Multicast Routing Algorithms for Sparse Splitting Optical Networks[1]

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1. C. K. Constantinou, K. Manousakis, G. Ellinas, "Multicast routing algorithms for sparse splitting optical networks," *Comput. Commun.*, vol. 77, pp. 100–113, Mar. 2016.

Outline

1. Background
2. Problem Statement
3. Existing and proposed heuristics
4. Numerical results
5. Conclusions

Background

- One-to-many multicast applications - data transmission from one source to multiple destinations
  - Telepresence, online teaching, ultra-high-definition TV delivery, video conferencing, etc.
- Optical multicasting is more spectrally efficient than IP multicasting^
- Current networks may not have full multicast capability – sparse splitting

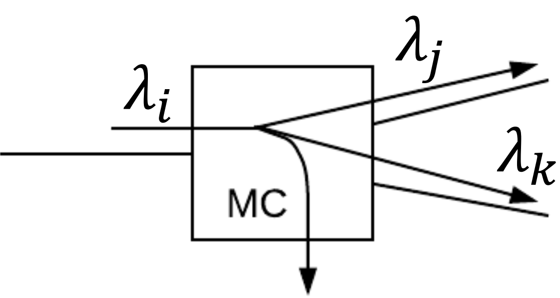
^ L. H. Sahasrabuddhe and B. Mukherjee, "Light-trees: optical multicasting for improved performance in wavelength routed networks," *IEEE Commun. Mag.*, vol. 37, no. 2, pp. 67-73, 1999.

Node Multicast Capabilities

- Multicast-capable (MC) node – an input signal going through it can be dropped locally and/or switched to one, many, or all of its output ports
- Multicast-incapable (MI) node
  - Drop-or-continue (DoC) – an input signal can be either dropped locally or switched to an output port
  - Drop-and-continue (DaC) – enhanced over DoC with extra capability that an input signal can be split into two copies, one dropped locally and the other switched to an output port

MC Node Architecture

Full wavelength conversion



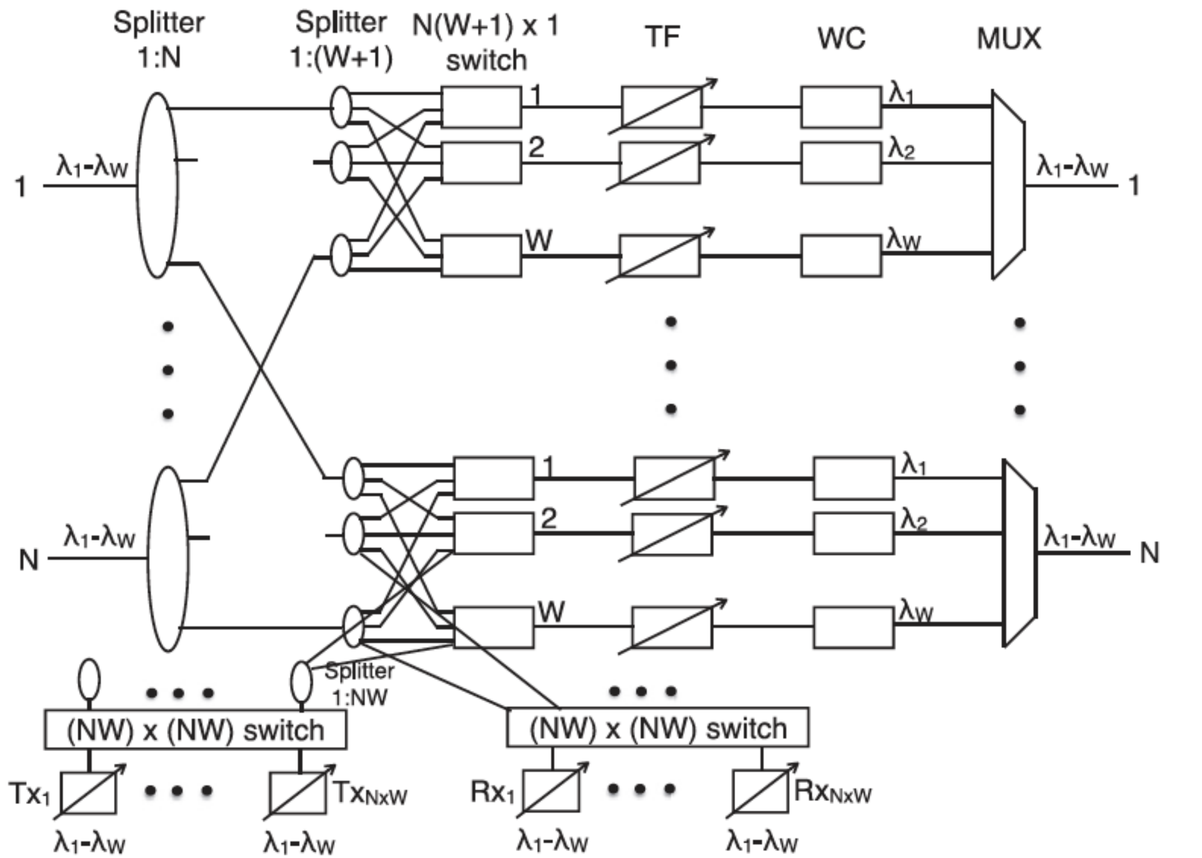
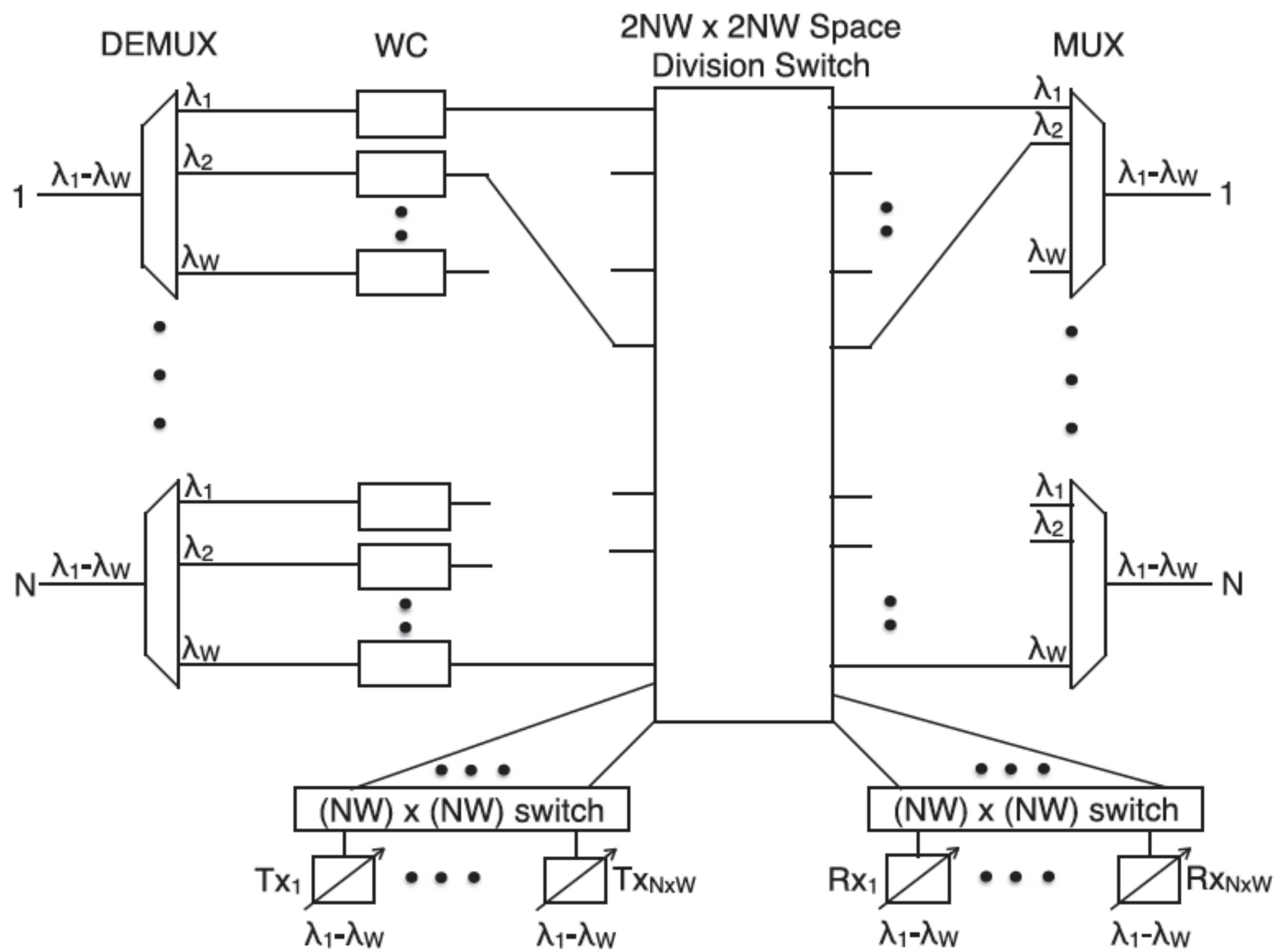


Fig. 1. MC node architecture utilized in the current work (adopted from [5]) (WC: wavelength converters, TF: tunable filters, *W* wavelengths per link, node degree *N*).

[5]. X. Zhang, J. Y. Wei and C. Qiao, "Constrained multicast routing in WDM networks with sparse light splitting," *J. Lightw. Technol.*, vol. 18, no. 12, pp. 1917–1927, 2000.

DoC Node Architecture



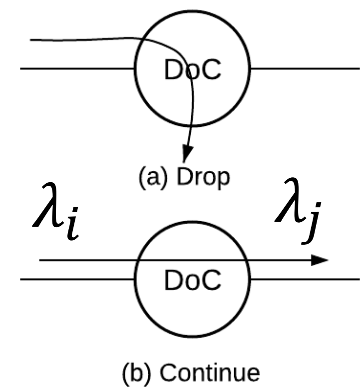


Fig. 2. MI (DoC) node architecture utilized in the current work (adopted from [5]) (WC: wavelength converters, W wavelengths per link, node degree N).

DaC Node Architecture

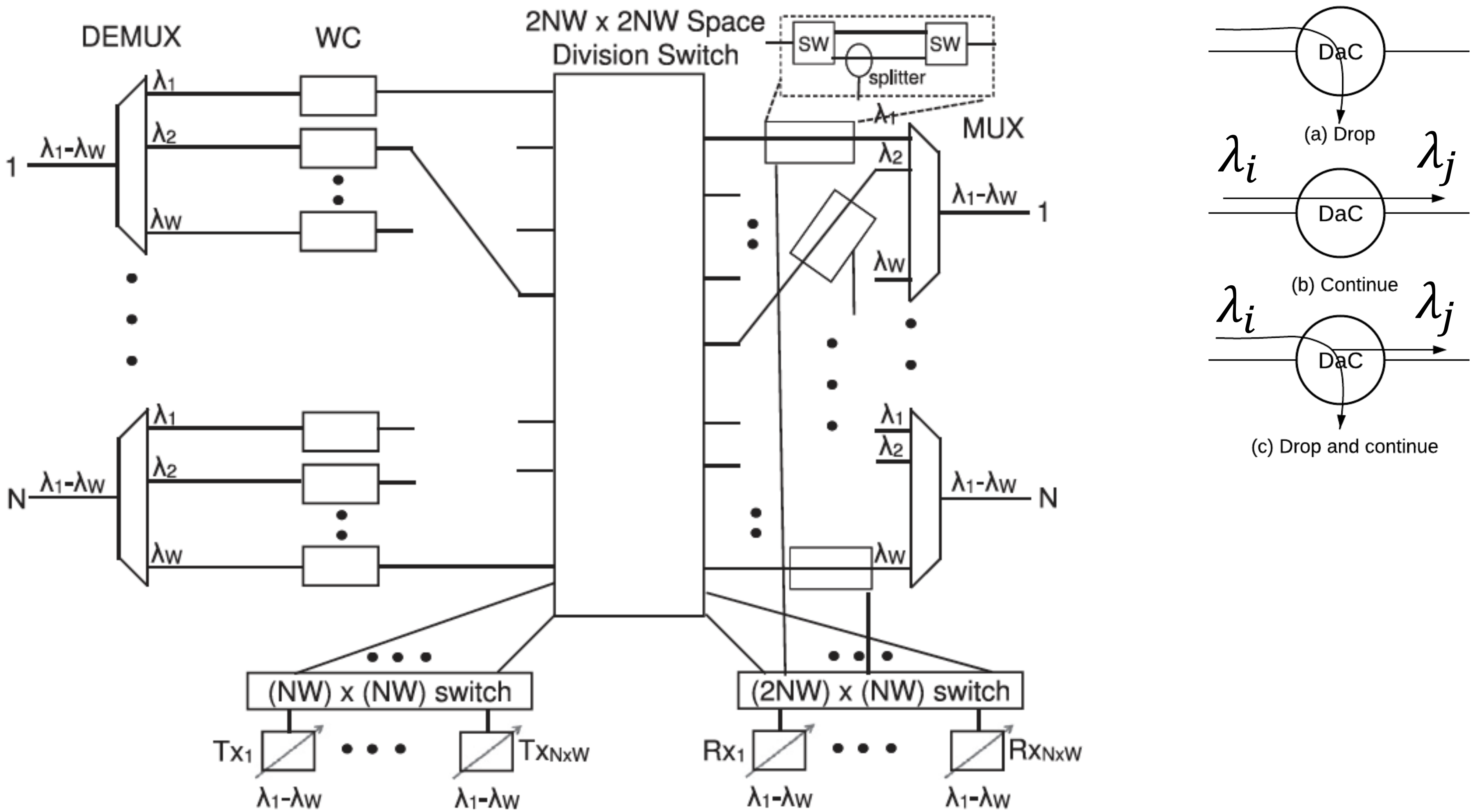
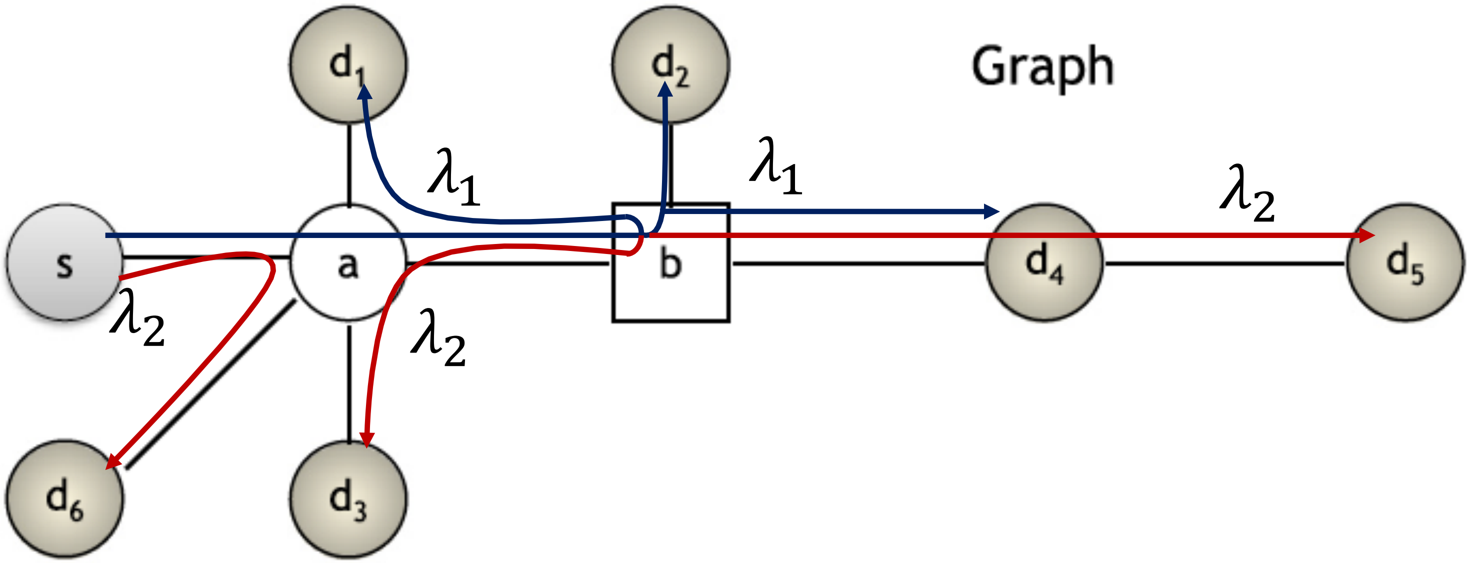


Fig. 3. MI (DaC) node architecture utilized in the current work (*WC*: wavelength converters, *SW*: switches, *W* wavelengths per link, node degree *N*).

Example of Multicast Session

- Routing Subgraph for a multicast session



Problem Statement

- Input
  - Network graph: $G=(V_G, A_G)$
  - Full wavelength conversion in each node
  - c_{ij}: the cost of arc $[i, j]$ in A_G
  - Number of wavelengths on each network fiber (arc): W
  - Set of MC nodes: MC_{set}
  - Multicast session consisting of a source and k destinations: $S, S = \{s, D\} = \{s, d_1, d_2, \dots, d_k\}$
- Output – routing subgraph $RSG = (V_{RSG}, A_{RSG})$ with the minimum cost

Existing Heuristics

- DaC networks – DaC and MC nodes
  - Member-only (MO)
    - No cycles permitted -> high cost
- DoC networks – DoC and MC nodes
  - On-tree MC node first (OTMCF) [21]
    - Connect MI destinations to the closest MC nodes
    - Connect source to the MC nodes and MC destinations
  - Nearest MC node first (NMCF) [21] – reversed procedure to OTMCF
  - Multicasting using splitters (MUS) [22]
    - Improvement over NMCF

[21]. C. Y. Hsieh and W. Liao, "All-optical multicast routing in sparse splitting WDM networks," *IEEE J. Sel. Areas Commun.*, vol. 25, no. 6, pp. 51–62, 2007.
[22]. S. Cho, T. J. Lee, M. Chung, and H.Choo, "Minimum cost multicast ro uting based on high utilization MC nodes suited to sparse-splitting optical networks," in *Proc. ICCSA*, 2006.

Proposed Heuristics

- MPH* - based on minimum path heuristic (MPH)
- Sparse-splitting multicast routing heuristic (SSMRH)

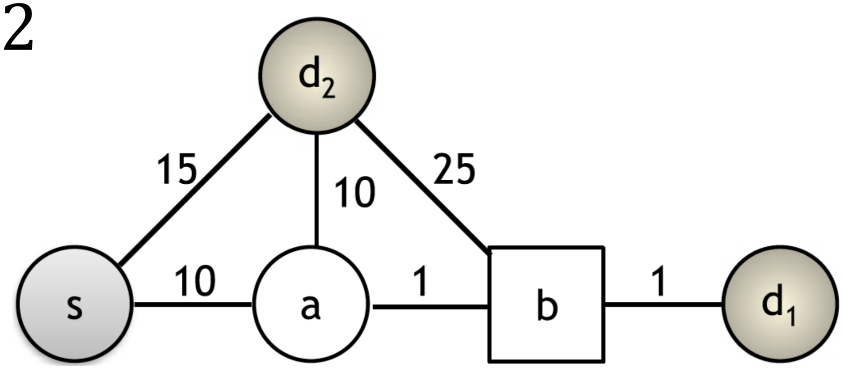
MPH*

1. $RSG = (V_{RSG}, A_{RSG}) = (\{s\}, \emptyset)$, $X = \{s\}$, $Y = D$, $c = 0$
   $\forall i, j \in V_G$: $w_{ij} = 0$
2. $\forall v' \in D, v'' \in V_G$: Calculate $P_{v'v''} \rightarrow$ Derive $P_{v''v'}$ by reversing the arcs of $P_{v'v''}$
3. While $(Y \neq \emptyset)$
   (a) Find $P_{uv}, u \in X, v \in Y$: $c_{P_{uv}} \leq c_{P_{u^*v^*}}, \forall u^* \in X, v^* \in Y$
   (b) $\forall v' \in V_{P_{uv}}$: If $(v' \in MC_{set})$ $X \leftarrow X \cup \{v'\}$
   (c) If $(DaC = 1)$
      (1) $X \leftarrow X \cup \{v\}$
      (2) If $(u \notin MC_{set})$ $X \leftarrow X/\{u\}$
   (d) $RSG \leftarrow RSG \cup P_{uv}$
   (e) $c \leftarrow c + c_{P_{uv}}$
   (f) $\forall [v', v''] \in A_{P_{uv}}$: $w_{ij} \leftarrow w_{ij} + 1$
   (g) $Y \leftarrow Y/\{v\}$

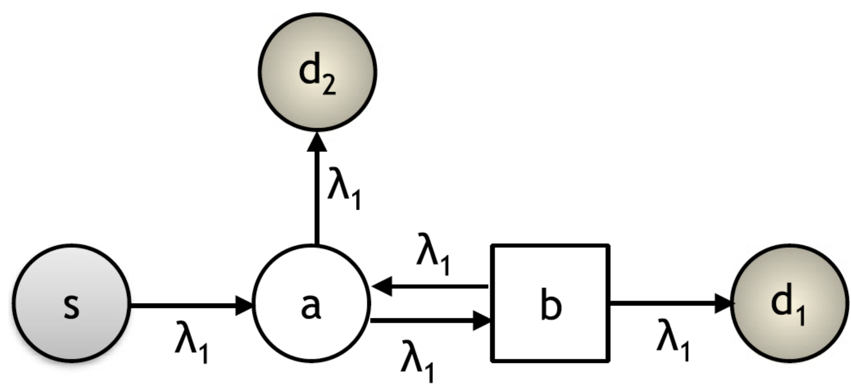
DoC Network Example of MPH*

- $X = \{s\}, Y = \{d_1, d_2\}, c = 0$
- $P_{d_1 s} = d_1 \to b \to a \to s, c_{P_{d_1 s}} = 12$
- $P_{d_2 s} = d_1 \to s, c_{P_{d_2 s}} = 15$
- Select $P_{sd_1}, c = c + c_{P_{sd_1}} = 12$
- $X = \{s, b\}, Y = \{d_2\}, c = 12$
- $P_{d_2 s} = d_1 \to s, c_{P_{d_2 s}} = 15$
- $P_{d_2 b} = d_2 \to a \to b, c_{P_{d_2 b}} = 11$
- Select $P_{bd_2}, c = c + c_{P_{bd_2}} = 23$
- $X = \{s, b\}, Y = \emptyset, c = 23$

Network



RSG



Other Examples

- MPH∗ as well as the existing algorithms have improved performance *if specific MC nodes are added in the destination set*

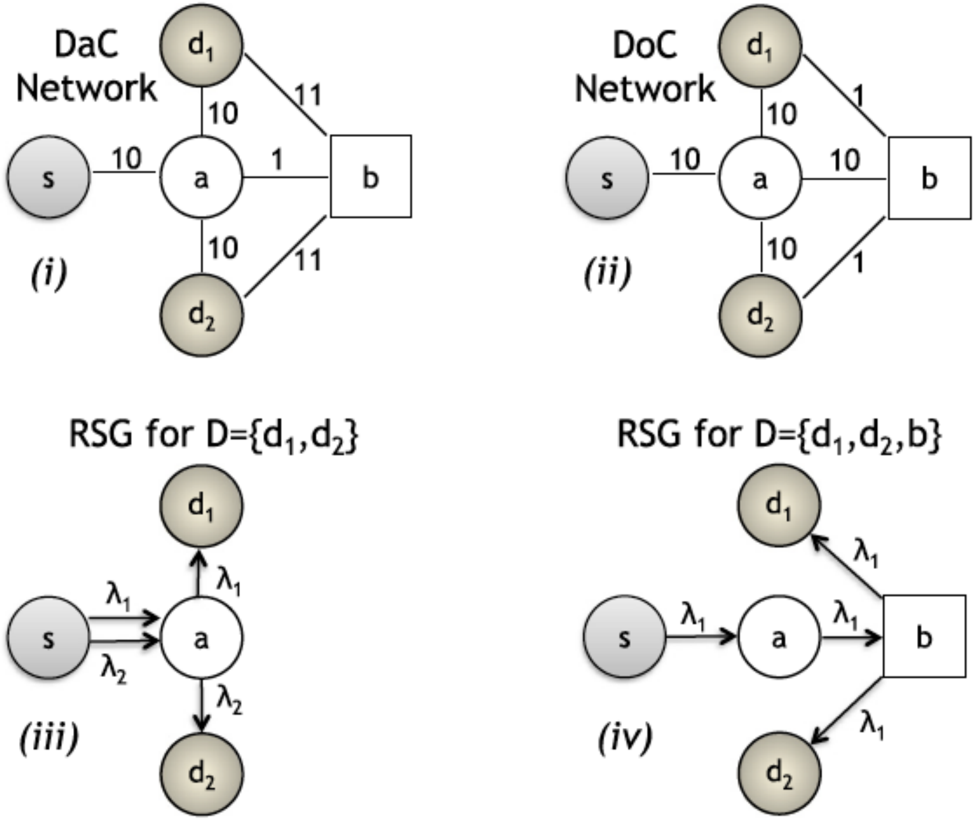


Fig. 8. Improving the performance of MPH* by adding an MC node in the destination set.

SSMRH

1. $X = D$
2. Apply *base* heuristic for destination set X: $\rightarrow RSG, c, w_{ij}\ \forall i, j \in V_G$
3. $\forall u \in MC_{set}$ and $u \notin V_{RSG}$:
   (a) $X \leftarrow X \cup \{u\}$
   (b) Apply *base* heuristic for destination set X: $\rightarrow$ $RSG\{u\}$, $c\{u\}$, $w_{ij}\{u\}\ \forall i, j \in V_G$
   (c) $X \leftarrow X / \{u\}$
4.
   (a) Find $v \in MC_{set}$ and $v \notin V_{RSG}$: $c\{v\} \leq c\{v^*\}$, $\forall v^* \in MC_{set}$ and $v^* \notin V_{RSG}$
   (b) If $c\{v\} \geq c$, Stop. Else Continue
5. $RSG = RSG\{v\}$, $c = c\{v\}$, $w_{ij} = w_{ij}\{v\}\ \forall i, j \in V_G$
6. $X \leftarrow X \cup \{v\}$
7. Return to Step 3

Test Conditions

- Test networks: USNET, NSFNET, and 18 randomly created networks
- Link cost varies from 1 to 1000
- Different k, the number of destinations and different z, the number of MC nodes which are placed at the nodes that have the largest degree^
- 500 multicast sessions
- MO and MUS were modified to support both networks while OTMCF and NMCF were applied without any changes

^ S. W. Wang, "Allocation of light splitters in all-optical WDM networks with sparse light splitting capabilities," *Telecommun. Syst.,* vol. 52, no. 1, pp. 261–270, 2013.

Performance Metrics

$$c_H^S = \sum_{[i,j] \in A_{RSG_H^S}} w_{ij}^{H,S} c_{ij} \qquad \bar{c}_H = \frac{1}{l} \sum_i c_H^{S_i} \quad i = 1, \ldots, l$$

$$I_H = 100 \times \frac{\bar{c}_H - \bar{c}_{opt}}{\bar{c}_{opt}}$$

$$SO_H = 100 \times \frac{\text{number of suboptimal } RSG\text{ s}}{500}$$

- I_H is the extra average cost of heuristic H compared to the optimum
- SO_H is the percentage of the cases where heuristic H fails to find the optimal solution

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Numerical Results

- SSMRH performs the best for all cases and close to optimum
- SSMRH performs the best in terms of the percentage of the derived optimal solutions

Evaluation on the USNET graph.

	z	k	$\overline{c}_{opt}$	$\overline{c}_{MUS}$	$\overline{c}_{SSMRH}$	I_{MUS}	I_{SSMRH}	SO_{MUS}	SO_{SSMRH}
	4	3	7204,6	7452,3	7205,3	3,44	0,01	26,4	0,4
		6	12454,2	12902,9	12462,0	3,60	0,06	44,4	3,2
		9	16972,7	17466,2	16985,6	2,91	0,08	51,4	6,0
		12	21408,8	21881	21422	2,20	0,06	56,4	3,6
	8	3	6477,1	6679,2	6483,4	3,12	0,10	35,6	2,0
		6	10227,2	10614,0	10244,6	3,78	0,17	53,2	6,2
DoC		9	13178,0	13607,5	13197,5	3,26	0,15	62,2	10,8
		12	15908,6	16360	15924	2,83	0,09	70,6	9,2
	12	3	6182,0	6378,5	6184,0	3,18	0,03	37,8	1,6
		6	9295,3	9682,3	9310,7	4,16	0,17	58,4	5,8
		9	11680,2	12206,4	11692,1	4,51	0,10	70,2	5,8
		12	13773,5	14334	13784	4,07	0,07	67,8	5,2
		Avg	**12063, 5**	**12463, 7**	**12074, 6**	**3, 42**	**0, 09**	**52, 87**	**4, 98**
	4	3	6205,5	6340,2	6211,6	2,17	0,10	23,4	2,2
		6	9303,9	9804,6	9383,4	5,38	0,85	57,4	18,8
		9	11484,2	12286,0	11686,9	6,98	1,77	79,0	45,4
		12	13397,2	14505	13749	8,27	2,63	90,0	63,6
	8	3	6127,7	6317,7	6129,4	3,10	0,03	35,6	1,4
		6	9113,5	9622,5	9144,3	5,59	0,34	67,6	10,6
DaC		9	11183,2	12002,4	11273,4	7,33	0,81	85,6	29,6
		12	13011,2	14168	13161	8,89	1,15	95,0	46,6
	12	3	6043,7	6214,7	6044,2	2,83	0,01	37,2	0,6
		6	8921,1	9276,1	8927,9	3,98	0,08	66,8	3,2
		9	10927,3	11441,6	10940,9	4,71	0,12	79,2	6,8
		12	12681,8	13271	12700	4,65	0,14	83,4	12,2
		Avg	**9866, 7**	**10437, 5**	**9946, 0**	**5, 3**	**0, 7**	**66, 7**	**20, 1**

Numerical Results (Cont.)

Table 2
Evaluation on the NSFNET graph.

	z	k	$\bar{c}_{opt}$	$\bar{c}_{existing}$	$\bar{c}_{SSMRH}$	$I_{existing}$	I_{SSMRH}	$SO_{existing}$	SO_{SSMRH}
	3	2	3499,2	3595,8 (MUS)	3499,2	2,76	0,00	11,60	0,00
		4	5949,9	6388,2 (MUS)	5949,9	7,37	0,00	34,20	0,00
		6	8044,8	8674,5 (MUS)	8046,0	7,83	0,01	38,60	0,40
		8	9837,0	10516,5 (MUS)	9838,2	6,91	0,01	31,20	0,20
	6	2	3335,4	3408,6 (MUS)	3335,4	2,19	0,00	11,60	0,00
		4	5386,2	5655,3 (OTMCF)	5388,0	5,00	0,03	37,20	0,40
DoC		6	6884,7	7044,6 (OTMCF)	6887,4	2,32	0,04	34,40	1,00
		8	8094,6	8237,4 (OTMCF)	8096,4	1,76	0,02	33,40	0,40
		Avg	**6379, 0**	**6690, 1**	**6380, 1**	**4, 52**	**0, 01**	**17, 04**	**0, 30**
	3	2	3202,5	3286,5 (MUS)	3202,5	2,62	0.00	14,60	0,00
		4	4776,9	5123,7 (MUS)	4789,8	7,26	0,27	42,80	4,40
		6	5904,0	6508,8 (MO)	5937,3	10,24	0,56	63,60	11,20
		8	6767,1	7584,6 (MO)	6837,0	12,08	1,03	73,20	20,60
	6	2	3185,4	3285,3 (MUS)	3185,4	3,14	0.00	19,00	0,00
		4	4732,2	5115,3 (MUS)	4737,6	8,10	0,11	53,40	2,00
DaC		6	5828,7	6266,7 (MO)	5841,0	7,51	0,21	62,00	5,00
		8	6636,9	7174,2 (MO)	6675,6	8,10	0,58	70,60	15,40
		Avg	**5129, 2**	**5543, 1**	**5150, 8**	**7, 38**	**0, 35**	**49, 90**	**7, 33**

Performance Metrics (Cont.)

$$\mathcal{I}_H^j = \frac{1}{3}\sum_i \left(100 \times \frac{\bar{c}_H^j[i] - \bar{c}_{SSMRH}^j[i]}{\bar{c}_{SSMRH}^j[i]}\right), \quad i = \frac{n}{10}, \frac{2n}{10}, \frac{3n}{10}$$

$$\mathcal{J}_H = \frac{1}{18}\sum_j \mathcal{I}_H^j, \quad j = 1, \ldots, 18$$

- $\mathcal{I}_H^j$ gives the average value of the % relative increase of the average cost compared to SSMRH for heuristic H and network *j*
- $\mathcal{J}_H$ is the average value of $\mathcal{I}_H^j$ over all randomly created networks

Numerical Results (Cont.)

- SSMRH performs best
- For the base heuristics of DoC case, OTMCF and MUS have the best performance
- For the base heuristics of DaC case, MPH* gives results closer to the ones obtained by SSMRH

Table 3
Evaluation on the randomly created networks.

		z	$\mathcal{J}_{MO}$	$\mathcal{J}_{MPH^*}$	$\mathcal{J}_{OTMCF}$	$\mathcal{J}_{NMCF}$	$\mathcal{J}_{MUS}$
DoC	**Act. cost**	$\frac{n}{10}$	72,12	14,25	6,26	33,64	9,60
		$\frac{2n}{10}$	76,41	10,63	6,77	23,64	6,87
		$\frac{3n}{10}$	72,27	8,66	6,58	15,71	5,56
		Avg	**73,60**	**11,18**	**6,54**	**24,33**	**7,34**
	W. usage	$\frac{n}{10}$	39,33	15,14	8,47	25,10	11,06
		$\frac{2n}{10}$	41,03	11,54	8,97	19,57	8,02
		$\frac{3n}{10}$	39,96	8,89	10,59	14,03	6,25
		Avg	**40,11**	**11,86**	**9,34**	**19,57**	**8,44**
DaC	**Act. cost**	$\frac{n}{10}$	17,45	3,11	28,91	61,81	4,56
		$\frac{2n}{10}$	13,22	3,54	20,37	39,24	5,87
		$\frac{3n}{10}$	9,97	3,46	16,29	26,20	5,97
		Avg	**13,55**	**3,37**	**21,86**	**42,42**	**5,47**
	W. usage	$\frac{n}{10}$	8,16	2,70	40,80	61,67	5,75
		$\frac{2n}{10}$	6,81	3,41	27,88	40,22	7,52
		$\frac{3n}{10}$	6,29	3,62	23,75	27,59	7,59
		Avg	**7,09**	**3,24**	**30,81**	**43,16**	**6,96**

Conclusions

- Investigated the problem of multicast routing for DaC and DoC networks with sparse-splitting capabilities
- Proposed ILP formulation and heuristics
  - The proposed algorithms achieve an important decrease of the average cost of the derived solutions, compared to existing algorithms
  - The proposed algorithms obtain the optimal solution for the majority of the investigated cases

Thank you.

Questions or comments?

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