has been shown that most of the power (approx 70% of total energy consumption of all telecommunication network equipment) is consumed in broadband access networks [2-6]. The power consumption of an optical network can be reduced by applying sleep mode (off the unused function and demand traffic on the link) or switching off mode (turning off the unused equipment) in the network.

To investigate the effect of power efficiency on spare capacity efficiency, in this study first the demands are routed using shortest path Dijikstra's algorithm and then protection is provided using spare capacity optimization model of *p*-cycle formation. The total power consumption and spare capacity have been calculated.

Secondly the demands are routed using power aware routing algorithm. To provide protection again *p*-cycle model is used. Power conscious routing is used to minimize the power consumption of working paths. PCR is similar to the shortest path routing, with power consumption also taken into account. In optical networks, the capacity or the wavelengths are available in abundance, therefore the objective of this algorithm is to minimize the total power consumption of network components, which are in ON/ACTIVE state. An OXC (having multiplexer/ de-multiplexer and wavelength cross connect switch) and amplifiers (are deployed in links to make up for signal strength losses) which are already used by a path will be preferred as compare to use other OXCs and amplifiers which are not used. A new wavelength may be used for routing of another working path with already used OXC and amplifier. Thus a trade off is being made between number of wavelengths (capacity) and power consumption as some of the OXCs and amplifiers will not be used and kept in sleep mode.[7]

In the next section of the paper we discuss the concept of p-cycle and the routing algorithms used for power consumption

2. P-CYCLE CONCEPT

P-Cycle is known as pre-configured protection cycle used for the designing and operation of mesh restorable network. P-Cycle has the combined characteristics of mesh based and ring based protection methods. Using *p*-cycle, a mesh network is protected from link failure with the advantage of ring like speed and mesh like capacity efficiency. The combined advantage of faster restoration speed and high capacity efficiency makes it far superior than any other scheme. In case of any failure p-cycle guarantee the recovery of the effected services same as with other protection schemes.

P-Cycle is based on the bi-directional link switched rings (BLSR) protection scheme in which traffic flows in both the directions. P-Cycle is different from the conventional ring protection. It provides two protection paths for each span as straddling spans [8-10].

3. ROUTING ALGORITHM

The power consumption of the network depends on its components. According to some studies, the power consumption of a network practically remains constant, thus it is believed to be independent of bit rate. Thus the equipment employed in the spans and at nodes are the major power consuming components. To minimize the power consumption we want to select a path from source to destination such that the total number of amplifiers and OXCs are minimum. To calculate the working path from source to destination shortest path routing and power conscious routing algorithm have been used in this study.

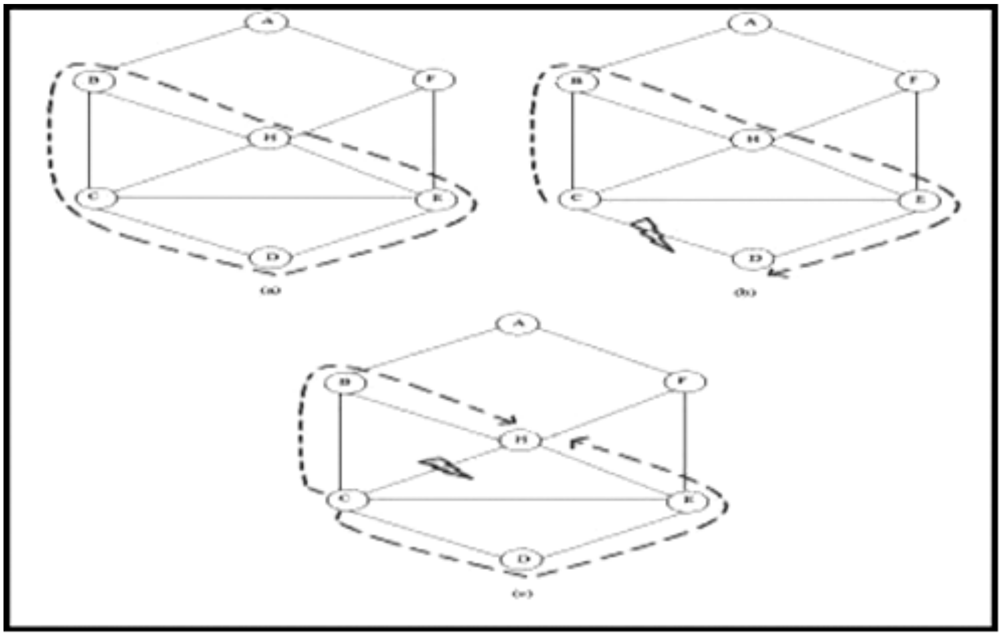

Figure 1: (a) *p*-Cycle (b) On-cycle span failure (c) Straddling span failure

Shortest path routing algorithm determine path from source to destination using Dijkstra's algorithm. After routing, the power consumption of network is obtained by calculating power consumption of active working nodes and spans. Comparative study of power efficiency and spare capacity efficiency has been done in this work.

Power conscious routing (PCR) is proposed so that the power consumption is minimized. OXCs and amplifiers already in use are consuming power. If these OXCs and amplifiers are included in the routing path for other demands, additional wavelengths are to be used but the power consumption for these OXCs and amplifiers will not increase. In this method we select a path that reuses the previously-used spans as much as possible and costs least for the previously-non-used spans for the next demand in order to save energy. The overall non-used spans after routing of demands will be put in sleep mode. They will be activated again in case of any failure if required.

The figure 2 explains the PCR algorithm.

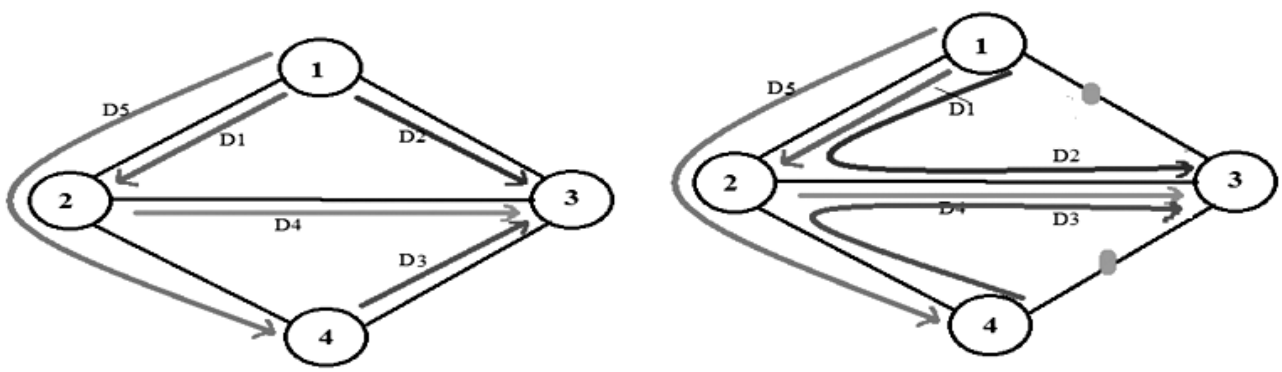

Figure 2: (a) Paths allocated to demands by shortest path routing
(b) Paths of Demands after PCR routing.

4. ILP FORMULATION

Mathematical Model for Network

4.1. SETS

S = Set of spans, indexed by j

N = Set of nodes, indexed by n

P = Set of P-cycles, indexed by p

4.2. PARAMETERS

P_{amp} = power consumed by an amplifier (e.g. EDFA), in Watts.

P_{sleep} = power consumed by an amplifier in sleep mode, in Watts

P_{OXC} = power consumed by OXC at nodes, in Watts.

w_j = working capacity on span j

X_j^p = equal to 1 if p-cycle p protects span j as on-cycle span; equal to 2 if p-cycle p protects span j as straddling span; 0 otherwise

π_j^p = equal to 1 if p-cycle p crosses span j; 0 otherwise

C_n = equal to 1 if node n is active; 0.01 if in sleep mode

m_j = number of amplifiers on span j

4.3. VARIABLES

n_p = number of copies of p-cycle p

s_j = spare capacity required on span j

Aw_j = equal to 1 if span j is active due to working capacity; otherwise 0

Ap_j = equal to 1 if span j is active due to p-cycle crossing it; otherwise 0

Sl_j = equal to 1 if span j can be put in sleep mode; otherwise 0

P_T = total power consumed by amplifiers and OXCs in network

The objective of ILP is :

Minimize:

$$\sum_{j \in S} s_j \tag{1}$$

Subject to;

$$w_j \leq \sum_{p \in p} \pi_j^p, \qquad j \in s \tag{2}$$

$$s_j = \sum_{p \in p} \pi_j^p . n_p, \qquad j \in s \tag{3}$$

$$Aw_j = 1, \quad j \in s,\ if\ w_j > 0 \tag{4}$$

$$Ap_j = 1, \quad j \in s,\ p \in P,\ if\ n_p.\pi_j^p > 0 \tag{5}$$

$$Sl_j = 1, \quad j \in S,\ if\ Ap_j > Aw_j \tag{6}$$

$$P_T = \sum_{j \in S}\left(P_{amp}.Aw_j + P_{sleep}.Sl_j\right).m_j + \sum_{n \in N} P_n.C_n, \quad j \in S, n \in N \tag{7}$$

Here equation 1, aims at minimizing the total spare capacity (of all spans), required to obtain p-cycles for protection of spans. In equation 2, it is taken care of that each and every working capacity unit in each span is provided protection. Equation 3 ensures that there is sufficient spare capacity on each span for every selected p-cycle. Equation 4 depicts if the span is active because of working capacity assigned to it. Equation 5 shows if the span is active due to p-cycle passing through it. Equation 6 finds the spans which are to be put in sleep mode, those who do not have working capacity but a p- cycle passes through it. Equation 7 calculates the total power consumed by spans in active mode, sleep mode and the power consumed by nodes.

5. SIMULATIONS AND RESULTS

For investigation two networks, (a) 8 nodes and 11 spans bi directional network and (b) 14 nodes 19 spans NSFET network have been used. In all simulations low traffic levels are considered as compared to standard traffic levels. It is believed that maximum wastage of power is during low traffic transfer. It is assumed that each span has enough spare capacity to hold capacity required for protection by$p$-cycles. Erbium doped fiber amplifiers

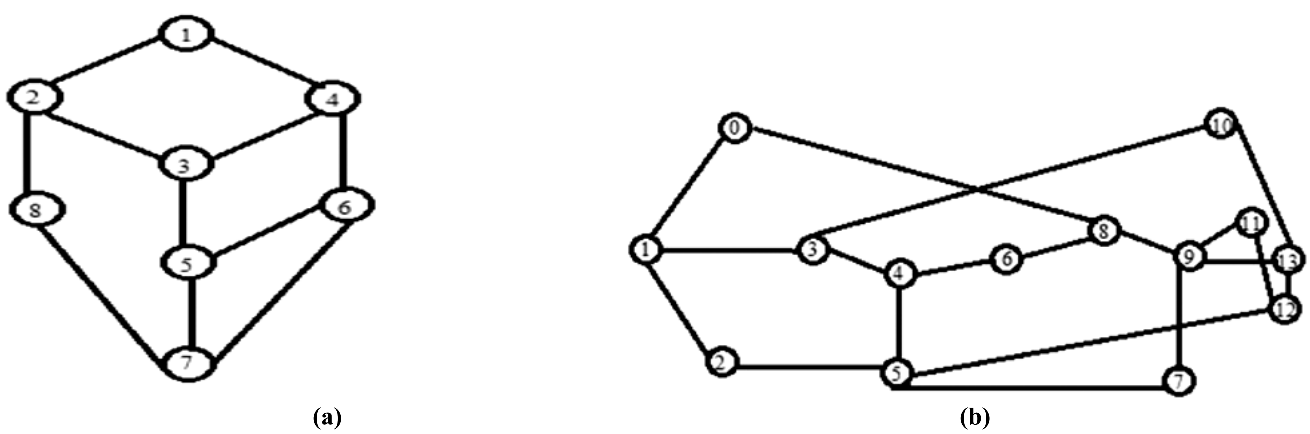

Figure 3: (a) 8 node 11 spans optical network (b)14 node 19 spans optical network

Table 1
Comparison between SPR and PCR with respect to no. of *p*-Cycles, total spare capacity and power consumption for 3 different demand matrices for 8 nodes 11 spans network

No. of Demands	*No. of p -Cycles*		*Total Spare Capacity*		*Power Consumption*		
	SPR	*PCR*	*SPR*	*PCR*	*SPR (in W)*	*PCR (in W)*	*% Decrease*
10 Demands	2	4	13	24	580	478.5	17.500%
15 Demands	4	5	24	30	594	505.5	14.898%
25 Demands	5	6	33	36	594	568	4.377%

Table 2
Comparison between SPR and PCR with respect to no. of *p*-Cycles, total spare capacity and power consumption for 2 different demands for 14 nodes 19 span NSFET network

No. of Demands	*No. of p -Cycles*		*Total Spare Capacity*		*Power Consumption*		
	SPR	*PCR*	*SPR*	*PCR*	*SPR (in W)*	*PCR (in W)*	*% Decrease*
15 Demands	1	3	14	35	6763	5353	20.84%
25 Demands	3	4	30	52	7348	5733	21.97%
35 Demands	3	6	51	66	7348	5458	25.72%

(EDFA) and OXCs are used with their power consumption specifications studied in [11] [12]. We have considered 2 amplifiers in each span. We took a set of 10, 15 and 25 demands routed using shortest path routing algorithm (Dijkstra). The resulting working capacity in each span is obtained and placed in ILP model as input for spare capacity optimization model for *p*-cycles. The same process is repeated for the power conscious routing (PCR) for above stated set of demands.

The networks shown in figure 3 has three main variables: number of p-cycles, spare capacity in spans and total power consumption for the optimization model. The comparative study of SPR and PCR in figure 4, 5, 6 and 7 shows that PCR requires more capacity than SPR in spans, thus not capacity efficient. However, from the results of table I the total power consumed by PCR is 17.5%, less than the SPR for 10 demands and hence power efficient. Similarly for the NSFNET of 14 nodes and 19 spans table II shows the total power consumed by PCR is 20.84% less than SPR for 15 demands, which makes PCR more power efficient but at the cost of capacity efficiency.

The above result shows that PCR is more power efficient than SPR at the cost of spare capacity efficiency.

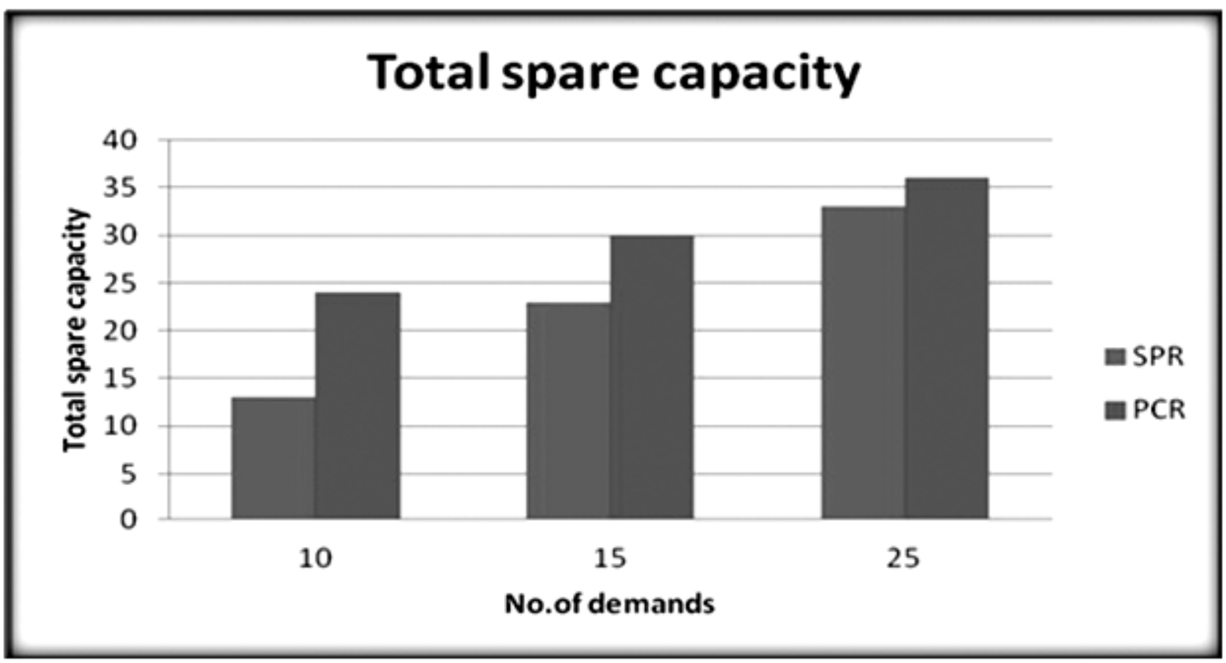

Figure 4: Comparison of total spare capacity required for 8 nodes and 11 spans network

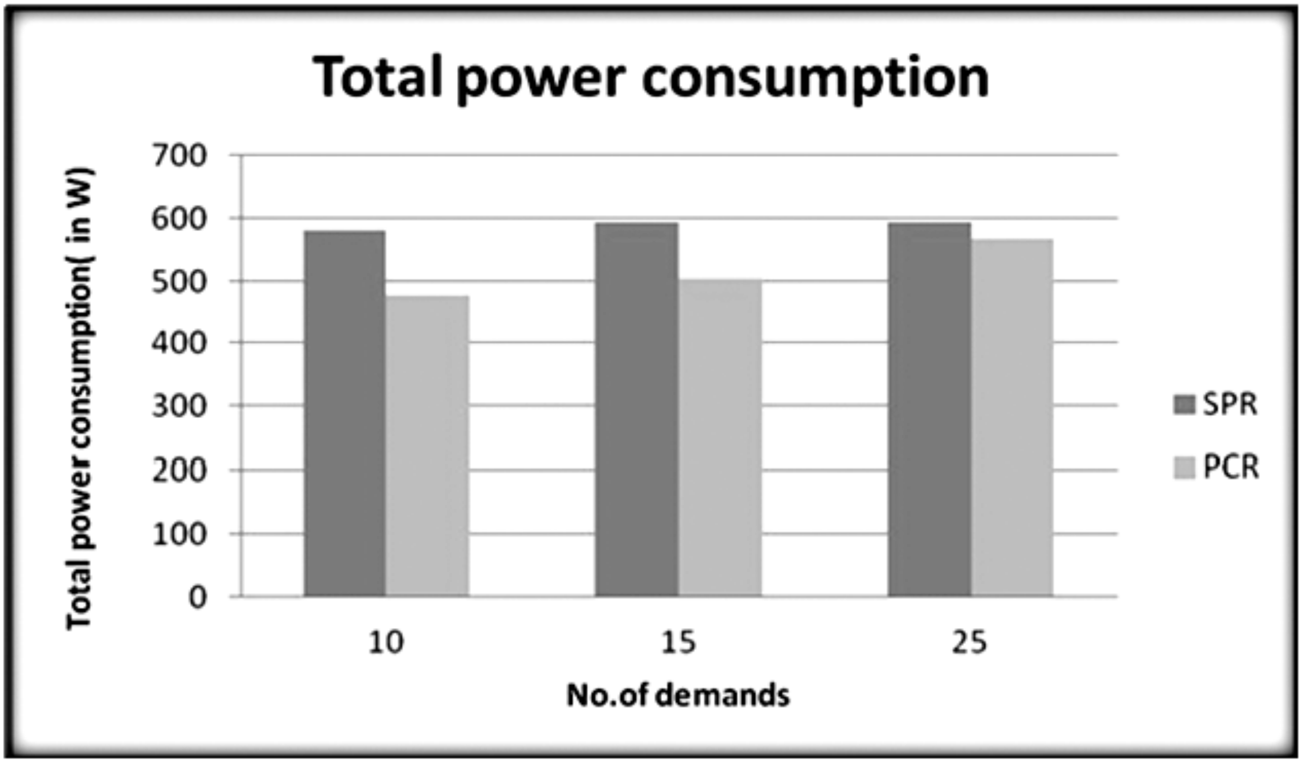

Figure 5: Comparison of total power consumption for 8 nodes and 11 spans network

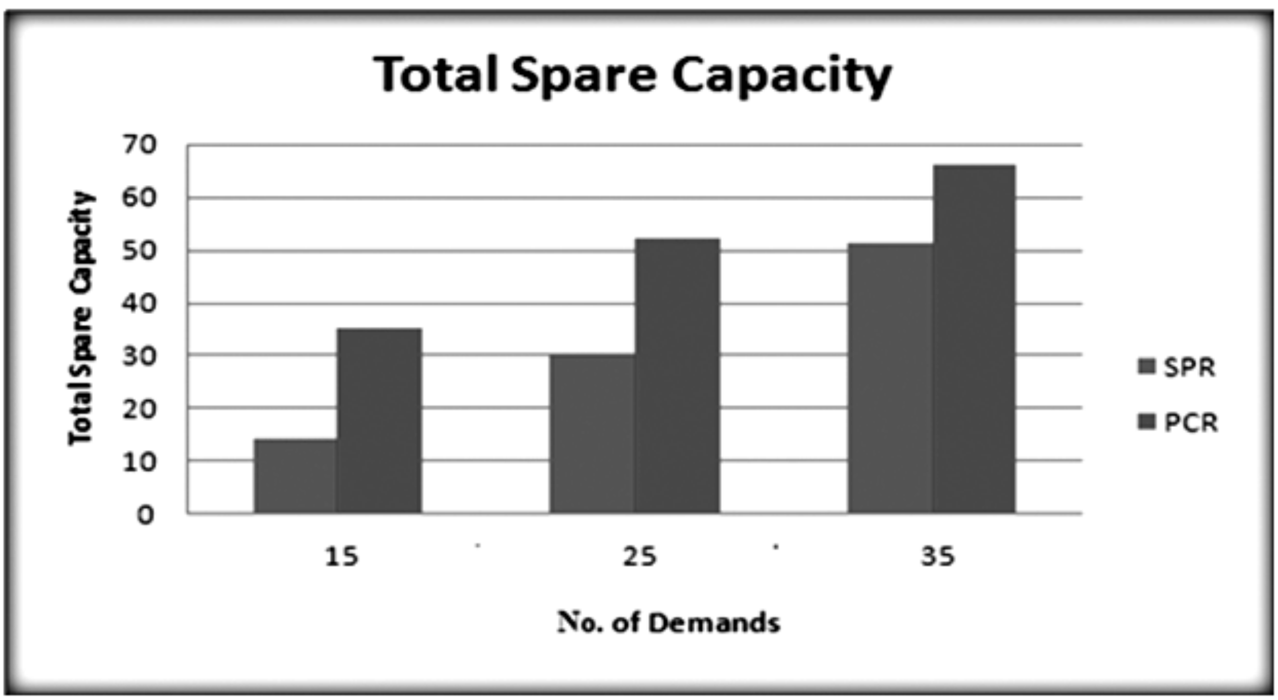

Figure 6: Comparison of total spare capacity required for 14 nodes and 19 spans network

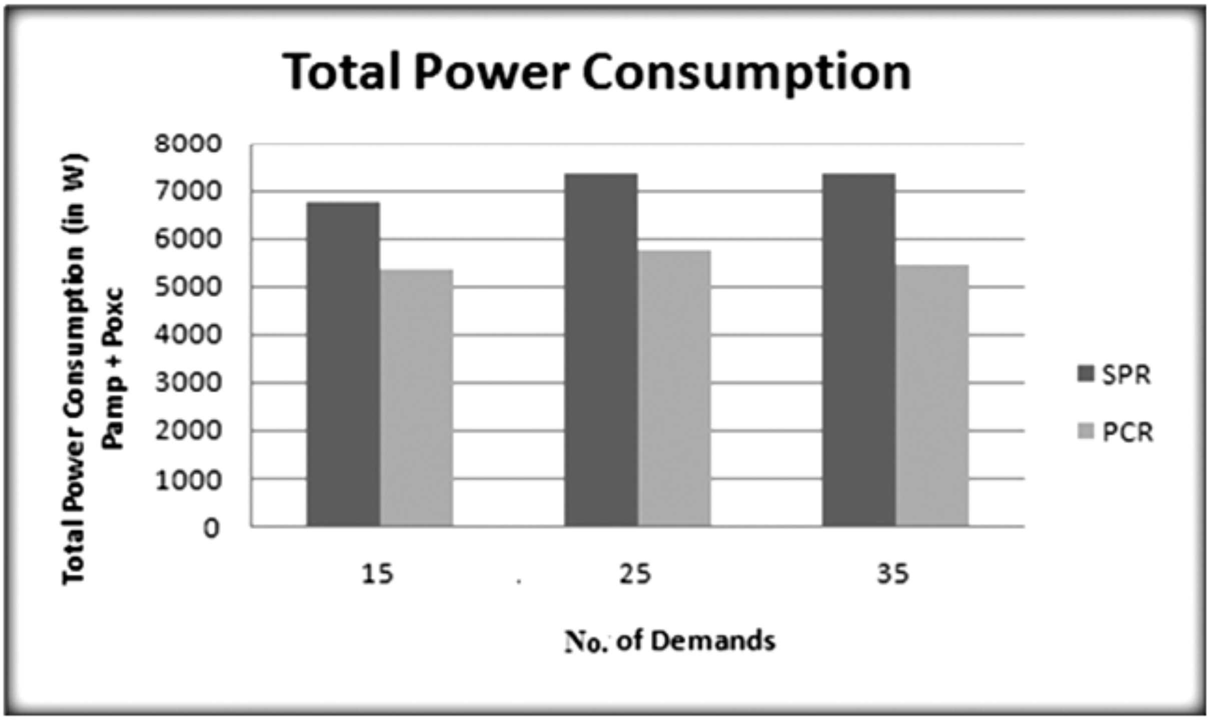

Figure 7: Comparison of total power consumption for 14 nodes and 19 spans network

6. CONCLUSION

After optimizing the mathematical model for power consumption and total spare capacity we can conclude that PCR- power conscious routing is power efficient but at the cost of spare capacity. PCR consumes far less power as compared to SPR when the traffic is low. From table I power efficiency of 17.5% is achieved with power conscious routing for less traffic level for 8 nodes 11 spans network and 20.84% for NSFNET. The power efficiency together with p-cycle can be obtained at the cost of capacity efficiency and here the spare capacity nearly doubles for both the networks. As the traffic level increases then it will become difficult to get better power efficiency because the requirement for active nodes and active spans will be increased for large amount of traffic.

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