Traffic Classification and Service in Wavelength Routed All-optical Networks

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***Abstract*— Wavelength routed all-optical networks require that continuous wavelengths be established from source to destination nodes if no wavelength converters exist in the network. The requests to establish these lightpaths can be blocked, depending on the availability of the wavelengths. It has been discovered that lightpaths of longer length suffer higher blocking probability than those of shorter lightpaths, which is known as the Fairness Problem. The Traffic Classification and Service (ClaServ) Method is introduced to optimize the Fairness Problem as well as reduce the traffic blocking probability. Simulation results for a 4x4 Mesh-Torus network and a NSFNET topology show that the ClaServ method can greatly reduce the blocking probability for average network traffic requests.**

***Keywords:* DWDM; all optical network; fairness; ClaServ; blocking probability; hierarchy; waveband**

I. INTRODUCTION

As the demand for bandwidth in the Internet increases, the need for all-optical networks becomes more apparent [1]. All-optical networks rely on photons being transmitted, rather than electrical pulses, allowing for faster transmission of data, and at larger quantities if DWDM is used. This requires that wavelengths be established end-to-end, creating a path between the source and destination for the photons to flow. This wavelength path is also called a lightpath.

For the wavelength routed all-optical networks, in the absence of wavelength converters, the same wavelength must be available on each link of the path for establishing a lightpath; this is known as the wavelength-continuity constraint [2]. In the following part of this article, we assume the networks for study satisfy this constraint.

The wavelength-continuity constraint requires that common wavelengths are established for the lightpath when a request is made at the source or destination. Traffic requests are a series of requests under a randomly arriving pattern. The traffic requests for establishing a lightpath between a source node and a destination node (s-d pair) randomly arrive to the network and require a random length of service time. The lightpaths' length (number of hops) may vary with the network topology. It has been studied in [3] that the traffic for requesting a longer lightpath suffers a higher blocking probability than the traffic for requesting a shorter lightpath because the number of interfering sessions on a path tends to increase with the number of hops. Our simulation results are shown in Fig. 1 for a 4x4 Mesh-Torus network with each link accommodating 240 wavelengths. Note that when the traffic load (Erlang) approaches 400, the traffic for establishing the 4-hop lightpath suffers more than 95% blocking probability while the traffic for establishing the 1-hop lightpath experiences no blocking probability. While no network administrator would allow such a high blocking probability, it is still interesting to observe this situation since it can happen under worst-case circumstances.

This phenomenon can be described as the Fairness Problem and can be defined as the inability of call requests of shorter lightpaths to have an equal blocking probability as call requests of longer lightpaths. The solution to this problem would be to equalize the blocking probability of call requests for both short and long lightpaths.

Two methods have been proposed to solve the Fairness Problem in [4]. In the Protecting Threshold Method (Thr), the single-hop traffic is assigned an idle wavelength only if the number of idle wavelengths on the link is equal to or above a given threshold. The Wavelength Reservation Method (Rsv) assigns a given wavelength on a specified link to a traffic arrival stream. The Thr method deteriorates the blocking probability of the calls for establishing single-hop lightpath as well as the average call blocking probability, but only slightly reduce the blocking probability of the calls for long lightpath.

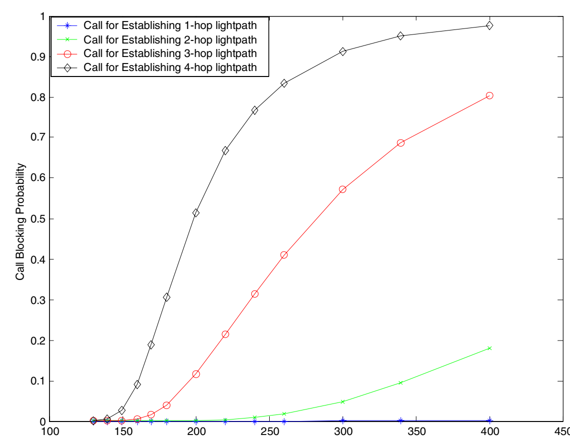

Figure 1. The blocking probability of the establishment of the lightpaths

The reason is that not only the amount but also the distribution of the single-hop lightpath on each link of the path causes the interference to the long lightpath. Not only the single-hop lightpath, but also other short lightpath can interfere with the long lightpath too.

Here we propose the traffic classification and service (ClaServ) method to optimize the Fairness Problem. The traffic requests are classified depending on the number of hops that are traversed from the source to the destination. These classified traffic requests are offered different levels of service to guarantee low blocking probability to optimize the Fairness Problem. To do so, all wavelengths on the link are equally separated into a set of wavebands, which are sorted and contain the same number of indexed wavelengths. Separating the wavelengths into wavebands can benefit the hierarchal searching of the available wavelengths to speed up the processing for the establishment of lightpaths in Dense Wavelength Division Multiplexing (DWDM) [5] Networks. The combination of the Waveband Access Range Method (WAR) and the Waveband Reservation Method (WRsv) is used to serve the classified traffic. Both WAR and WRsv assume that routing has been completed through a distributed routing protocol.

The remaining part of this article is arranged as follows. Section II introduces the classification of traffic. Section III introduces the WAR and the WRsv methods. The simulation results and performance evaluation are given in Section IV. Finally, conclusions are drawn in Section V.

II. TRAFFIC CLASSIFICATION

The traffic requests are classified by the number of hops they are going to traverse. The number of hops is also called the *type*, which is the classifier of the traffic. The traffic requests can be classified either at the source node or at the destination node. When classified at the source node, as traffic requests arrive, the source node checks the routing table to find the path to the destination and count the number of hops along this path. This number determines the *type* of the traffic. This first method is called *Source Traffic Classification*. When classified at the destination node, the traffic request maintains a counter that is incremented as the packet is sent from the source to the destination, along the predetermined path. Each intermediate node increments the counter when a request is received. The value of the counter at the destination node determines the *type* of the traffic. This method is called *Destination Traffic Classification*. Destination Traffic Classification can be implemented into distributed signaling protocols, such as the ones presented in [6]. Fig. 2 shows the process of classifying traffic as it arrives at the source node. Destination Traffic Classification is illustrated here. Fig. 2 (a) shows a request arriving at the source node. A path is found for the s-d pair. The source node generates a PROB packet and sends it toward the destination node along the path to collect wavelength availability information on the path. As shown in Fig. 2 (b), the PROB packet contains a counter field that is initialized to zero at the source node. Fig. 2 (c), shows the counter being incremented at each intermediate node and the destination node. Assuming that the value of the counter equals to N at the destination node, this traffic request's *type* is N-hop traffic.

III. WAVEBAND ACCESS RANGE AND WAVEBAND RESERVATION METHOD

The Waveband Access Range (WAR) and the Waveband Reservation (WRsv) methods are two methods that reduce the interference of the establishment of shorter lightpaths to longer lightpaths. A short lightpath may be considered a lightpath of 1-hop or 2-hops, whereas a long lightpath can be 3-hop, 4-hop or more. The following two subsections describe WAR and WRsv and show that both methods can improve the performance of the blocking probability and also optimize the fairness problem.

A. *Waveband Access Range Method*

The Waveband Access Range Method (WAR) is a method of assigning wavelengths to lightpath requests. This method involves the division of the set of wavelengths on a link into waveband access ranges. When requests arrive at the source or destination, the node will select a wavelength to assign to the lightpath. This wavelength will be selected from its respective wavebands, based on the request's *type*. Normally, the traffic with small number of hops has a smaller waveband access range than the traffic with large number of hops. For example, Fig. 3 shows K wavebands on each link. The 1-hop traffic requests can only access the first X wavebands. The 2-hop traffic can access the first Y wavebands. All the other type traffic can access all the K wavebands.

B. *Waveband Reservation Method*

The Waveband Reservation Method (WRsv) reserves wavebands to reduce the blocking probability of the establishment of longer lightpaths.

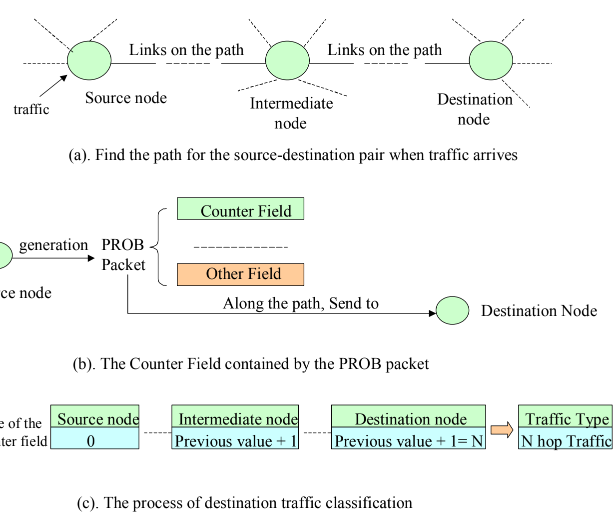

Figure 2. Destination Traffic Classification

Thus, one or more wavebands can be reserved for requests of large number of hops. The reserved wavebands are normally reserved for the traffic requests with longer lightpaths, and the shorter lightpaths are granted unreserved wavebands. The wavebands are organized as illustrated in Fig. 4. Wavebands 1 to K-2 are unreserved, whereas waveband K-1 is reserved for 3-hop and 4-hop lightpaths and waveband K is reserved for 4-hop lightpaths only. A request for longer lightpaths search unreserved wavebands first and are forced to compete with requests for shorter lightpaths. If no available wavelengths are found, then a search for wavelengths in the reserved wavebands is made. This allows the reserved waveband to be kept relatively free, if the need arises to use them when the other wavebands are used up by shorter lightpaths.

C. *The combination of the WAR and WRsv methods*

Both of the WAR and WRsv methods can be used at the same time to achieve the low blocking probability for all type of traffic. For the traffic with small number of hops, the WAR method limits their interference to other type of traffic. For the traffic with large number of hops, the WRsv method guarantees the low interference from other type of traffic. The combination of the WAR and WRsv methods serves the classified traffic to guarantee the degree of the interference one type of traffic received from other type of traffic or the degree of interference one type of traffic contributes to other type of traffic. In this way, the interference among the traffic is under control, the fairness can be achieved for all type of traffic.

IV. Simulation Results and Performance Evaluation

Simulation experiments have been used to evaluate the ClaServ Method and compared the networks' performance with and without employing the ClaServ Method. We used the OPNET Modeler as our simulation tool and compared the performance of the networks in two aspects (i) the fairness achievement, and (ii) the average call blocking probability. We studied the NSFNET Network, shown in Fig. 5, and the 4x4 Mesh Torus Network, shown in Fig. 6. Both networks have 1-hop, 2-hop, 3-hop, and 4-hop type of traffic requests. The networks have the following parameters. (i) Each link has 240 bi-directional wavelengths available when no lightpaths exist; (ii) The destinations of the lightpaths are equally distributed; (iii) The requests are random and follow a Poisson Distribution; (iv) The call holding time (lightpath duration) is exponentially distributed with a mean of one time unit; (v) The shortest path routing algorithms is used to allocate the path for the s-d pair; (vi) It is assumed that there is no delay between nodes; (vii) The Random wavelength assignment algorithm is used for assigning the wavelength to the path [7].

Fig. 7 shows that the 240 wavelengths on each link are separated into 8 wavebands with 30 wavelengths per waveband. To perform the ClaServ method, waveband 1, 2, 3, and 4 can be accessed by all type of traffic, waveband 5 and 6 can be accessed by 2-hop, 3-hop and 4-hop traffic, waveband 7 and 8 are reserved for 3-hop and 4-hop traffic.

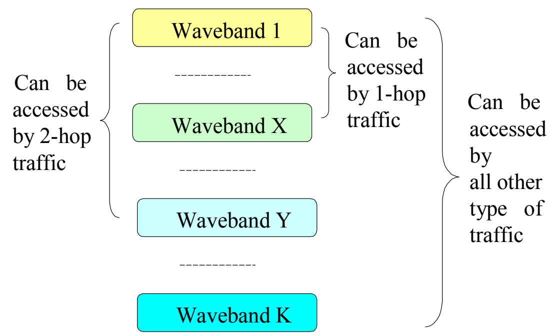

Figure 3. Waveband Access Range Method

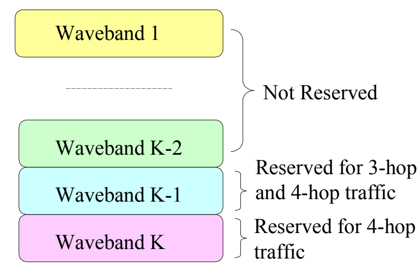

Figure 4. Waveband Reservation Method

Fig. 8 shows the blocking probability of the 4x4 Mesh-Torus network without the ClaServ method for traffic of four different types. Fig. 9 shows the same scenario with the ClaServ method implemented. It can be observed that by using the ClaServ method, with the wavebands divided as in Fig. 7, the blocking probability for 4-hop traffic requests was reduced 100 times and the blocking probability for 3-hop traffic was reduced by a factor of 4 times, when the traffic load was 150 calls per unit time. Notice that 2-hop traffic gets blocked more often when ClaServ is implemented. This follows the Fairness Problem and the solution, in that the blocking probability is equalized for all types of traffic. 1-hop traffic suffers a very low blocking probability and is almost too small to collect valid data.

Fig. 10 and 11 shows the NSFNET network's performance for all types of traffic without and with the use of the ClaServ methods respectively. It can be seen that in this asymmetric network, ClaServ improves the blocking probability for 4-hop traffic requests by a factor of 50 and by a factor of 2 for 3-hop traffic requests, when the traffic load was 95 calls per time unit. Note that 2-hop traffic requests have also increased when ClaServ is introduced, but is closer to the blocking probabilities of 3-hop and 4-hop traffic. 1-hop traffic suffers a very low blocking probability in this scenario and is too small to collect valid data.

Fig. 12 and 13 shows the comparison of the average traffic blocking probability with and without using the ClaServ method in the 4x4 Mesh-Torus network and NSFNET network respectively. Fig. 12 illustrates that when the traffic load is 150 calls per unit time in the 4x4 Mesh-Torus network, the

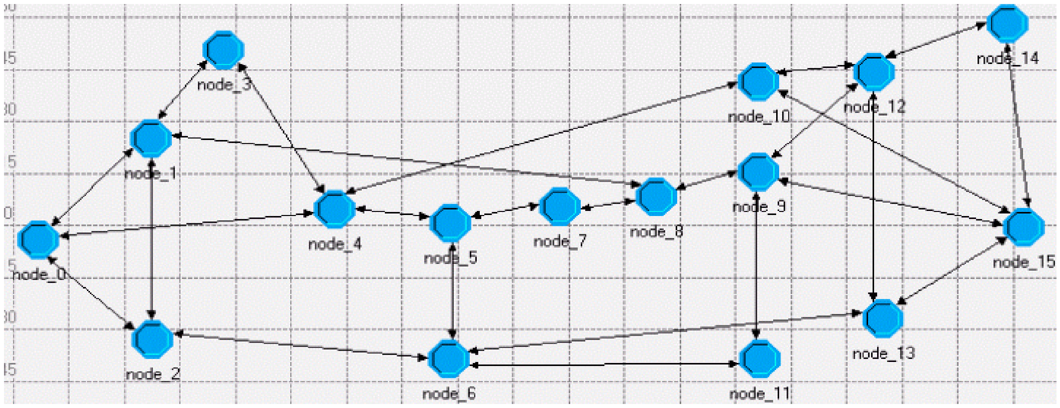

Figure 5. The NSFNET Network

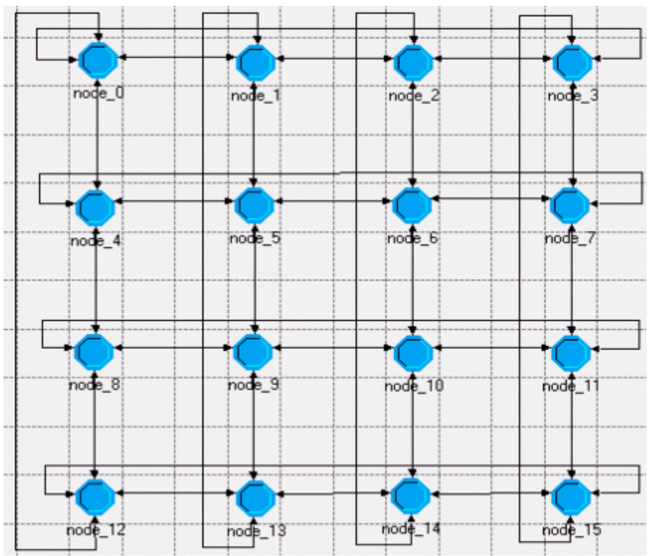

Figure 6. The 4*4 Mesh Torus Network

ClaServ method can reduce the average traffic blocking probability by a factor of 20. Fig. 13 shows that when the traffic load is 95 calls per unit time in the NSFNET network, the ClaServ method reduces the average traffic blocking probability by 10 times. Notice that at larger amount of traffic load, both ClaServ and non-ClaServ graphs converge to the same blocking probability.

From these graphs it can be observed that the ClaServ method optimizes the Fairness Problem by equalizing the blocking probabilities of 2-hop, 3-hop and 4-hop traffic when the network are required running under small traffic blocking probability (the practical situation). The network traffic experiences small blocking probability when the traffic load is low, as the traffic load increases, the ClaServ's optimization to the fairness problem declines. ClaServ also reduces the average blocking probability when the networks running under a small blocking probability for requests of varying number of hops.

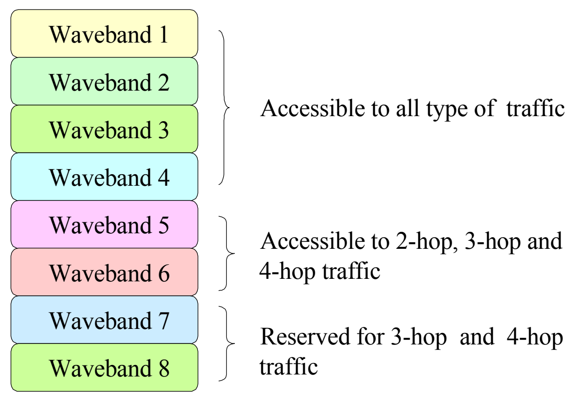

Figure 7. Waveband Access and Reservation for all type of traffic

V. CONCLUSION

As all-optical networks are deployed by carriers and ISPs, a growing concern will arise by customers that they will not get the same level of service for their lightpath establishment requests, due to the Fairness Problem. As the number of peers in an optical network grows in size, the difficulty to establish longer lightpaths to those peers will also increase. ClaServ has been shown to reduce and optimize the Fairness Problem, maximizing the usage of the wavelengths through the classification of traffic and the division of wavelengths into wavebands. Carriers and ISPs can benefit from using ClaServ to bring added value to their customers, by guaranteeing a more reliable method of establishing lightpaths to peers.

The simulation results show that when the small blocking probability is required, under a symmetric 4x4 mesh-torus topology, the ClaServ method can reduce the blocking probability 100 times for 4-hop traffic, 4 times for 3-hop traffic, and 20 times for the overall network traffic.

Under a asymmetric NSFNET topology, the ClaServ method can reduce the blocking probability 50 times for 4-hop traffic, 2 times for 3-hop traffic, and 10 times for the overall network traffic. The ClaServ method helps the 4x4 Mesh-Torus network and the NSFNET network achieve the fairness for four different types of traffic as well as reduce the average

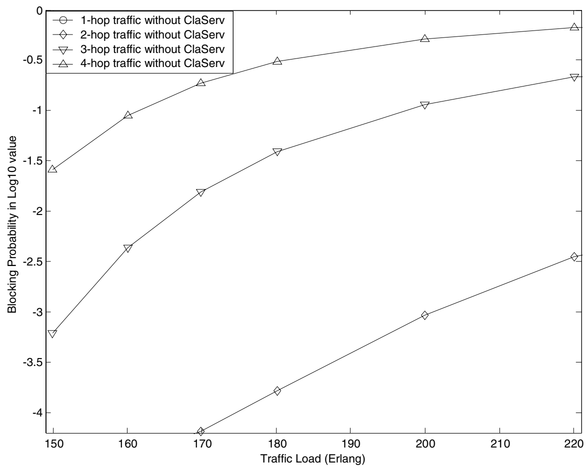

Figure 8. Mesh-Torus Network performance without using ClaServ Method

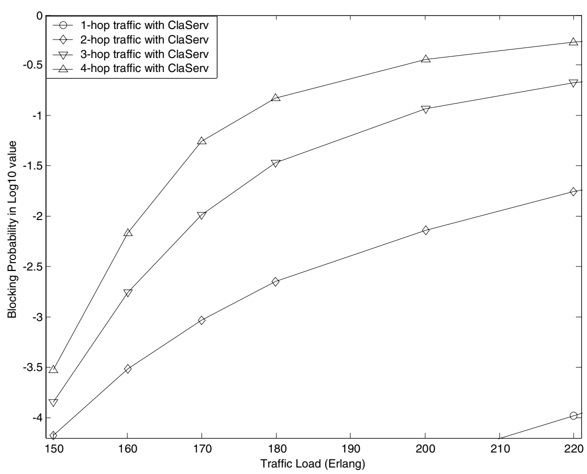

Figure 9. Mesh-Torus Network performance with using ClaServ Method

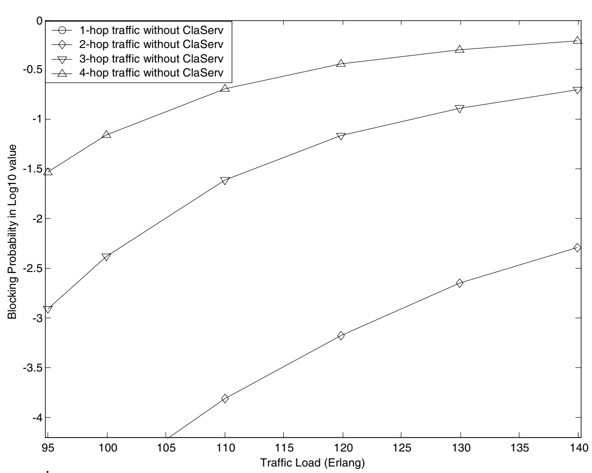

Figure 10. NSFNET Network performance without using ClaServ Method

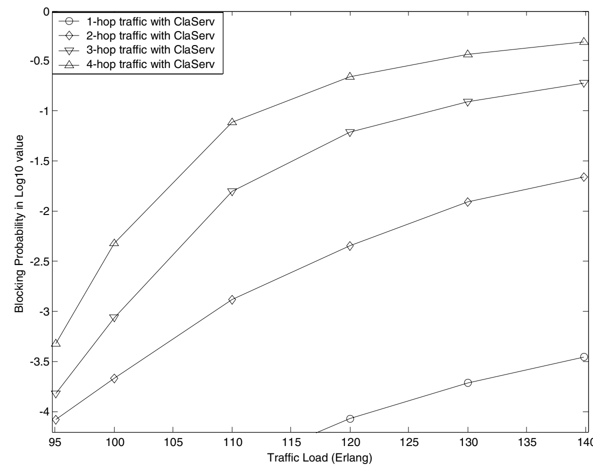

Fig. 11. NSFNET Network performance with using ClaServ Method

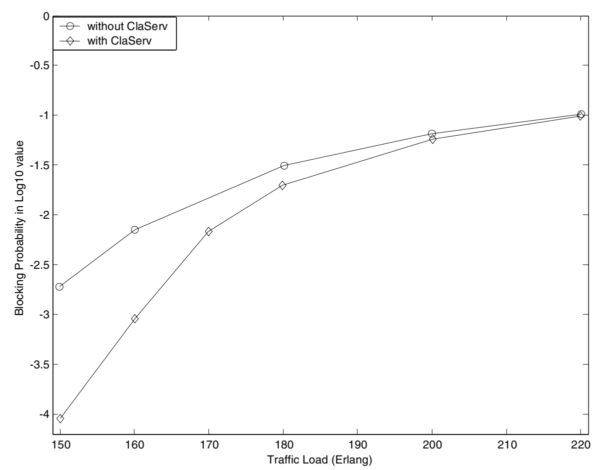

Fig. 12. The Average Traffic blocking probability in 4x4 Mesh-Torus network with and without using ClaServ Method

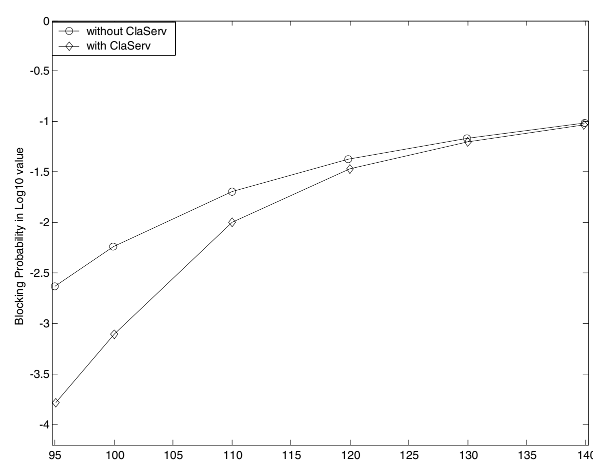

Fig. 13. The Average Traffic blocking probability in NSFNET network with and without using ClaServ Method

traffic blocking probability when both networks are required running under small traffic blocking probability.

The ClaServ method can be easily implemented into a distributed managed signaling protocol. The traffic can be classified either at the source node or at the destination node, different service for different traffic can be provided at the destination node with the combination of the waveband access range method and the waveband reservation method.

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