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EVALUATION OF HIDDEN MARKOV MODEL BASED ADAPTIVE PROVISIONING OF OPTICAL BURST SWITCHING NETWORKS AMENABLE FOR UPGRADATION TO GREEN FLEXIGRID NETWORKS

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ABSTRACT

Catering to the evolving bandwidth-on-demand applications requires flexible provisioning architectures that ensure fairness to both high end and low end users of internet. Dynamic classification of network paths into long and short, based on traffic dependent connection holding times and a wavelength allocation from different subsets for these categories is a necessity for implementing energy saving hybrid switching, loss recovery and flexi grid bit rate variable schemes. Therefore, this study evaluates such a scheme of dynamic classification based on HMM predicted connection-holding times with tightly integrated adaptive burst sizing and segregated wavelength allocation for long and short categories. Simulation study of a 28 node OBS network shows that this coupled scheme reduces delays and results in throughput improvement of 67% for long and 12% for short traffic over schemes that employ adaptive burst sizing based on number of active traffic flows and independent wavelength assignment schemes.

Keywords: Traffic Prediction, Wavelength Assignment, Adaptive Resource Allocation, Link Holding Time

1. INTRODUCTION

Evolving nature of service delivery, fueled by growing bandwidth-on-demand applications and wireless backhaul is forcing the upgradation of modulation formats from simple 10 Gbps OOK per DWDM channel to complex DPSK and multibit QAM modulation formats and is expected to lead ultimately to flexi grid or elastic optical networks right down to the access networks (Gerstel *et al*., 2012). But these complex schemes though economically feasible in the core networks have to seamlessly integrate with less complex schemes that the legacy metro and access networks can gracefully migrate to, so as to ensure low operational expenses to the end-users. Resource provisioning in Optical Burst Switching (OBS), has to be modified so that they can easily adopt hybrid schemes for loss recovery, hybrid switching and flexible bit-rates. When paths in the core network have to dynamically handle different types of bursts either long or short in duration, then accordingly optimal schemes also have to be varied dynamically ensuring energy saving and maximum throughput with minimal delay. If in addition, wavelength allocation is also done from within designated wavebands for these different types of traffic, it is also possible to ensure wavelength continuity in critical applications even down to access networks allowing compatibility with legacy systems. This would require provisioning based on dynamic path-dependent connection holding times. If the predicted connection holding time of the chosen path is used for adaptive burst sizing and wavelength allocation, then the blocking probability and burst losses can be minimized. Tornatore *et al.* (2005) have shown that a knowledge of required connection holding times for any incoming application can ensure resource

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savings through efficient shared-path protection. The work of Fiorani *et al.* (2013) illustrates that knowledge of the short and long traffic paths in the network is crucial for implementing of energy efficient hybrid switching (Fiorani *et al*., 2013). Therefore our approach of predicting path-dependent connection-holding times available in the network at any time when matched to the knowledge of requirements of incoming application will ensure efficient transport.

Reports so far show resource allocation schemes for burst sizing and wavelength allocation are carried out mostly independent of each other. They can be broadly classified into service differentiated priority-based (Zhang *et al*., 2009; Coulibaly *et al*., 2011), total TCP flow-level statistics based (Ramantas and Vlachos, 2011; Bonald *et al*., 2011) or feedback based (Rumley *et al*., 2009) schemes for adaptive burst sizing and minimum wavelength usage based or statistical usage based (Johnson *et al*., 2001; Drakos *et al*., 2012; Shekhawat *et al*., 2008) schemes for wavelength allocation. Adaptive optical burst sizing schemes reported by Bonald *et al*. (2011) adjusts the burst sizes based on total number of traffic flows and not on the available path-specific connection times. The closest approach to path dependent connection aware scheduling is the one reported by (Rumley *et al*., 2009) but is prone to delays since each core node controls the allocation based on feedback from other nodes. Therefore appropriate predictive schemes for path-dependent connection-holding times will be required. Hidden Markov Model (HMM), provides the solution for wide variety of applications such speech tagging and noun-phrase chunking (Chomphan, 2012), is also flexible enough to predict any type of internet traffic (Dainotti *et al*., 2008) and has been demonstrated for wavelength assignment in WDM networks by Johnson *et al*. (2001). In this study, we use thresholding of HMM predicted path-dependent connection holding times and show that this connection-time impairment aware provisioning of Burst Sizes and Associated Wavelength Allocation (ABS-WA) can reduce delays and improve throughput. This scheme can also be used for dynamically selecting slow or fast switching, ensuring energy saving and can also indicate the scenarios where varying bit-rates will improve the efficiency of transport.

The forthcoming sections 2 and 3 outlines traffic prediction and resource allocation using HMM and section 4 presents the simulation results of execution of this scheme in a 28 node mesh topology.

2. HMM BASED HOLDING TIME PREDICTION

In the HMM used in this work, the state of the nodes at any instant of time t in the network form a set, the departure time of a burst, the wavelength assigned to it, the arrival time of a incoming burst and its assigned wavelength are the observations associated with each state. Each possible path between any source to destination pair can be represented as a sequence of transitions of states C of appropriate length and path-dependent connection holding time for traffic flow between each source destination pairs is modeled as the hidden states of the HMM (Khanna and Liu, 2006). For every observatory period Tb, the difference between departure time from the previous node to the arrival time at the successive hops is estimated from the observables of the system. In this analysis, we assume that the future connection arrival instants and holding times are not known beforehand.

Connection holding time of a burst km routed on a wavelength λm through a link Lij (km) between a pair of nodes (Ni, Nj), is designated as CTh (Lij (km)) and is defined as the difference between the observed time of departure Td (km, Ni) of the burst from the transmitting node Ni to the time of receipt of the entire burst Ta (km, Nj) at the receiving node Nj as shown below in Equation (1):

$$\mathrm{CTh}(L_{ij}(k_m)) = \mathrm{Ta}(km, N_j) - \mathrm{Td}(k_m, N_i) \quad (1)$$

Therefore the connection holding time for the burst km through the entire path p1 from source s to destination d CThsd (km, p1) is the accumulated delay through the multiple intermediate hops between the nodes in the path and can be written as a summation of the connection holding times over all the links in the path as depicted in Equation (2):

$$\mathrm{CThsd}(k_m, p1)) = \sum_{ij} \mathrm{CTh}(L_{ij}(k_m)) \quad (2)$$

Following the formulation of HMM as per Rabiner (1989), transition array A, storing probability of state j following state i (independent of time), observation array B, storing probability of observation v1 being produced from state j (independent of time) and π the initial probability array are computed. Decoding the HMM to extract the hidden states for a given state sequence is done using Viterbi algorithm.

3. RESOURCE ALLOCATION USING HMM

3.1. Adaptive burst sizing

For an incoming application at the ingress node, the HMM predicted connection holding time for the shortest path to the required destination is used to assign burst size adaptively as per ABS-WA algorithm given below. If the predicted link holding time is less than a specified threshold, a minimum burst size is assigned otherwise a burst length less than or equal to a maximum value is assigned:

```
1: $L_h$ = the predicted link holding time of a link
2: $minT_{Lh}$ = the threshold that defines the minimum link
        holding time
3: $min_{size}$ = the minimum burst size
4: $max_{size}$ = the maximum burst size
5: If $L_h \le minT_{Lh}$            Then
        6: Burst Size = $min_{size}$
            Else  $L_h > minT_{Lh}$ Then
        7: Burst Size $\le max_{size}$
  End if
```

3.2. Wavelength Allocation

The proposed wavelength allocation algorithm allocates wavelength to the paths based on its connection holding time. The link holding time differs greatly from a link to another. In section 3.1, our approach classifies the link as either short term or long term based on link holding time. Long-term paths have greater priority on wavelength resources as it has long link holding time. On the other hand, short-term paths have lower priority over resources. Two threshold values Thmin and Thmax are set based on predicted link holding times. The available N data channels are split in two categories. All wavelength numbers higher than a specific minimum called Th_{min} are assigned to short-term paths and all wavelength numbers equal to or less than a maximum called Th_{max} is assigned to long traffic. All short-term paths are assigned wavelength channel numbers higher than this threshold number. This wavelength assignment section of ABS-WA algorithm is given below:

```
1: $Th_{min}$ = threshold value representing the minimum wavelength num berfor short- term paths
2: $Th_{max}$ = threshold value representing the maximum wavelength number for long-termtraffic
3: If ($L_h \le minT_{Lh}$) (connection holding time = Short)
Else {connection holding time = Long}
4: If (connection holding time = Short) then
5: Allocate wavelength > Thmin but $\le$ N using LAUC
6: Else  (connection holding time = long) then
7: Allocate wavelength $\le Th_{min}$ using LAUC
End if
```

4. SIMULATION

In this section, we examine the performance of HMM based Traffic Prediction (HMM-TP) technique with an extensive simulation study based upon the ns-2 network simulator.

Topology considered for the simulation is a mesh topology depicted in **Fig. 1**. There are 14 edge nodes and 14 core nodes with a total of 10 1Gbps wavelength channels per link of which 2 are control channels and the rest 8 are data channels. Header-burst offset time of 40μs has been used for simulation.

Self-similar traffic model is used for simulating short-term traffic and TCP is used for long-term. 6 TCP traffic flows and 5 sets of short-term traffic flows are set up between each pair of ingress-egress nodes. Shortest path routing with available unused channel filling in each of the appropriate wavelength subgroups with deflection routing of contending bursts has been employed. The normalized load defined as the total actual load per link to the total capacity of the link has been varied from 0.1 to 1. An offline analysis of connection holding times for probe traffic of varying normalized loads of short traffic along all paths of this network, monitored for a period of 10s, was used to calculate average connection holding times. This average connection time over all paths for short traffic is used to set threshold minLth. In order to reduce the transmission overheads which are higher for short bursts, the number of wavelength channels to be assigned for short term flows should be larger and hence Th_{max} is set to be 3 (0.37% of N). The performance of the HMM based ABS-WA, is compared with the adaptive Optical Burst Switching (AOBS) method reported by (Bonald *et al*., 2011). For the HMM-TP simulation, out of 8 data channels considered, Th_{min} was set at 3 resulting in 5 available channels for short-term traffic and 3 channels for long-term traffic. The minsize and maxsize values for the burst size are set as 10KB and 40KB, respectively.

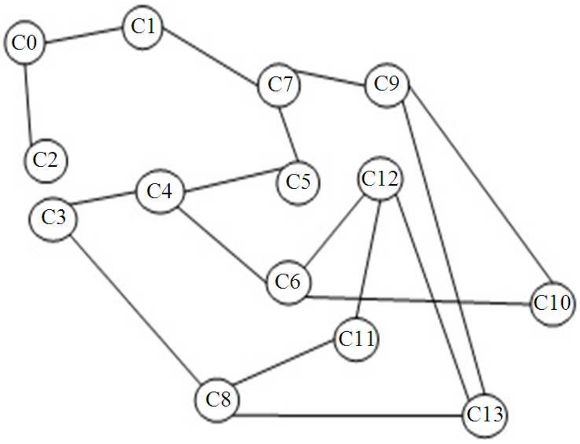


Fig. 1. Network topology

5. RESULTS

Simulations were carried out by varying the normalized traffic load from 0.1 to 1.0 and all the blocking probability, end-to-end delay, packets throughput ratio, was monitored for both AOBS and our HMM based ABS-WA schemes.

5.1. Blocking Probability

Figure 2 shows the blocking probability for ABS-WA and AOBS techniques. As the normalized traffic load is increased from 0.1 to 1, we can see that the blocking probability increases, because of congestion and overloading. The proposed ABS-WA technique has 42.7% lower blocking probability when compared to AOBS since it adaptively adjusts the burst size, based on holding time. In order to verify which kind of traffic shows lesser blocking probability, simulation results were analyzed for long traffic and short traffic separately.

The results of burst delay and burst received are depicted in **Fig. 3a and b**, respectively, for both the techniques. The overall burst delay is reduced by 0.38% and the received bursts are 10.4% more, for ABS-WA when compared to AOBS.

5.2. Packet loss ratio and end to end delay

Figure 4 shows that packet loss ratio for short traffic is lower by 27% and long traffic is lower by 62% when compared to AOBS technique. The reduction in the blocking probability of short traffic is attributed to the larger number of wavelengths allocated for the same.

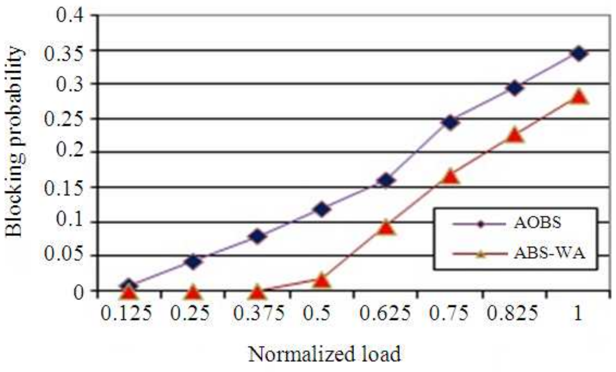
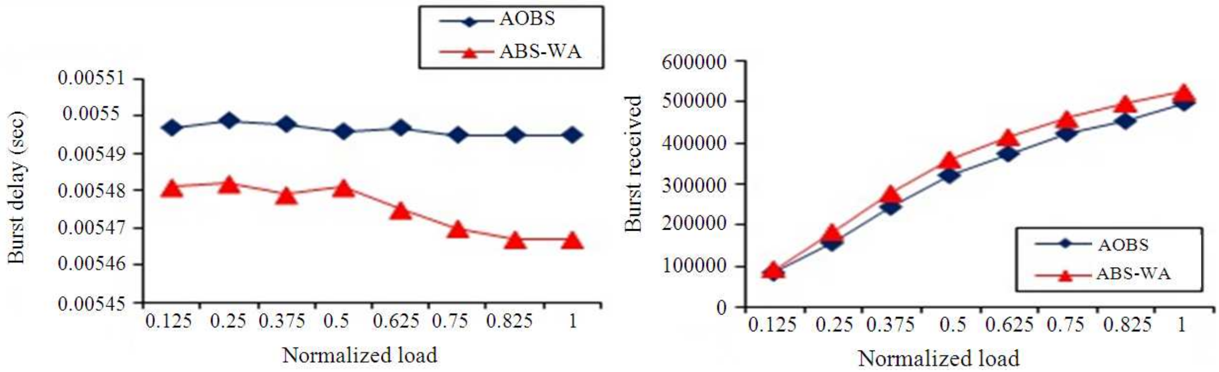


Fig. 2. Variation of Blocking Probability with normalized load

Even though number of wavelengths allocated for long traffic is lesser, the blocking probability for long traffic remains lower by 62 and 78% respectively in comparison to AOBS showing that this scheme provides more efficient use of wavelengths. AOBS allocates burst sizes based on total number of traffic flows in the network at a point of time and not on the load in the particular route whereas our technique allocates burst sizes based on connection time availability of the particular route at the particular instant of time and is hence more efficient.

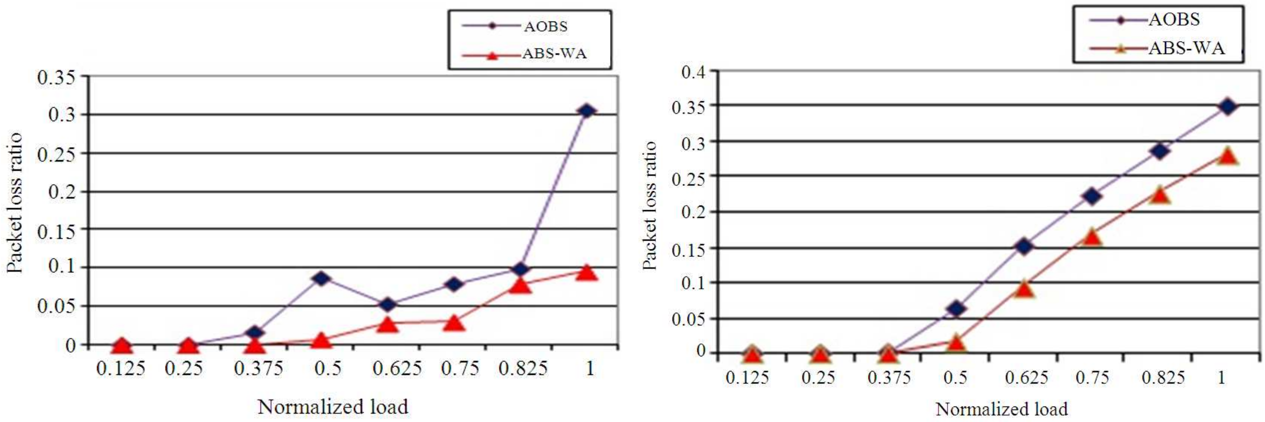
In comparison to AOBS scheme, the reduction in average end-to-end delay in short traffic using HMM ABS-WA is only 0.02% but the throughput ratio is larger in accordance with the trend observed in blocking probability (**Fig. 4**). For long traffic, a large reduction in delay by 78% is seen for HMM ABS-WA scheme (**Fig. 5**) which is another consequence of connection-time aware provisioning of ABS-WA scheme in comparison to the AOBS scheme of fixed increase in burst size based on number of active flows in the network.

For short term traffic the end to end delay is almost similar between HMM-TP and AOBS but there is 8% increase in throughput. For long term traffic the end to end delay for traffic flows in HMM-TP is much less over AOBS and thereby results in higher throughput for the proposed traffic prediction. This is due to that AOBS assigns fixed increase on burst size based on number of active links in the network but HMM-TP actively predicts the resource utilization on links and assigns burst size accordingly.



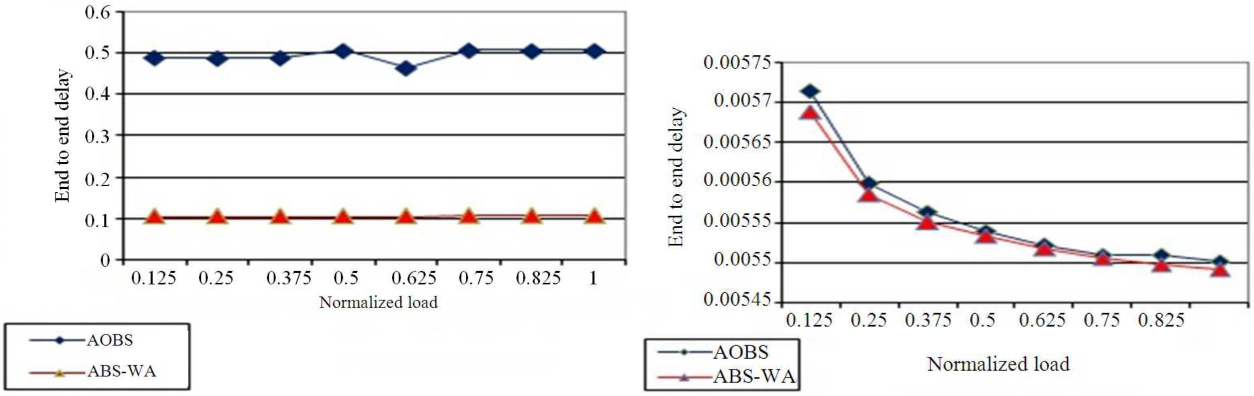
(a) (b)

Fig. 3. (a) Normalized Load Vs Burst Delay (b) Normalized Load Vs Burst received



(a) (b)

Fig. 4. Variation of loss ratio of packets with normalized load for (a) long traffic and (b) short traffic



(a) (b)

Fig. 5. End to end delay Traffic Characteristics for (a) long traffic (b) short traffic flows

6. CONCLUSION

This study, reports a study of using HMM based traffic prediction for both wavelength allocation and adaptive burst sizing technique on OBS network. Our technique also uses deflection routing technique to transmit the bursts through the optical network. HMM predicted link holding time has been used for adaptive burst sizing and for classification into short term flows which are assigned a separate set of wavelengths with larger number of channels set aside for short-term traffic. This method effectively increases throughput and reduces blocking probability when compared to AOBS reported earlier (Bonald *et al*., 2011). The improvement in the performance metrics of short-term traffic is mainly due to allocation of larger number of wavelength channels whereas those of long traffic is attributed to connection time aware burst sizing in each route. The proposed HMM predicted ABS-WA resource allocation method based on link holding time reduces the burst collision rate by more than 40% in comparison to previous work (AOBS scheme) leading to concomitant decrease in delay and improvement in throughput. Segregation of wavelengths for short bursts allows fast switching schemes to be employed preferentially for these wavelengths and slow but energy saving MEMS switching for long bursts enabling hybrid switching schemes to be implemented in each node. If the delays and throughput of the short bursts need to be improved, then one alternative is to use higher bit-rates selectively on these wavelengths. These schemes along with hybrid loss recovery has to be investigated further. Adaptive variation of number of wavelengths assigned depending on the dynamic changes in the short and long traffic ratios and the available number of data channels for the same network also needs further investigation.

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