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High utilization-efficiency Multicast in Optical Benes Switching Structure

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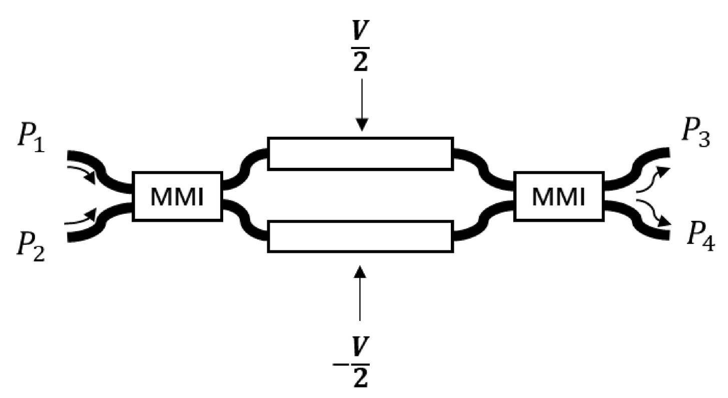
Introduction

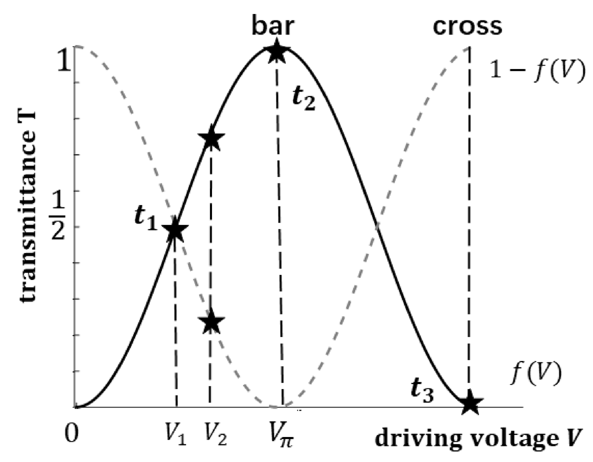
We propose a high utilization-efficiency multicast method that could improve the utilization of optical SEs and links in the structure, and moreover reduce the blocking probability of newly added switching requirements. In the proposed optical Benes structure, optical 2×2 SEs are adapted to variable output optical power by controlling the driving voltage. The routing algorithm of multicast switching paths in the structure is established based on the optimal selection of central optical switches.

High utilization-efficiency Multicast Method

The proposed 2×2 MZI optical SE that supports variable output optical power is shown in Fig.1(a). It is well known that the transmission of the MZI SE is the cosine function of the driving voltage, as shown in Fig.1(b). By adjusting the driving voltage applied to the SE, it's possible to detune any ratio of optical power at the two output ports. Based on the multicast of SEs, it is possible to implement the multicast of optical Benes switching structure that supports the routing from one input to multi outputs. The adjacency matrix is used to indicate the connection states between adjacent stages and calculate the connection states in a sequence of continuous stages. Define the adjacency matrix L_K that describes the connection states between the kth stage and the (k+1)th stage of Benes network. The specific definition is as Fig.1(c).



(a)



(b)

$$L_k = L(l_{ij}^k) = \begin{array}{c} \\ s_{1,k} \\ s_{2,k} \\ \vdots \\ s_{N/2,k} \end{array} \begin{array}{c} \begin{matrix} s_{1,k+1} & s_{2,k+1} & \cdots & s_{1,k+1} \end{matrix} \\ \begin{bmatrix} l_{11}^k & l_{12}^k & \cdots & l_{1,N/2}^k \\ l_{21}^k & l_{22}^k & \cdots & l_{2,N/2}^k \\ \vdots & \vdots & \ddots & \vdots \\ l_{N/2,1}^k & l_{N/2,2}^k & \cdots & l_{N/2,N/2}^k \end{bmatrix} \end{array}$$

(c)

Fig.1 (a) Structure of MZI; (b) Transmittance under driving voltage; (c) Definition of adjacency matrix

A multicast routing control method is proposed, which comprises the following steps: (a).calculate the matrix $X = L_1 \times L_2 \times \cdots \times L_{2n-2}$; (b). calculate the matrix $L_R = L_n \times L_{n+1} \times \cdots \times L_{2n-2}$; (c). Modify matrix Z so that there is at most one "1" in each column of the Z; (d). calculate the complete path of the multicast signal transmission in the Benes network; (e). calculate the control voltage matrix $V_{N/2\times(2n-1)}$ according to the established routing paths in the Benes network.

Adjust the control voltage on the relevant SE according to the control voltage matrix V to control the splitted optical power of each SE on the two output ports, which finally make the multicast signal output equal optical power after being routed in the Benes network.

$$X = \begin{array}{c} \\ s_{11} \\ s_{21} \\ s_{31} \\ s_{41} \\ s_{51} \\ s_{61} \\ s_{71} \\ s_{81} \end{array} \begin{array}{c} \begin{matrix} s_{17} & s_{27} & s_{37} & s_{47} & s_{57} & s_{67} & s_{77} & s_{87} \end{matrix} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 2 & 2 & 0 & 0 & 0 & 0 \\ 2 & 0 & 3 & 4 & 2 & 0 & 1 & 1 \\ 2 & 0 & 3 & 4 & 2 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 2 & 0 & 2 & 0 \\ 0 & 0 & 1 & 1 & 2 & 0 & 0 & 2 \\ 1 & 0 & 2 & 3 & 4 & 0 & 2 & 2 \\ 1 & 0 & 2 & 3 & 4 & 0 & 2 & 2 \end{bmatrix} \end{array}$$

(a)

$$L_R = \begin{array}{c} \\ s_{14} \\ s_{24} \\ s_{34} \\ s_{44} \\ s_{54} \\ s_{64} \\ s_{74} \\ s_{84} \end{array} \begin{array}{c} \begin{matrix} s_{17} & s_{27} & s_{37} & s_{47} & s_{57} & s_{67} & s_{77} & s_{87} \end{matrix} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 1 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 \end{bmatrix} \end{array}$$

(b)

$$Z = \begin{array}{c} \\ S_{24} \\ S_{34} \\ S_{84} \end{array} \begin{array}{c} \begin{matrix} S_{17} & S_{27} & S_{37} & S_{47} & S_{57} & S_{67} & S_{77} & S_{87} \end{matrix} \\ \begin{bmatrix} 0 & 0 & 1 & 1 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 \end{bmatrix} \end{array}$$

$$\Downarrow$$

$$Z = \begin{array}{c} \\ S_{24} \\ S_{34} \\ S_{84} \end{array} \begin{array}{c} \begin{matrix} S_{17} & S_{27} & S_{37} & S_{47} & S_{57} & S_{67} & S_{77} & S_{87} \end{matrix} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \end{array}$$

(c)

Input port/Switch	*Link path*	*Central Switch*	*Link path*	*Output Switch/port*
(I_6)S_{31}	→S_{22}→S_{13}→	S_{24}	→S_{25}→S_{36}→	S_{57}(O_9, O_{10})
			→S_{25}→S_{46}→	S_{87}(O_{15})
	→S_{22}→S_{33}→	S_{34}	→S_{35}→S_{16}→	S_{17}(O_2)
			→S_{35}→S_{26}→	S_{37}(O_5)
				S_{47}(O_7, O_8)
	→S_{62}→S_{73}→	S_{84}	→S_{85}→S_{86}→	S_{77}(O_{14})

(d)

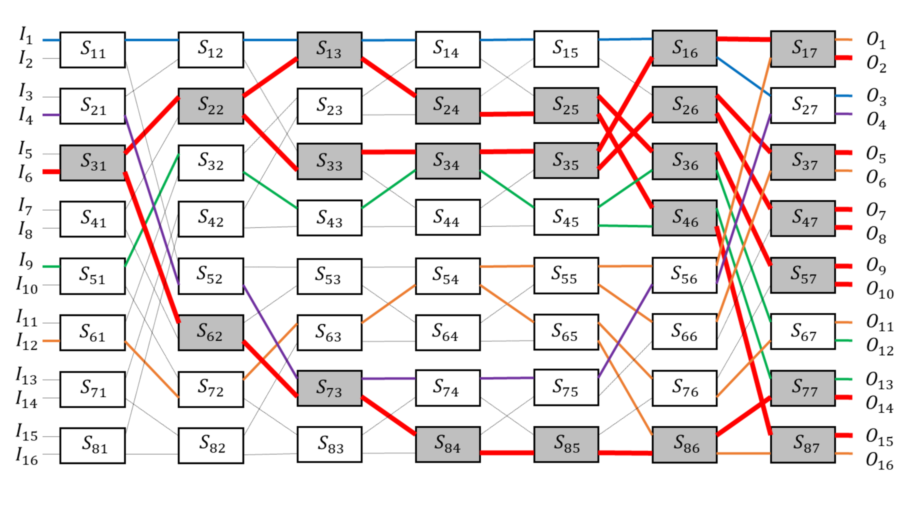
$$V = \begin{bmatrix} * & * & 1 & * & * & 1 & 0 \\ * & 0.45 & * & 0 & 0.39 & 0.61 & * \\ 0.23 & * & 0 & 1 & 0.33 & 1 & 1 \\ * & * & * & * & * & 0 & 0.5 \\ * & * & * & * & * & * & 0.5 \\ * & 0 & * & * & * & * & * \\ * & * & 1 & * & * & * & 1 \\ * & * & * & 0 & 1 & 0 & 1 \end{bmatrix}, (V_\pi)$$

(e)

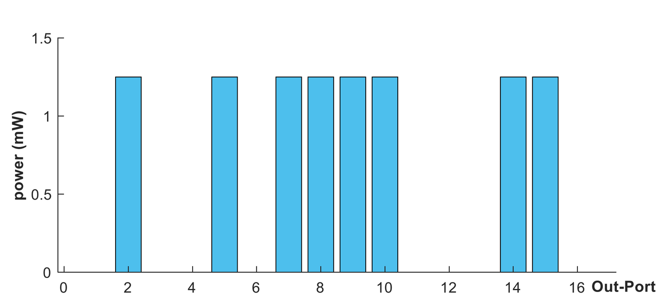
Fig.2 A specific implementation demo is used to illustrate the s process of the method. (a) Calculate the matrix X; (b) Calculate the matrix L_R; (c) Modify matrix Z; (d) Calculate the complete path; (e) Calculate the control voltage matrix $V_{N/2\times(2n-1)}$.

Results and conclusion

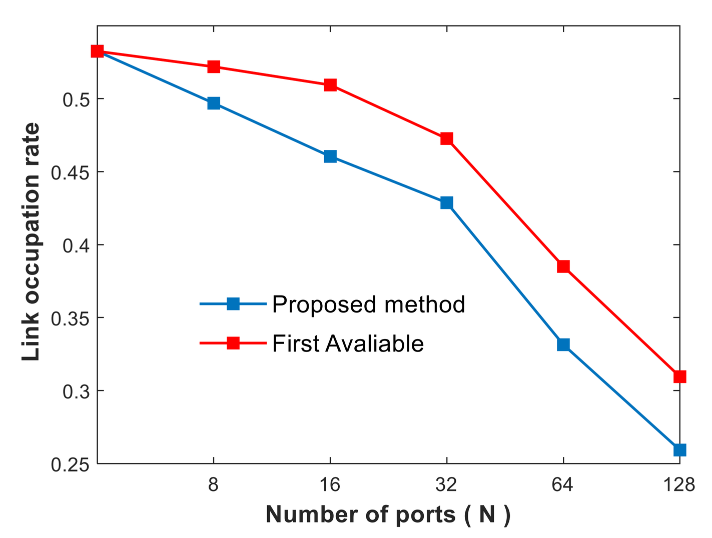
Fig.3(a) shows the result of multicast routing allocation on 16x16 Benes switching network. It can be seen from Fig.3(b) that adjusting the control voltage of each optical switch successfully makes the 1W input signal output equal 125mW at all destination ports. The simulation results are consistent with the theoretical results and indicating the correctness of the proposed multicast control method.



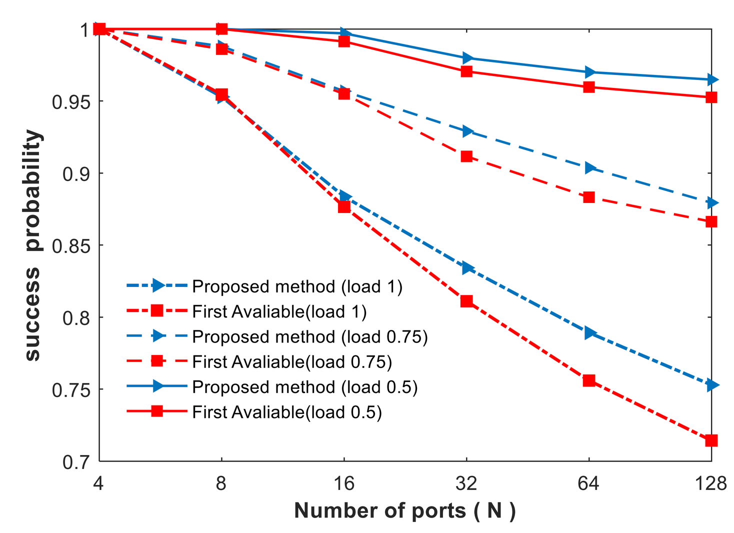
(a)



(b)



(c)



(d)

Fig.3 (a) Multicast routing distribution implementation; (b) The output power of output ports; (c) Link occupation rate with different ports; (d) Success probability with different ports.

Fig.3(c) shows, the link overhead of the proposed method is smaller than that of the First Avaliable method under different network sizes. And as the network size N increases, the link occupation rate of each method can be effectively reduced. Fig.3(d) proves that proposed method improves the success probability of multicast routing allocation compared with the First Avaliable method, which proves that optimization strategies can improve the success probability by increasing the number of idle links and this improvement becomes more obvious as the load further increases.

In conclusion, the proposed method can achieve high utilization-efficiency multicast in optical benes switching structure, and at the same time, the success probability of subsequent multicast routing allocation can be further improved.

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