Karlsruhe Institute of Technology

Master-Thesis

High Quality Hypergraph Partitioning via Max-Flow-Min-Cut Computations

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Contents

1 Experimental Results

1.1 Flow Algorithms and Networks

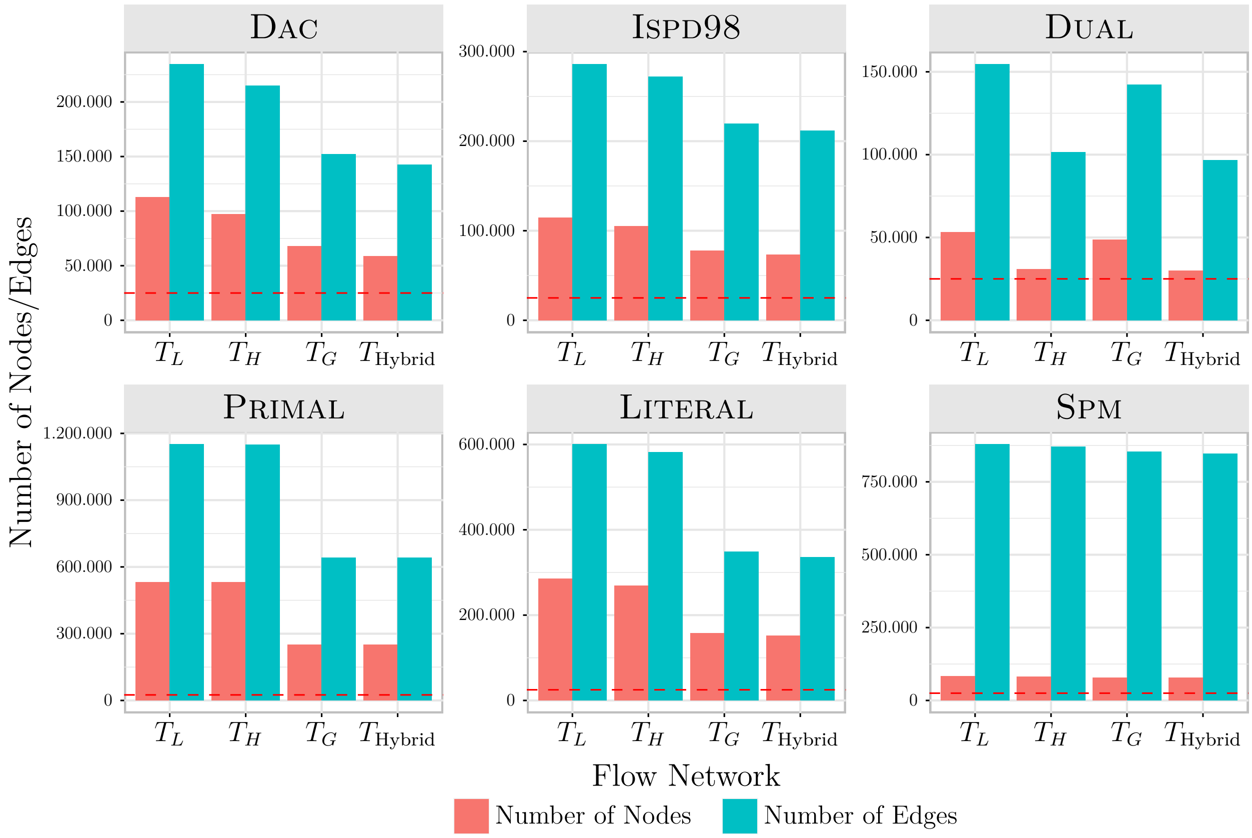

Figure 1: Comparison of the number of nodes and edges induced by flow problems of size $|V'| = 25000$ on our flow networks for different benchmark types. The red dashed lines indicates 25000 nodes.

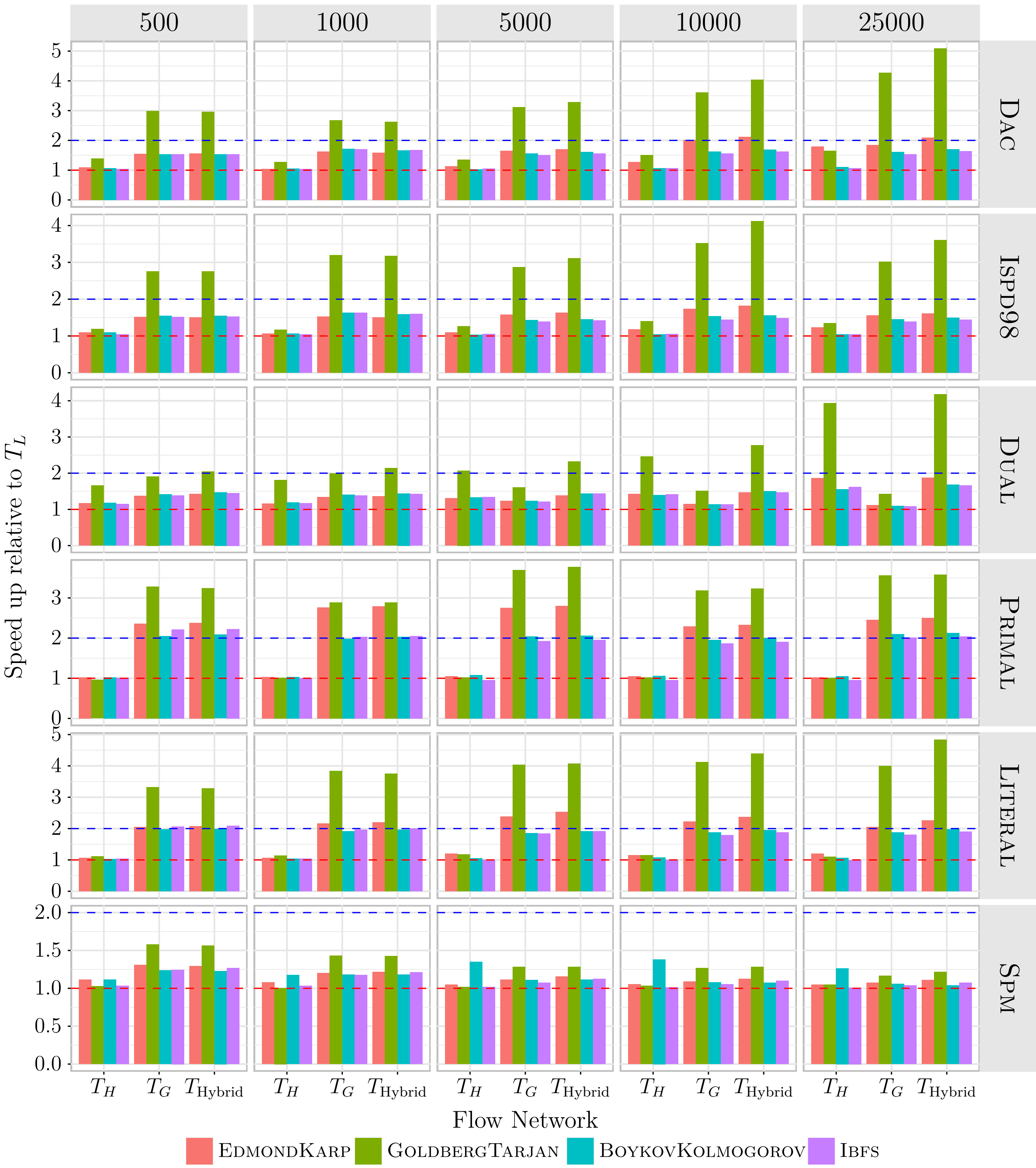

Figure 2: Speed-ups of the flow algorithms on different flow networks relative to execution on T_L for different problem sizes and types. The red resp. blue dashed line indicate a speed-up of 1 resp. 2.

$\|V'\|$	Ibfs $t[ms]$	BoykovKolmogorov $t[\%]$	GoldbergTarjan $t[\%]$	EdmondKarp $t[\%]$
500	0.81	1.79	24.56	**-7.36**
1000	**1.91**	12.92	26.88	13.90
5000	**13.52**	38.11	63.68	108.43
10000	**28.40**	53.52	92.56	182.79
25000	**64.18**	50.19	95.25	157.03

Table 1: Average running times of our maximum flow algorithms on flow network T_{Hybrid}. Note, all values in the table are in percentage relative to the running time of the Ibfs algorithm. In each line the fastest variant is marked bold.

Instance	$\|V'\|$	Ibfs $t[ms]$	BoykovKolmogorov $t[\%]$	GoldbergTarjan $t[\%]$	EdmondKarp $t[\%]$
All	500	0.81	1.79	24.56	**-7.36**
	1000	**1.91**	12.92	26.88	13.90
	5000	**13.52**	38.11	63.68	108.43
	10000	**28.40**	53.52	92.56	182.79
	25000	**64.18**	50.19	95.25	157.03
Dac	500	0.29	−10.46	11.79	**-34.02**
	1000	0.71	−9.51	18.18	**-35.86**
	5000	5.16	−5.94	12.21	**-17.03**
	10000	10.23	**-1.30**	33.46	32.26
	25000	**26.05**	2.14	112.29	67.77
Ispd98	500	0.42	−11.77	23.10	**-13.55**
	1000	0.98	−11.76	14.61	**-12.01**
	5000	7.33	**-1.06**	65.21	41.04
	10000	**15.19**	5.27	209.29	164.02
	25000	**41.50**	15.04	782.45	525.31
Dual	500	0.24	−12.17	1.24	**-42.11**
	1000	0.51	−11.40	3.32	**-43.34**
	5000	3.41	−7.46	7.30	**-43.50**
	10000	6.65	−2.56	21.99	**-37.53**
	25000	15.63	3.86	65.81	**-17.12**
Primal	500	**1.45**	24.48	58.97	143.23
	1000	**3.51**	22.79	66.63	200.62
	5000	**26.34**	23.07	122.09	589.46
	10000	**48.87**	14.37	110.18	484.42
	25000	**102.32**	17.38	237.90	852.30
Literal	500	**0.66**	0.55	61.36	38.80
	1000	**1.63**	8.06	51.86	84.71
	5000	**11.55**	13.41	94.09	227.94
	10000	**25.28**	14.81	130.87	375.89
	25000	**55.67**	7.27	125.34	367.70
Spm	500	1.60	3.50	8.07	**-39.46**
	1000	3.79	34.29	14.28	**-14.95**
	5000	**26.30**	121.86	65.34	105.19
	10000	**60.57**	196.95	103.28	256.18
	25000	**140.35**	169.78	14.70	62.44

Table 2: Average running times of our maximum flow algorithms on flow network T_{Hybrid}. Note, all values in the table are in percentage relative to the running time of the Ibfs algorithm. In each line the fastest variant is marked bold.

1.2 Configuring direct k-way Flow-based Refinement

	M2 - Ibfs without HE 1 removal							
Config.	(+F,-M,-FM)		(+F,+M,-FM)		(+F,+M,+FM)		Constant128	
α'	Avg[%]	$t[s]$	Avg[%]	$t[s]$	Avg[%]	$t[s]$	Avg[%]	$t[s]$
1	−6.09	13.36	−5.61	13.96	0.23	15.37	0.53	55.75
2	−3.19	16.57	−2.08	17.76	0.74	18.06	1.09	87.93
4	−1.82	21.66	−0.19	23.46	1.21	22.49	1.61	144.42
8	−0.84	30.35	0.98	32.87	1.71	30.23	2.16	257.41
16	−0.20	45.87	1.75	49.63	2.21	43.53	2.69	498.29
Ref.	(-F,-M,+FM)		6373.88	13.73				
	M2 - Ibfs with HE 1 removal							
Config.	(+F,-M,-FM)		(+F,+M,-FM)		(+F,+M,+FM)		Constant128	
α'	Avg[%]	$t[s]$	Avg[%]	$t[s]$	Avg[%]	$t[s]$	Avg[%]	$t[s]$
1	−6.43	12.87	−5.91	13.33	0.22	15.13	0.53	55.75
2	−3.38	15.69	−2.19	16.67	0.72	17.46	1.09	87.93
4	−1.95	20.29	−0.31	21.76	1.19	21.48	1.61	144.42
8	−0.99	28.28	0.90	30.48	1.69	28.54	2.16	257.41
16	−0.31	42.94	1.69	46.38	2.20	41.09	2.69	498.29
Ref.	(-F,-M,+FM)		6373.88	13.73				
	M2 - BoykovKolmogorov without HE 1 removal							
Config.	(+F,-M,-FM)		(+F,+M,-FM)		(+F,+M,+FM)		Constant128	
α'	Avg[%]	$t[s]$	Avg[%]	$t[s]$	Avg[%]	$t[s]$	Avg[%]	$t[s]$
1	−6.10	13.51	−5.62	14.22	0.23	15.19	0.53	55.75
2	−3.20	16.89	−2.08	18.23	0.74	17.97	1.09	87.93
4	−1.82	22.23	−0.20	24.29	1.21	22.50	1.61	144.42
8	−0.85	31.49	0.98	34.43	1.71	30.58	2.16	257.41
16	−0.20	48.66	1.75	53.23	2.21	45.04	2.69	498.29
Ref.	(-F,-M,+FM)		6373.88	13.73				

Table 3: Table contains results for different configurations of our flow-based refinement framework for increasing α'. The quality in column *Avg.* is relative to our baseline configuration (-F,-M,+FM).

Config.	(+F,-M,-FM)		(+F,+M,-FM)		(+F,+M,+FM)	
α'	M1 - Avg [%]	M2 - Avg [%]	M1 - Avg [%]	M2 - Avg [%]	M1 - Avg [%]	M2 - Avg [%]
1	−15.48	−6.10	−15.26	−5.62	0.14	0.23
2	−10.50	−3.20	−10.12	−2.08	0.36	0.74
4	−5.98	−1.82	−5.08	−0.20	0.67	1.21
8	−3.22	−0.85	−1.64	0.98	1.25	1.71
16	−1.52	−0.20	0.51	1.75	1.87	2.21
Ref.	(-F,-M,+FM)		6373.88			

Table 4: Comparison on quality of our framework with different source and sink set modeling approaches. M1 represents the approach of Sanders and Schulz and M2 is our new variant.

	M2 - BoykovKolmogorov		
Config.	(+F,-M,-FM)	(+F,+M,-FM)	(+F,+M,+FM)
α'	Avg[%]	Avg[%]	Avg[%]
1	−6.08	−5.57	0.23
2	−3.22	−2.10	0.72
4	−1.90	−0.26	1.18
8	−0.91	0.92	1.67
16	−0.29	1.65	2.15
Ref.	(-F,-M,+FM)	6376.03	
	M1 - GoldbergTarjan		
Config.	(+F,-M,-FM)	(+F,+M,-FM)	(+F,+M,+FM)
α'	Avg[%]	Avg[%]	Avg[%]
1	−15.45	−15.19	0.17
2	−10.51	−10.08	0.38
4	−5.97	−5.10	0.68
8	−3.22	−1.66	1.26
16	−1.67	0.46	1.84
Ref.	(-F,-M,+FM)	6376.03	

Table 5: Table contains results of the effectiveness test for different configurations of our flow-based refinement framework for increasing α'. The quality in column *Avg.* is relative to our baseline configuration (-F,-M,+FM).

1.3 Speed-Up Heuristics

	M2 - Ibfs			
Variant	Avg [%]	Min [%]	$t_{\text{flow}}[s]$	$t[s]$
KaHyPar-CA	7077.20	6820.17	-	29.26
KaHyPar-MF$_{(\text{R1,R2})}$	−2.40	−2.05	28.34	57.60
KaHyPar-MF$_{(\text{R1,R2,R3})}$	−2.41	−2.04	21.02	50.28
	M2 - BoykovKolmogorov			
Variant	Avg [%]	Min [%]	$t_{\text{flow}}[s]$	$t[s]$
KaHyPar-CA	7077.20	6820.17	-	29.26
KaHyPar-MF	−2.48	−2.13	51.76	81.02
KaHyPar-MF$_{(\text{R1})}$	−2.41	−2.05	41.21	70.47
KaHyPar-MF$_{(\text{R1,R2})}$	−2.40	−2.04	35.56	64.82
KaHyPar-MF$_{(\text{R1,R2,R3})}$	−2.41	−2.05	26.64	55.90
	M1 - GoldbergTarjan			
Variant	Avg [%]	Min [%]	$t_{\text{flow}}[s]$	$t[s]$
KaHyPar-CA	7077.20	6820.17	-	29.26
KaHyPar-MF	−2.13	−1.80	52.28	81.54
KaHyPar-MF$_{(\text{R1})}$	−2.05	−1.74	41.48	70.74
KaHyPar-MF$_{(\text{R1,R2})}$	−2.05	−1.73	35.27	64.54
KaHyPar-MF$_{(\text{R1,R2,R3})}$	−2.04	−1.75	27.62	56.88

Table 6: Results of our flow-based refinement framework with different speedup heuristics.

Partitioner	M2 - Ibfs Running Time $t[s]$						
	All	Dac	Ispd98	Primal	Literal	Dual	Spm
KaHyPar-CA	29.26	343.40	21.57	36.44	56.49	58.75	11.31
KaHyPar-MF$_{(R1,R2)}$	57.60	492.24	45.81	75.43	111.43	101.80	23.45
KaHyPar-MF$_{(R1,R2,R3)}$	50.28	451.82	38.16	64.78	96.46	89.70	20.70
Partitioner	M2 - BoykovKolmogorov Running Time $t[s]$						
	All	Dac	Ispd98	Primal	Literal	Dual	Spm
KaHyPar-CA	29.26	343.40	21.57	36.44	56.49	58.75	11.31
KaHyPar-MF	81.02	610.48	69.84	107.72	164.68	127.09	33.81
KaHyPar-MF$_{(R1)}$	70.47	526.26	55.56	91.10	136.17	113.87	30.62
KaHyPar-MF$_{(R1,R2)}$	64.82	503.04	47.31	84.65	123.63	101.41	28.95
KaHyPar-MF$_{(R1,R2,R3)}$	55.90	452.27	39.03	71.64	105.20	89.07	25.24
Partitioner	M1 - GoldbergTarjan Running Time $t[s]$						
	All	Dac	Ispd98	Primal	Literal	Dual	Spm
KaHyPar-CA	29.26	343.40	21.57	36.44	56.49	58.75	11.31
KaHyPar-MF	81.54	699.18	75.97	114.67	185.56	143.93	28.74
KaHyPar-MF$_{(R1)}$	70.74	600.87	59.69	94.90	150.56	128.67	26.47
KaHyPar-MF$_{(R1,R2)}$	64.54	573.41	50.28	88.11	134.84	113.59	24.80
KaHyPar-MF$_{(R1,R2,R3)}$	56.88	526.86	43.32	74.76	116.79	101.76	22.31

Table 7: Comparing the average running time of KaHyPar-MF with KaHyPar-CA.

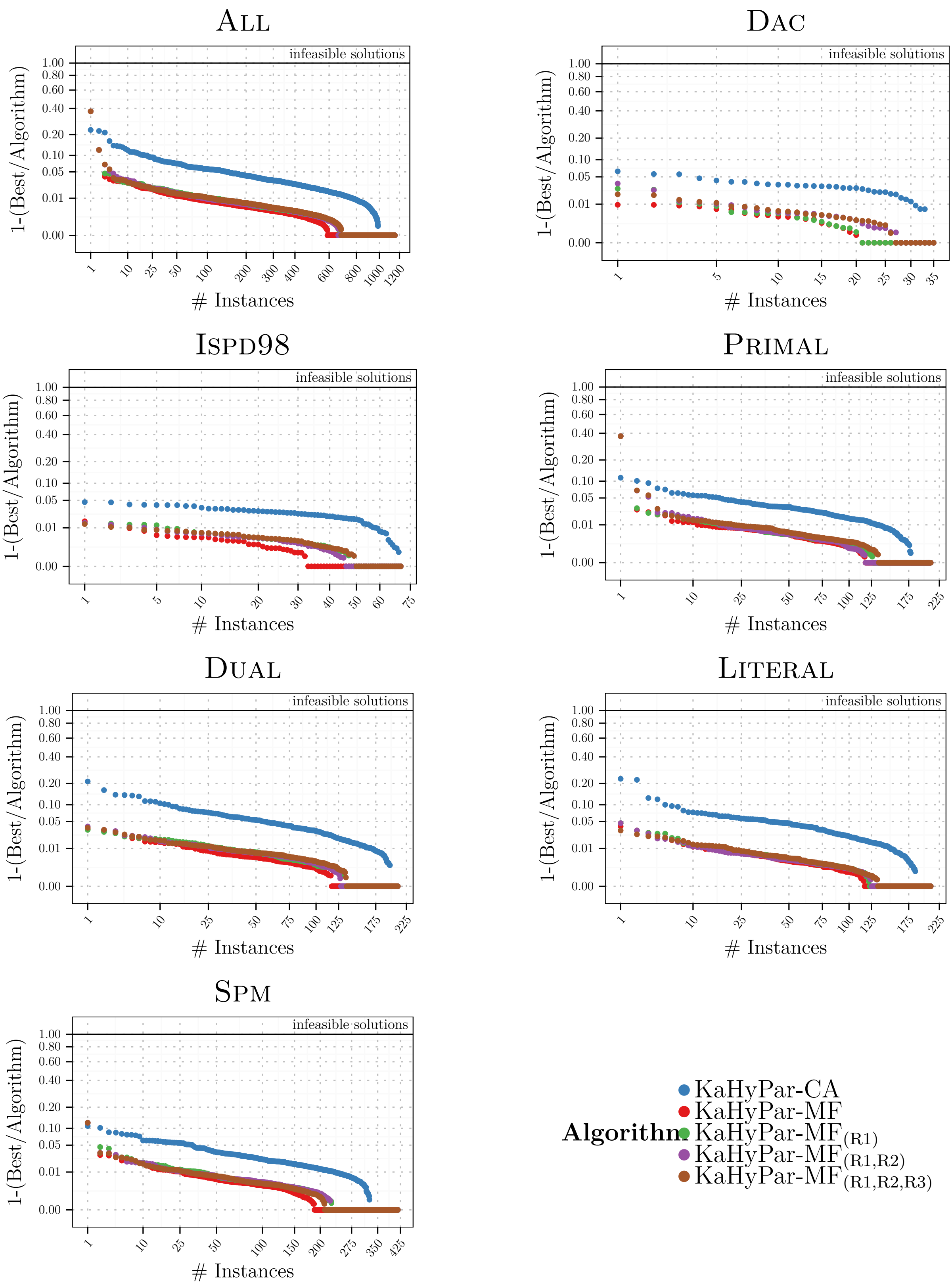

Figure 3: Min-Cut performance plots comparing KaHyPar-MF with KaHyPar-CA. M2 - Ibfs

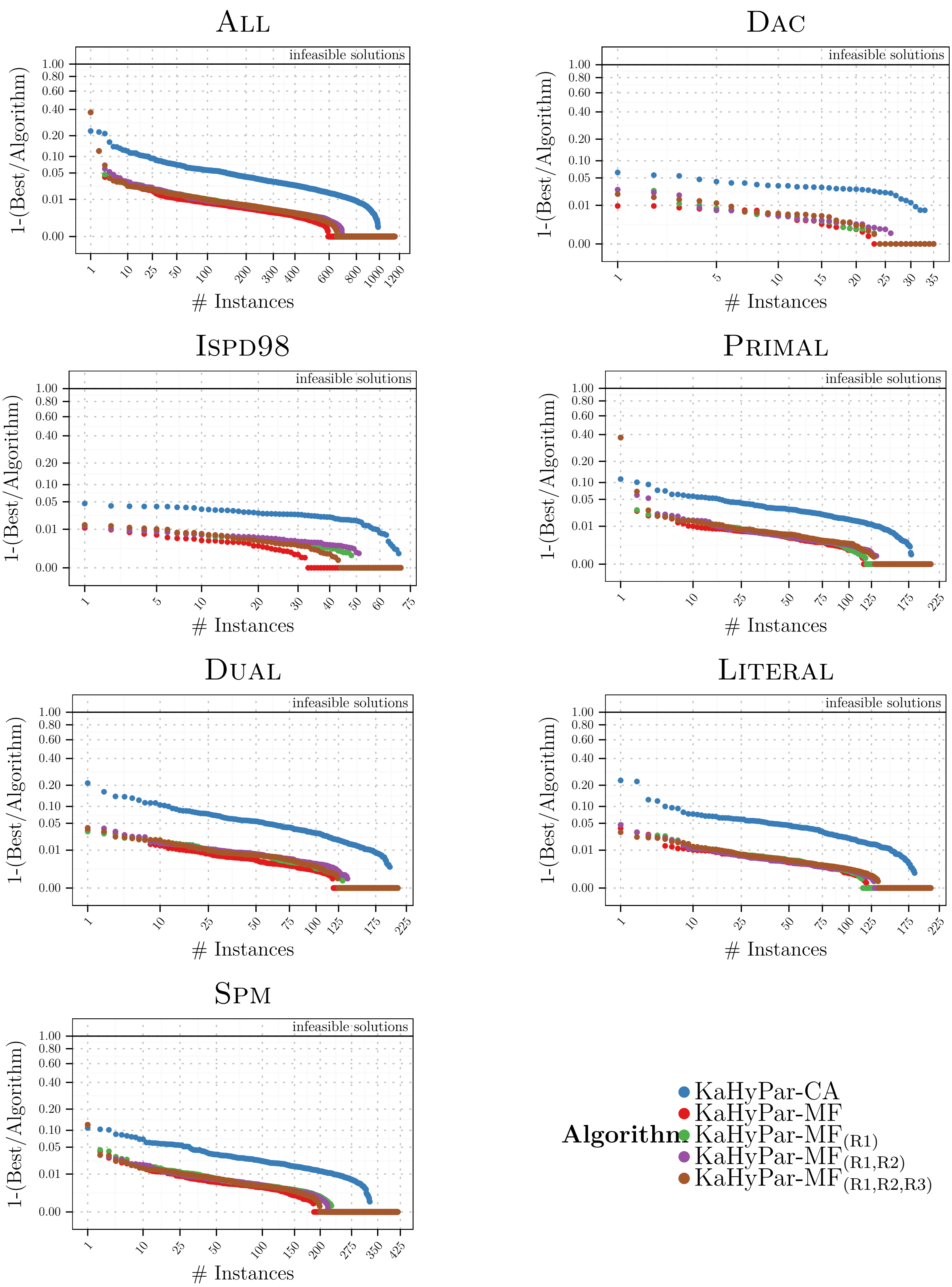

Figure 4: Min-Cut performance plots comparing KaHyPar-MF with KaHyPar-CA. M2 - BoykovKolmogorov

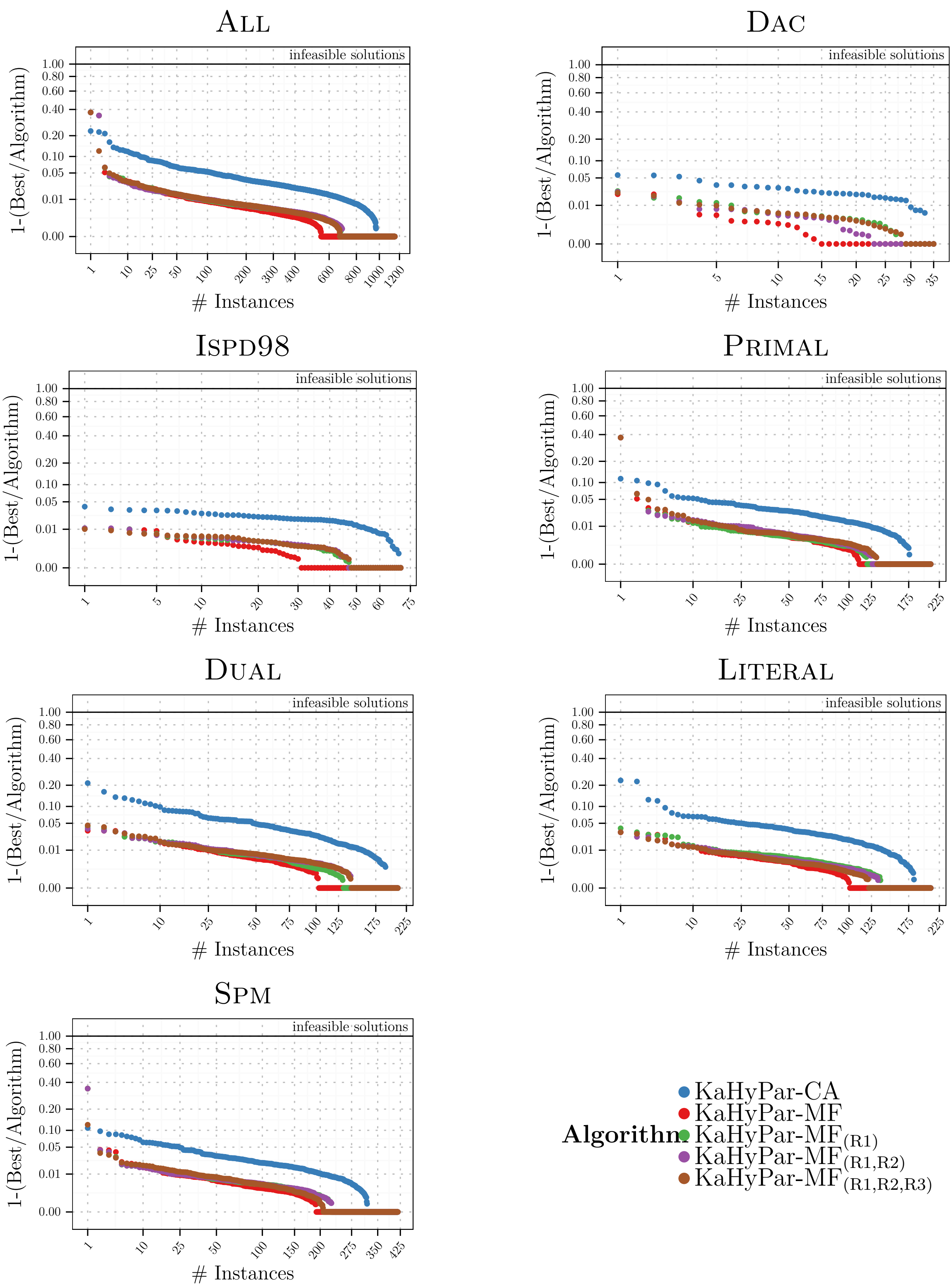

Figure 5: Min-Cut performance plots comparing KaHyPar-MF with KaHyPar-CA. M1 - GoldbergTarjan

1.4 Comparison with other Hypergraph Partitioners

Partitioner	M2 - BoykovKolmogorov Running Time $t[s]$						
	All	Dac	Ispd98	Primal	Literal	Dual	Spm
KaHyPar-MF	63.33	505.75	21.10	71.81	140.53	98.06	32.64
KaHyPar-CA	30.85	368.97	12.35	32.91	64.65	68.27	13.63
hMetis-R	78.47	446.36	29.03	66.25	142.12	200.36	40.64
hMetis-K	57.36	240.92	23.18	44.23	94.89	125.55	35.08
PaToH-Q	5.84	28.34	1.89	6.90	9.24	10.57	3.35
PaToH-D	1.21	6.45	0.35	1.12	1.58	2.87	0.75
Partitioner	M1 - GoldbergTarjan Running Time $t[s]$						
	All	Dac	Ispd98	Primal	Literal	Dual	Spm
KaHyPar-MF	62.24	637.58	22.29	71.63	140.84	106.24	29.61
KaHyPar-CA	31.05	368.97	12.35	32.91	64.65	68.27	13.91
hMetis-R	79.23	446.36	29.03	66.25	142.12	200.36	41.79
hMetis-K	57.86	240.92	23.18	44.23	94.89	125.55	35.95
PaToH-Q	5.89	28.34	1.89	6.90	9.24	10.57	3.42
PaToH-D	1.22	6.45	0.35	1.12	1.58	2.87	0.77

Table 8: Comparing the average running time of KaHyPar-MF with KaHyPar-CA and other hypergraph partitioners.

Partitioner	M2 - BoykovKolmogorov Average $\lambda - 1$						
	All	Dac	Ispd98	Primal	Literal	Dual	Spm
KaHyPar-MF	7727.97	17 480.70	5644.61	15 863.61	15 769.49	3038.31	6027.03
KaHyPar-CA	2.49	3.11	2.20	2.08	2.74	3.51	2.08
hMetis-R	15.79	3.64	1.62	2.07	2.80	43.44	19.77
hMetis-K	15.25	8.46	1.38	4.05	9.29	28.65	19.54
PaToH-Q	9.51	13.57	7.92	12.14	13.35	8.80	6.79
PaToH-D	16.77	23.75	15.08	18.27	21.54	18.31	12.92
Partitioner	M1 - GoldbergTarjan Average $\lambda - 1$						
	All	Dac	Ispd98	Primal	Literal	Dual	Spm
KaHyPar-MF	7819.11	17 590.10	5671.37	15 923.74	15 844.61	3061.94	6165.74
KaHyPar-CA	2.03	2.47	1.72	1.69	2.25	2.71	1.75
hMetis-R	15.21	2.99	1.14	1.69	2.31	42.33	19.22
hMetis-K	14.71	7.78	0.90	3.66	8.77	27.66	19.09
PaToH-Q	8.98	12.86	7.41	11.72	12.81	7.96	6.37
PaToH-D	16.21	22.98	14.54	17.83	20.97	17.40	12.50

Table 9: Comparison of average $(\lambda - 1)$ metric of KaHyPar-MF with KaHyPar-CA and other partitioners on different benchmark types. The results are in percentage relative to KaHyPar-MF.

Partitioner	M2 - BoykovKolmogorov Running Time $t[s]$						
	$k = 2$	$k = 4$	$k = 8$	$k = 16$	$k = 32$	$k = 64$	$k = 128$
KaHyPar-MF	23.56	39.84	56.44	68.69	86.73	108.35	125.74
KaHyPar-CA	12.68	17.02	23.70	30.78	41.38	56.95	76.05
hMetis-R	27.87	51.03	73.94	90.09	107.94	127.26	147.72
hMetis-K	25.47	31.92	42.06	52.87	73.30	108.15	151.63
PaToH-Q	1.93	3.58	5.39	6.95	8.32	9.97	11.34
PaToH-D	0.43	0.76	1.11	1.40	1.69	2.00	2.27
Partitioner	**M1 - GoldbergTarjan Running Time $t[s]$**						
	$k = 2$	$k = 4$	$k = 8$	$k = 16$	$k = 32$	$k = 64$	$k = 128$
KaHyPar-MF	22.13	38.51	55.04	67.83	85.75	108.97	128.04
KaHyPar-CA	12.68	17.16	23.88	31.01	41.69	57.35	76.61
hMetis-R	27.87	51.59	74.74	91.09	109.13	128.66	149.34
hMetis-K	25.47	32.27	42.50	53.41	74.00	109.12	152.92
PaToH-Q	1.93	3.61	5.44	7.01	8.40	10.06	11.44
PaToH-D	0.43	0.77	1.12	1.42	1.71	2.02	2.29

Table 10: Comparing the average running time of KaHyPar-MF with KaHyPar-CA and other partitioners for different values of k.

Partitioner	M2 - BoykovKolmogorov Average $\lambda - 1$						
	$k = 2$	$k = 4$	$k = 8$	$k = 16$	$k = 32$	$k = 64$	$k = 128$
KaHyPar-MF	1057.94	3105.80	5988.27	9292.89	14 582.34	21 735.78	31 477.02
KaHyPar-CA	2.32	2.62	2.86	2.73	2.55	2.28	2.08
hMetis-R	27.19	18.98	16.97	15.81	12.86	10.70	8.49
hMetis-K	27.59	17.84	15.75	15.58	11.78	10.25	8.48
PaToH-Q	11.74	9.14	9.14	10.01	9.38	9.05	8.10
PaToH-D	15.29	16.60	19.17	19.91	16.15	15.78	14.52
Partitioner	M1 - GoldbergTarjan Average $\lambda - 1$						
	$k = 2$	$k = 4$	$k = 8$	$k = 16$	$k = 32$	$k = 64$	$k = 128$
KaHyPar-MF	1064.06	3147.96	6062.80	9406.00	14 756.03	21 978.89	31 820.94
KaHyPar-CA	1.73	2.06	2.36	2.28	2.11	1.90	1.73
hMetis-R	26.46	18.26	16.34	15.25	12.33	10.23	8.08
hMetis-K	26.86	17.19	15.18	15.06	11.29	9.83	8.10
PaToH-Q	11.10	8.50	8.57	9.49	8.87	8.60	7.70
PaToH-D	14.62	15.94	18.55	19.34	15.62	15.31	14.09

Table 11: Comparison of average $(\lambda - 1)$ metric of KaHyPar-MF with KaHyPar-CA and other partitioners for different values of k. The results are in percentage relative to KaHyPar-MF.

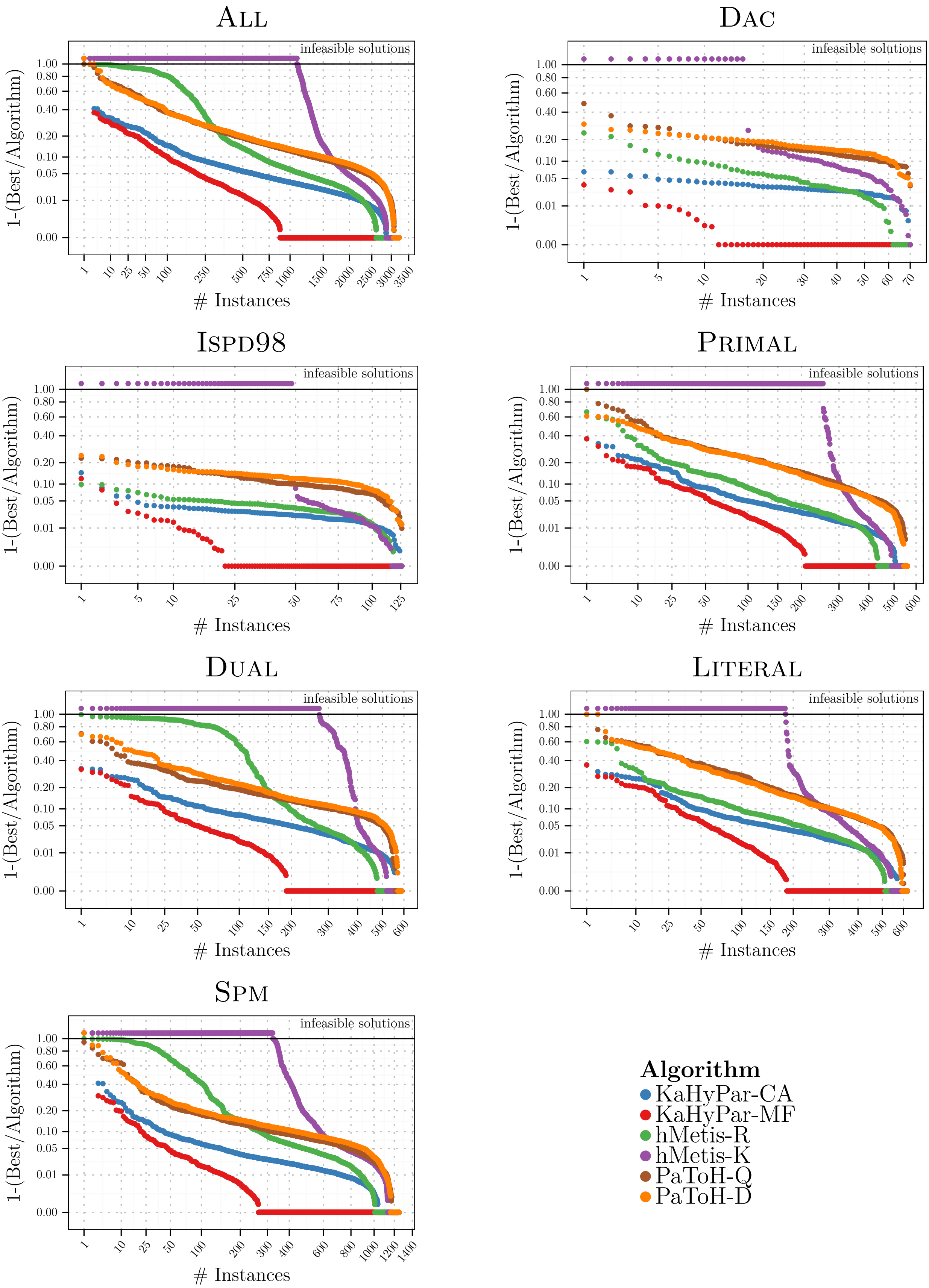

Figure 6: Min-Cut performance plots comparing KaHyPar-MF with KaHyPar-CA and other partitioners. M2 - BoykovKolmogorov

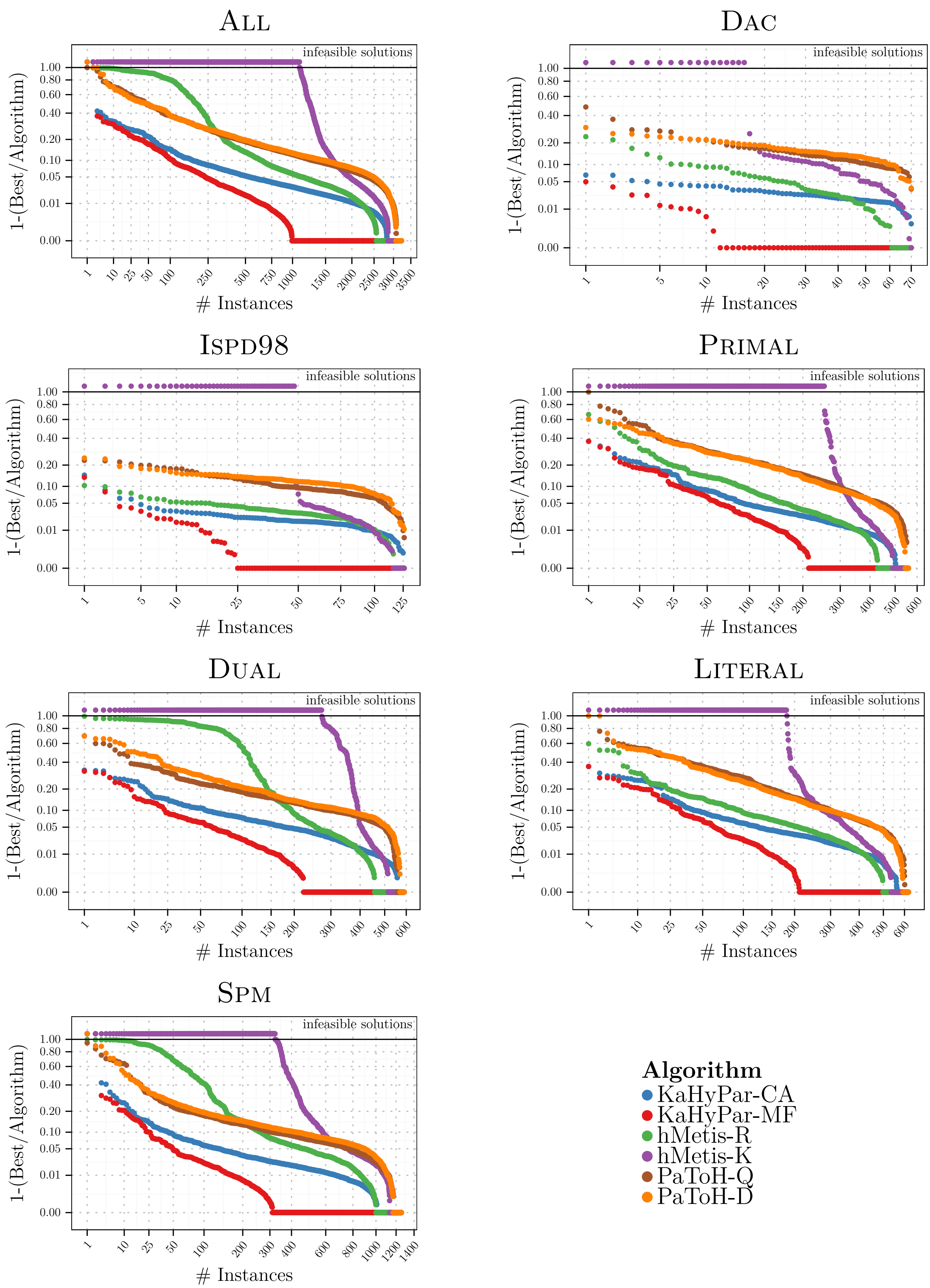

Figure 7: Min-Cut performance plots comparing KaHyPar-MF with KaHyPar-CA and other partitioners. M1 - GoldbergTarjan

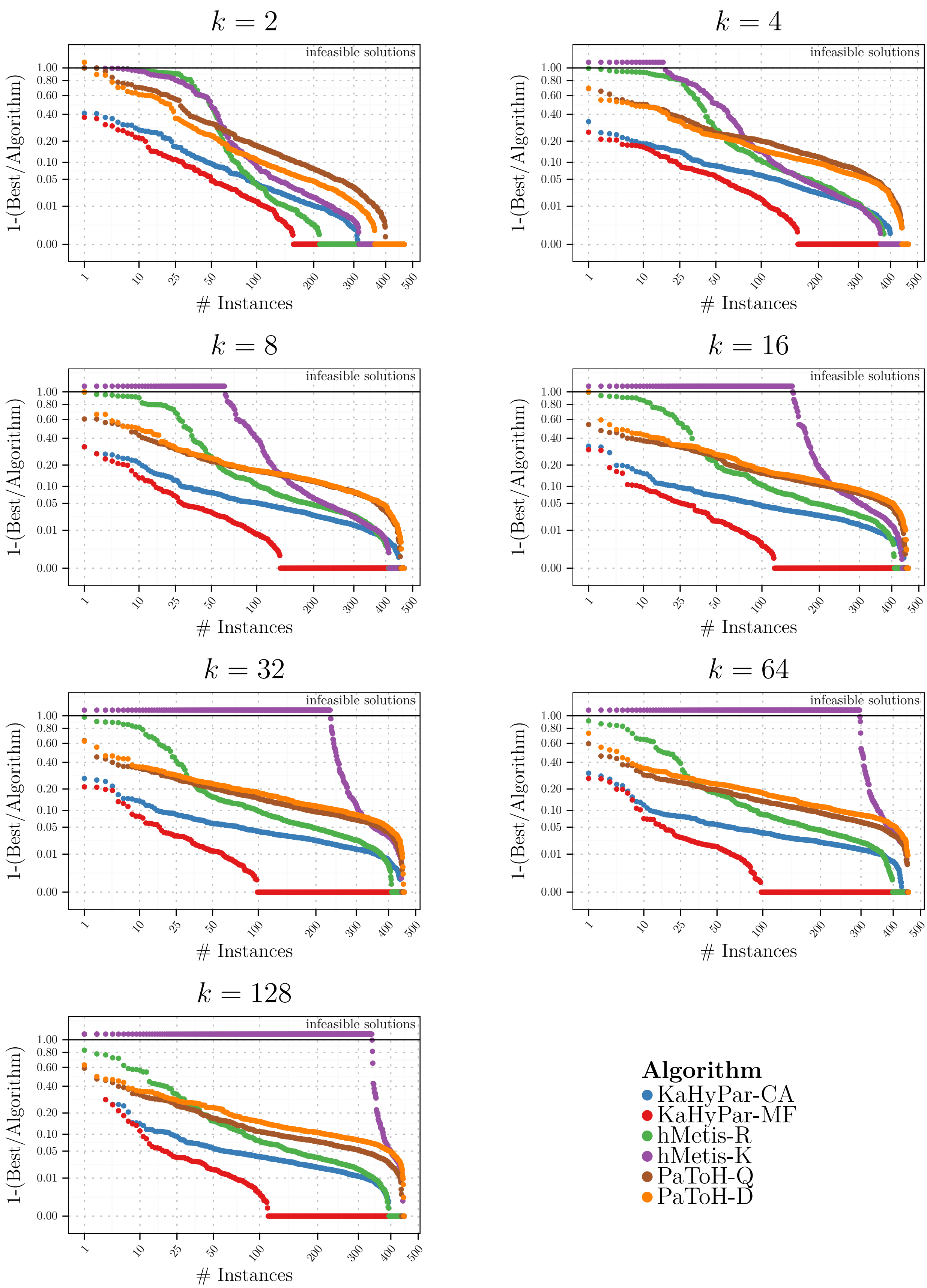

Figure 8: Min-Cut performance plots comparing KaHyPar-MF with KaHyPar-CA and other partitioners for different values of k. M2 - BoykovKolmogorov

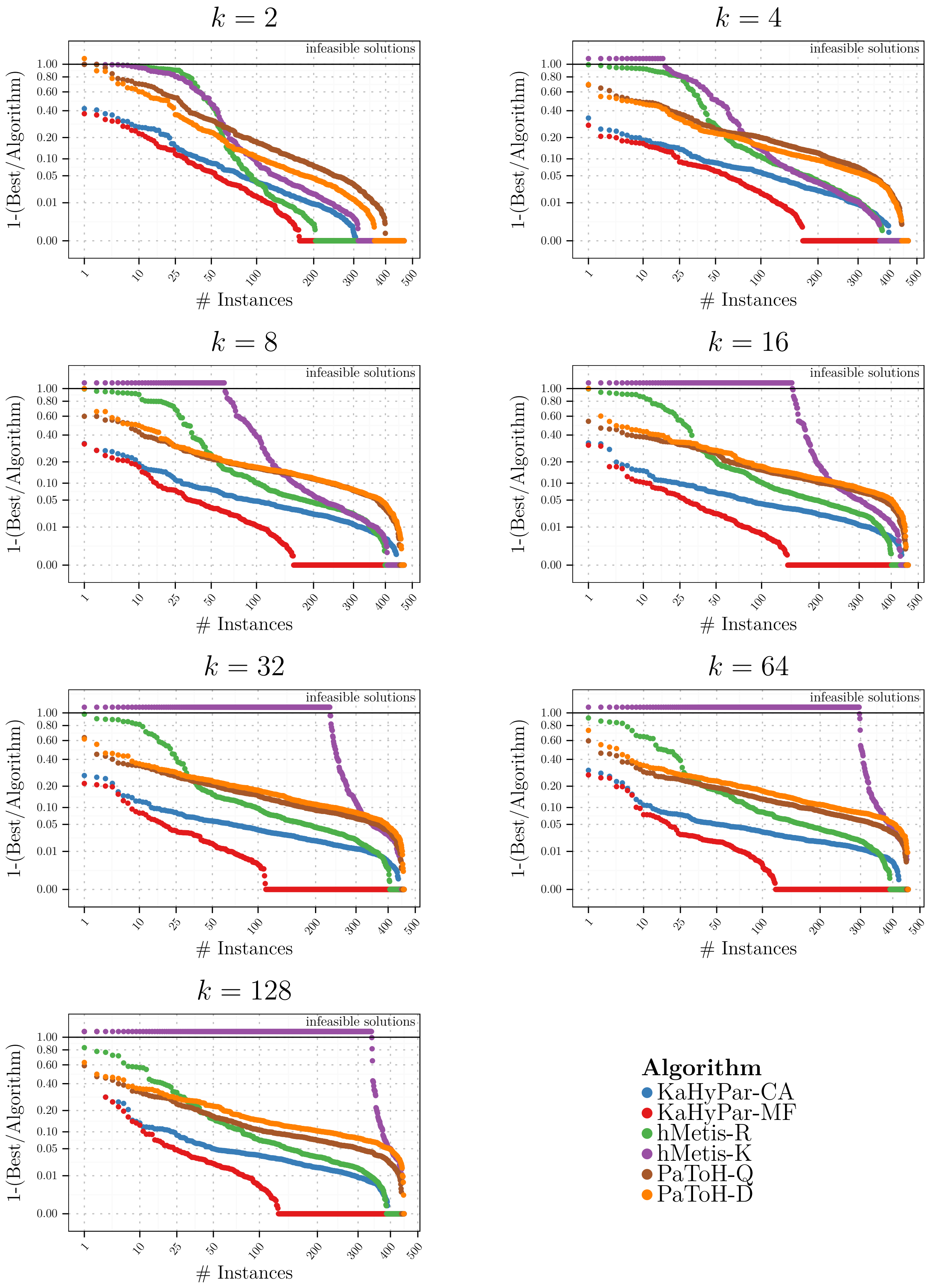

Figure 9: Min-Cut performance plots comparing KaHyPar-MF with KaHyPar-CA and other partitioners for different values of k. M1 - GoldbergTarjan