APPENDIX TO: DYNAMIC MEMORY BANDWIDTH ALLOCATION FOR REAL-TIME GPU-BASED SOC PLATFORMS

Measured EDFs of Parboil Benchmarks and WCET Estimation

Tables I-X show per-cluster information for all 10 Parboil benchmarks excluding histo, whose information is reported in Table I of the main paper. Similarly to the main paper, we report the maximum observed values of e_i^0 and e_i^1, as well as the mean and standard deviation of the fitted normal distribution, and the corresponding percentiles for e_i^0 and e_i^1. Note that here, percentiles are indicated in "number of 9s", that is, a value of x indicates that the percentile is at least $1 - 10^{-x}$ (e.g., for $x = 3$, the percentile is at least 99.9%).

Cluster #	1	2	3	4	5	6
worst measured e_i^0	0.50	0.75	1.15	2.27	4.56	6.30
worst measured e_i^1	2.27	3.44	4.82	6.71	9.50	12.81
$Q = 0$, mean	0.43	0.67	1.06	2.16	4.48	6.20
$Q = 0$, std	0.023	0.024	0.027	0.028	0.021	0.027
e_i^0 percentile (9s)	2	3	3	4	4	3
$Q = 1$, mean	2.13	3.29	4.65	6.60	9.38	12.64
$Q = 1$, std	0.036	0.034	0.048	0.041	0.037	0.046
e_i^1 percentile (9s)	4	5	3	2	3	3

TABLE I: Clustering: sad benchmark. Time values are in us.

Cluster #	1	2	3	4	5	6
worst measured e_i^0	1.30	1.81	2.77	3.25	4.88	5.42
worst measured e_i^1	2.07	3.44	4.92	5.71	7.67	9.35
$Q = 0$, mean	1.23	1.75	2.67	3.14	3.80	5.32
$Q = 0$, std	0.021	0.019	0.021	0.024	0.021	0.026
e_i^0 percentile (9s)	3	3	6	5	4	4
$Q = 1$, mean	1.93	3.29	4.77	5.60	7.55	9.18
$Q = 1$, std	0.031	0.036	0.039	0.036	0.029	0.047
e_i^1 percentile (9s)	5	4	4	2	4	3

TABLE II: Clustering: bfs benchmark. Time values are in us.

Cluster #	1	2	3
worst measured e_i^0	2.57	3.96	5.43
worst measured e_i^1	3.68	5.43	6.97
$Q = 0$, mean	2.50	3.90	5.35
$Q = 0$, std	0.022	0.022	0.025
e_i^0 percentile (9s)	3	2	3
$Q = 1$, mean	3.60	5.31	6.88
$Q = 1$, std	0.029	0.038	0.028
e_i^1 percentile (9s)	2	3	3

TABLE III: Clustering: spmv benchmark. Time values are in us.

Cluster #	1	2	3	4
worst measured e_i^0	3.65	6.23	8.45	9.66
worst measured e_i^1	4.97	7.76	9.96	12.21
$Q = 0$, mean	3.58	6.17	8.35	9.63
$Q = 0$, std	0.022	0.022	0.025	0.014
e_i^0 percentile (9s)	3	2	4	1
$Q = 1$, mean	4.83	7.64	9.82	12.14
$Q = 1$, std	0.032	0.034	0.044	0.020
e_i^1 percentile (9s)	5	3	3	3

TABLE IV: Clustering: stencil benchmark. Time values are in us.

Cluster #	1	2	3	4	5
worst measured e_i^0	1.80	3.12	4.89	5.66	7.12
worst measured e_i^1	2.44	4.44	6.90	8.30	9.64
$Q = 0$, mean	1.73	3.06	4.82	5.59	7.06
$Q = 0$, std	0.020	0.019	0.024	0.022	0.023
e_i^0 percentile (9s)	3	3	2	3	2
$Q = 1$, mean	2.33	4.29	6.79	8.19	9.53
$Q = 1$, std	0.030	0.037	0.037	0.034	0.032
e_i^1 percentile (9s)	3	4	2	3	3

TABLE V: Clustering: lbm benchmark. Time values are in us.

Cluster #	1	2	3
worst measured e_i^0	1.32	2.72	4.48
worst measured e_i^1	1.38	2.81	4.55
$Q = 0$, mean	1.23	2.63	4.28
$Q = 0$, std	0.034	0.033	0.086
e_i^0 percentile (9s)	2	2	2
$Q = 1$, mean	1.24	2.66	4.29
$Q = 1$, std	0.040	0.049	0.088
e_i^1 percentile (9s)	3	2	2

TABLE VI: Clustering: cutcp benchmark. Time values are in us.

Cluster #	1	2	3
worst measured e_i^0	0.54	1.83	3.37
worst measured e_i^1	0.61	1.86	3.42
$Q = 0$, mean	0.47	1.76	3.29
$Q = 0$, std	0.026	0.020	0.032
e_i^0 percentile (9s)	2	3	2
$Q = 1$, mean	0.48	1.77	3.3
$Q = 1$, std	0.033	0.024	0.037
e_i^1 percentile (9s)	4	4	3

TABLE VII: Clustering: mri_q benchmark. Time values are in us.

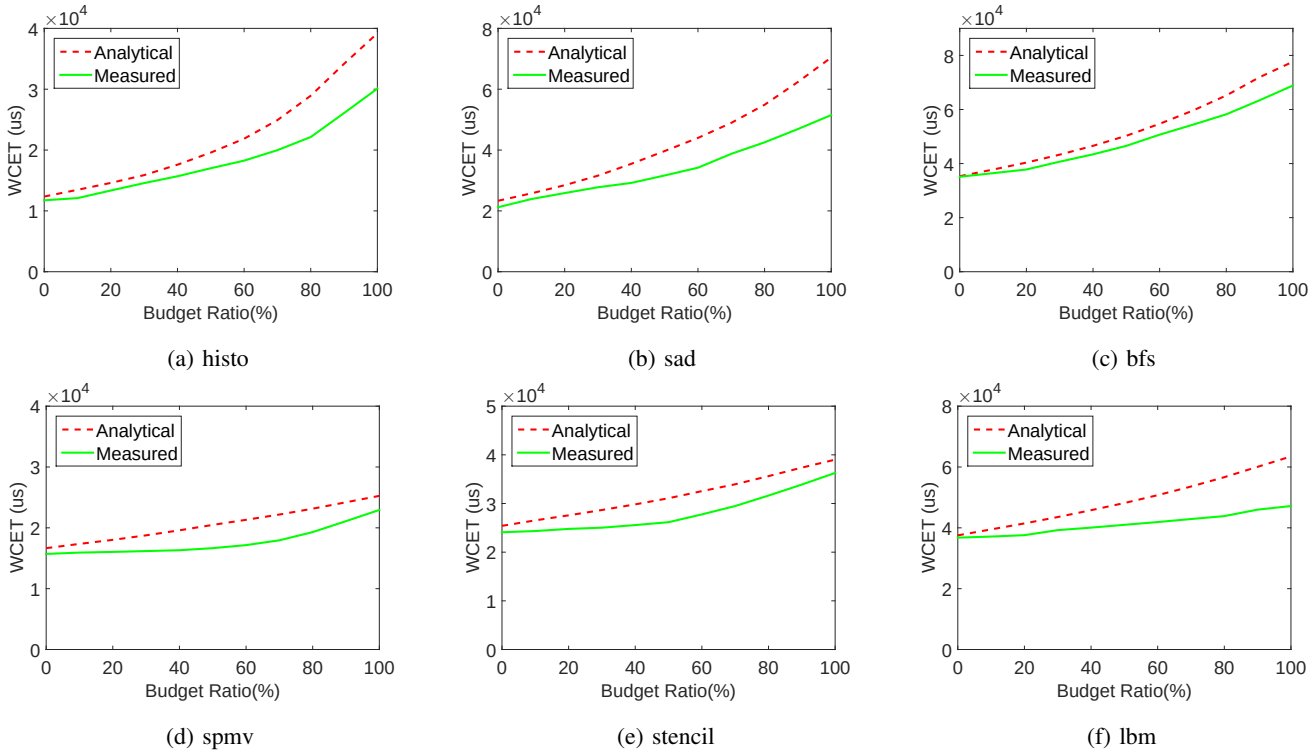
Cluster #	1	2	3	4
worst measured e_i^0	3.81	4.21	4.56	5.66
worst measured e_i^1	3.86	4.26	4.64	5.70
$Q = 0$, mean	3.74	4.15	4.47	5.63
$Q = 0$, std	0.026	0.023	0.028	0.013
e_i^0 percentile (9s)	2	2	3	1
$Q = 1$, mean	3.75	4.16	4.49	5.64
$Q = 1$, std	0.029	0.026	0.032	0.018
e_i^1 percentile (9s)	4	4	5	3

TABLE VIII: Clustering: mri_gridding benchmark. Time values are in us.

Cluster #	1	2	3	4	5
worst measured e_i^0	1.80	2.12	3.25	4.90	5.70
worst measured e_i^1	1.85	2.14	3.29	4.99	5.78
$Q = 0$, mean	1.73	2.05	3.14	4.83	5.63
$Q = 0$, std	0.023	0.019	0.029	0.032	0.023
e_i^0 percentile (9s)	2	3	4	1	2
$Q = 1$, mean	1.75	2.06	3.16	4.85	5.65
$Q = 1$, std	0.028	0.022	0.035	0.047	0.030
e_i^1 percentile (9s)	3	3	4	2	5

TABLE IX: Clustering: tpacf benchmark. Time values are in us.

Figures 1 and 2 compare the measured WCET with the analytical WCET for all Parboil benchmarks, divided into memory-bound and compute-bound benchmarks, as a function



(a) histo (b) sad (c) bfs

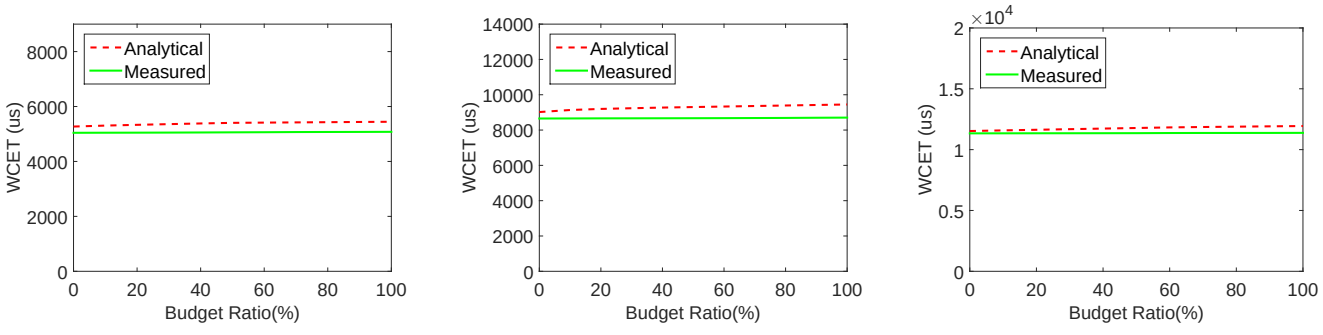
(d) spmv (e) stencil (f) lbm

Fig. 1: Analytical WCET vs Measured WCET for memory-bound benchmarks

Cluster #	1	2	3	4
worst measured e_i^0	0.70	1.66	2.17	3.40
worst measured e_i^1	0.73	1.70	2.22	3.42
$Q = 0$, mean	0.62	1.63	2.11	3.31
$Q = 0$, std	0.023	0.015	0.023	0.031
e_i^0 percentile (9s)	3	1	2	2
$Q = 1$, mean	0.64	1.64	2.12	3.32
$Q = 1$, std	0.028	0.019	0.030	0.039
e_i^1 percentile (9s)	3	3	3	2

TABLE X: Clustering: sgemm benchmark. Time values are in us.

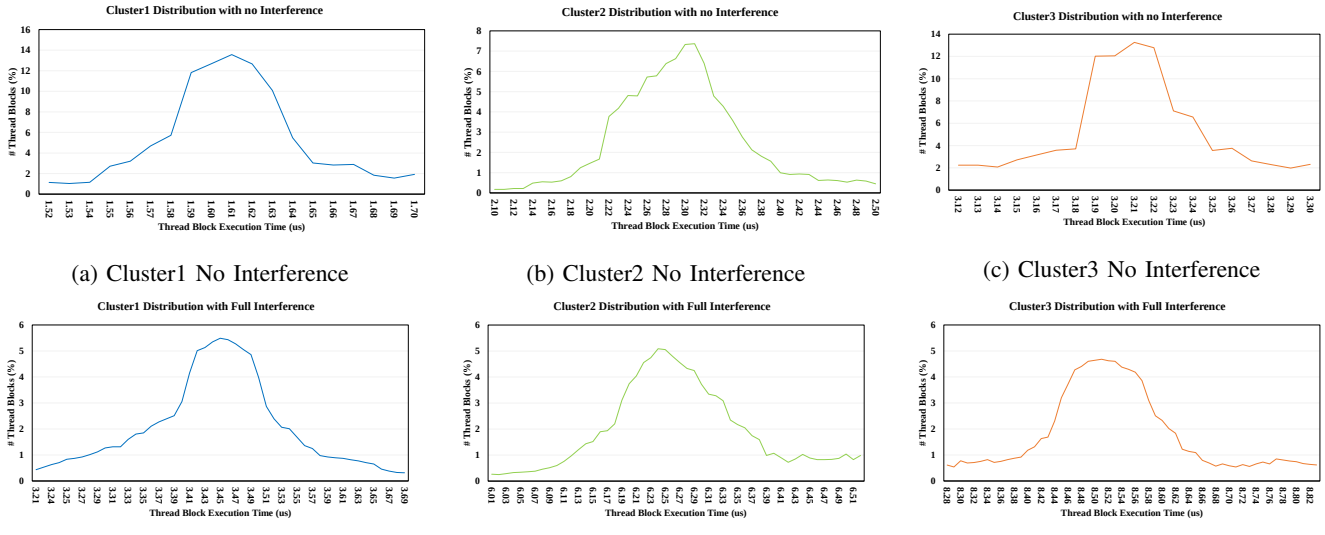
of the budget ratio Q. As in Section VII-B, the measured WCET is obtained by executing each kernel one million times without instrumentation in conjunction with synthetic, memory-intensive BE tasks, while the analytical WCET is obtained through Algorithm 1. Note that compute-bound benchmarks are largely unaffected by memory interference, as both the measured and analytical WCET remains almost constant with increasing values of Q. Finally, Figures 3, 4, 5, 6, 7, and 8 show the EDF for the execution times of the thread block clusters of the memory-bound Parboil benchmarks: histo, sad, bfs, lbm, stencil, and spmv, respectively. We show the distributions both for the case of no interference ($Q = 0$), which is used to derive e_i^0, and the case of full interference ($Q = 1$), which is used to derive e_i^1.



(a) cutcp (b) mri_q (c) mri_gridding

(d) tpacf (e) sgemm

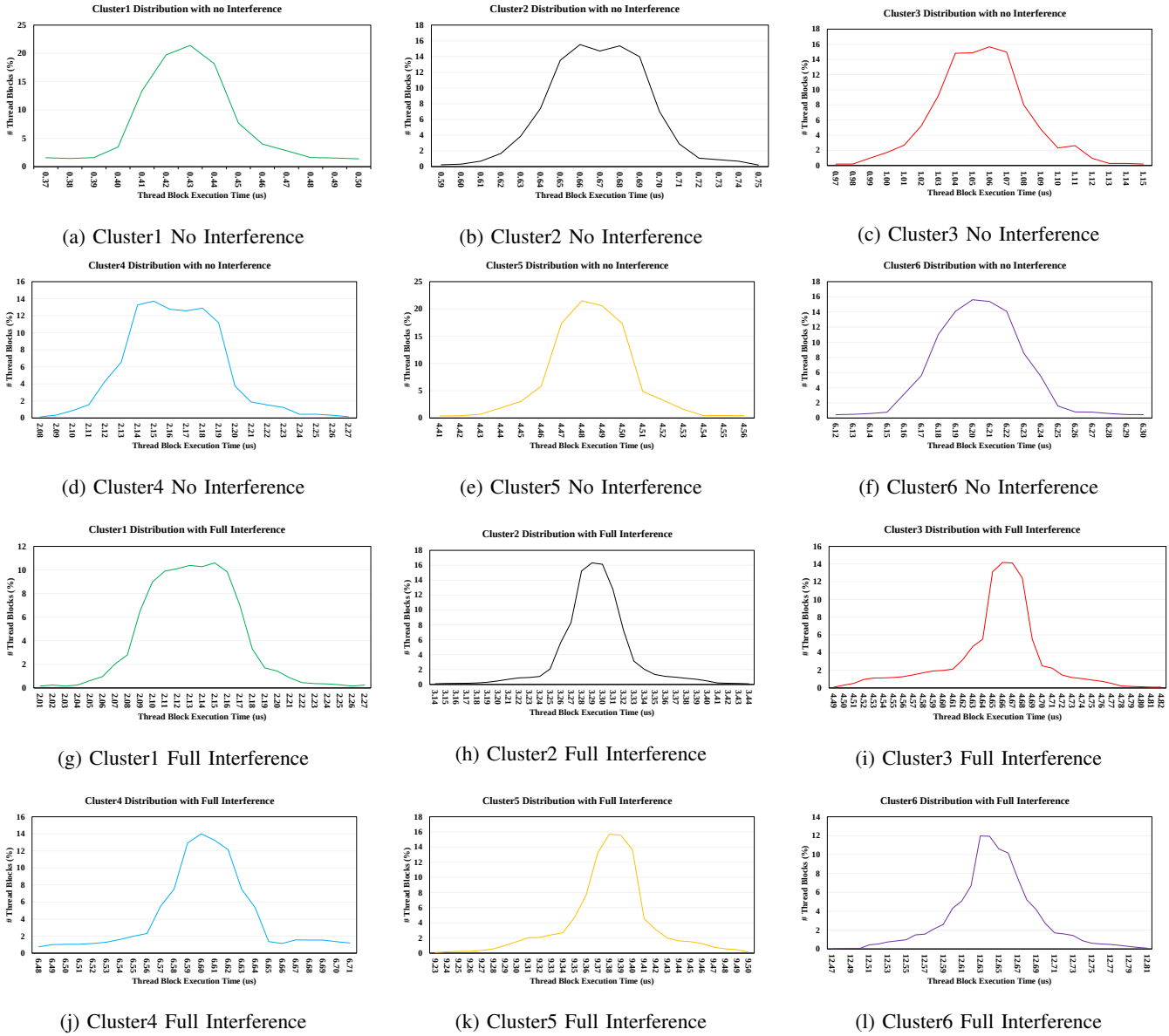
Fig. 2: Analytical WCET vs Measured WCET for compute-bound benchmarks



(a) Cluster1 No Interference (b) Cluster2 No Interference (c) Cluster3 No Interference

(d) Cluster1 Full Interference (e) Cluster2 Full Interference (f) Cluster3 Full Interference

Fig. 3: Distribution of block execution times for histo benchmark



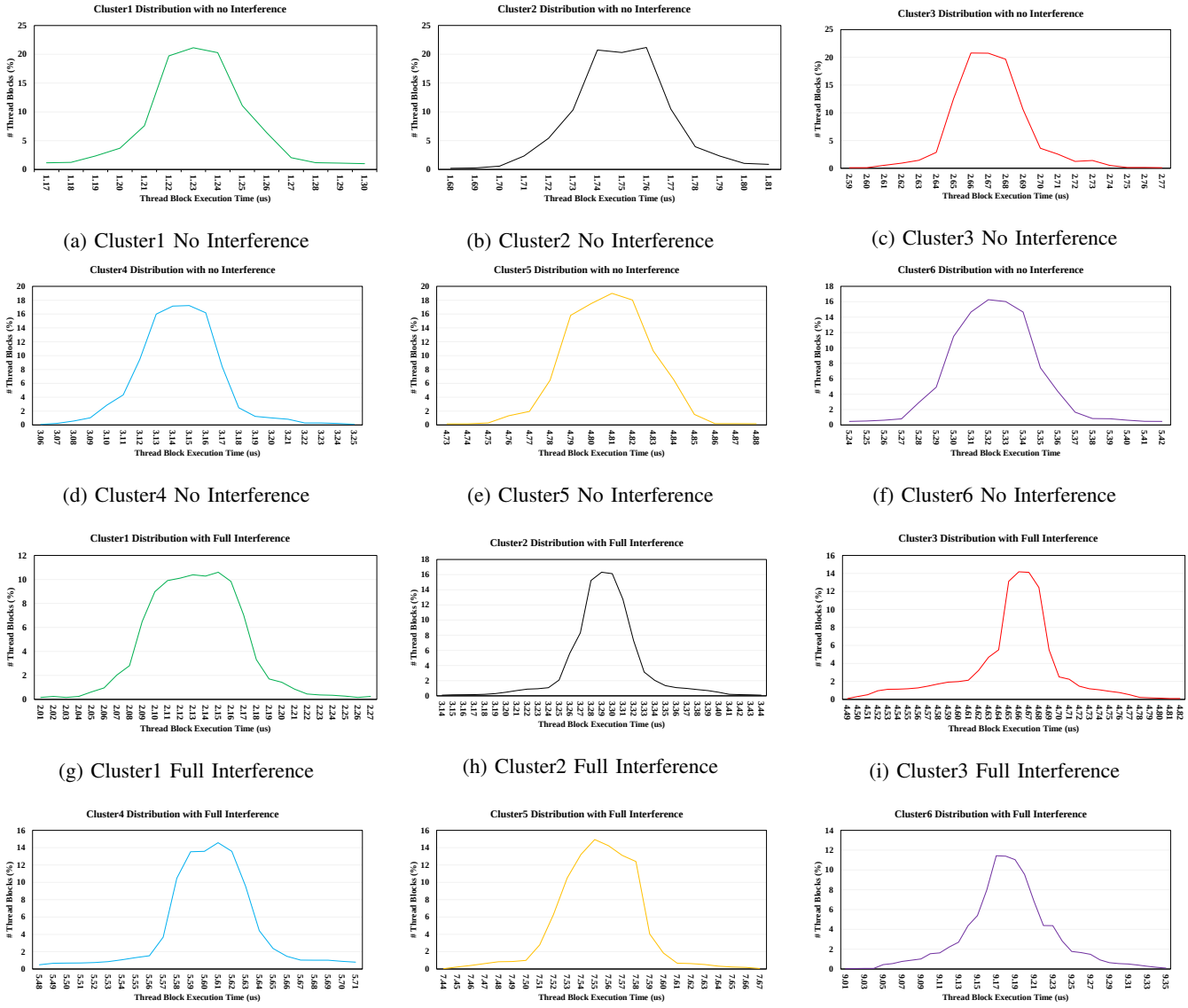
(a) Cluster1 No Interference (b) Cluster2 No Interference (c) Cluster3 No Interference

(d) Cluster4 No Interference (e) Cluster5 No Interference (f) Cluster6 No Interference

(g) Cluster1 Full Interference (h) Cluster2 Full Interference (i) Cluster3 Full Interference

(j) Cluster4 Full Interference (k) Cluster5 Full Interference (l) Cluster6 Full Interference

Fig. 4: Distribution of block execution times for sad benchmark



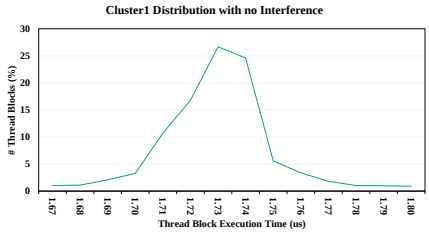
(a) Cluster1 No Interference (b) Cluster2 No Interference (c) Cluster3 No Interference

(d) Cluster4 No Interference (e) Cluster5 No Interference (f) Cluster6 No Interference

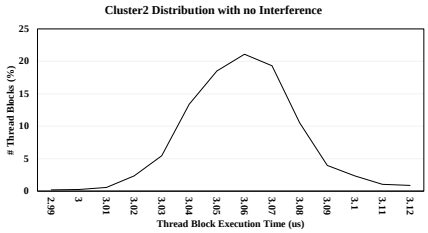
(g) Cluster1 Full Interference (h) Cluster2 Full Interference (i) Cluster3 Full Interference

(j) Cluster4 Full Interference (k) Cluster5 Full Interference (l) Cluster6 Full Interference

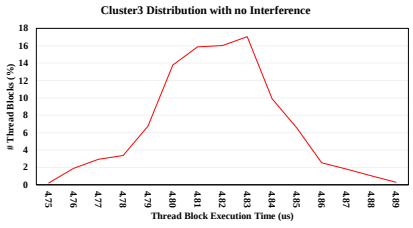
Fig. 5: Distribution of block execution times for bfs benchmark



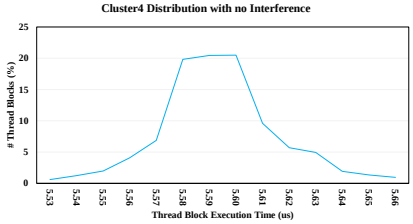
(a) Cluster1 No Interference



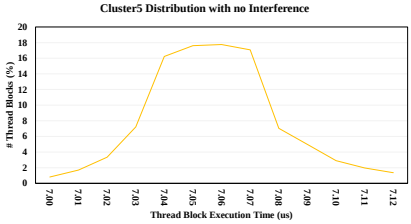
(b) Cluster2 No Interference



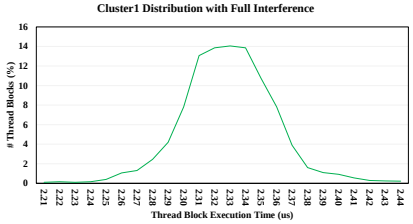
(c) Cluster3 No Interference



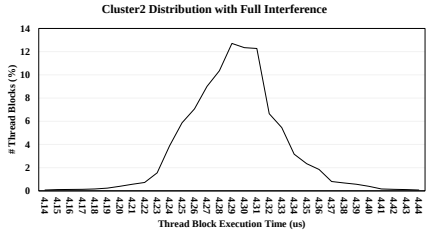
(d) Cluster4 No Interference



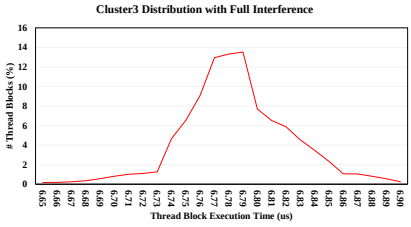
(e) Cluster5 No Interference



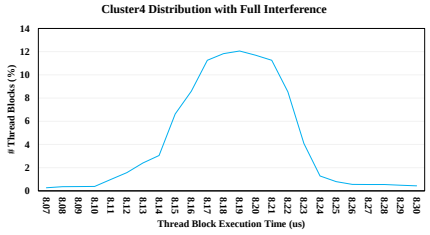
(f) Cluster1 Full Interference



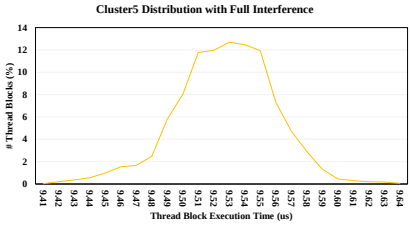
(g) Cluster2 Full Interference



(h) Cluster3 Full Interference

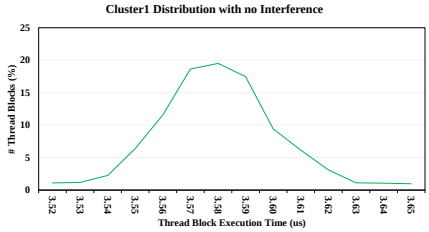


(i) Cluster4 Full Interference

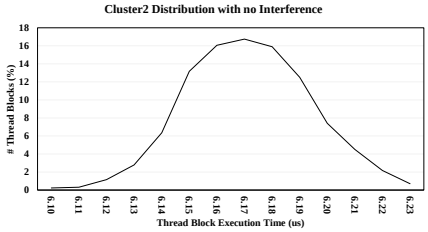


(j) Cluster5 Full Interference

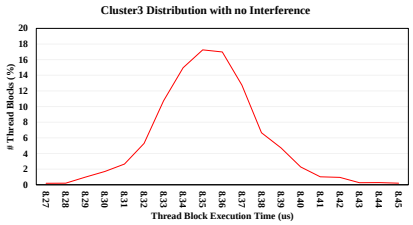
Fig. 6: Distribution of block execution times for lbm benchmark



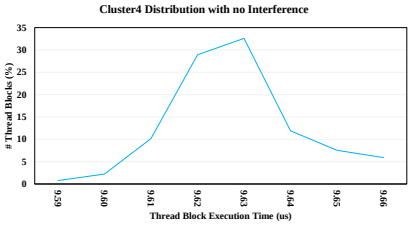
(a) Cluster1 No Interference



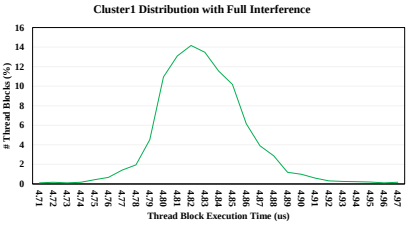
(b) Cluster2 No Interference



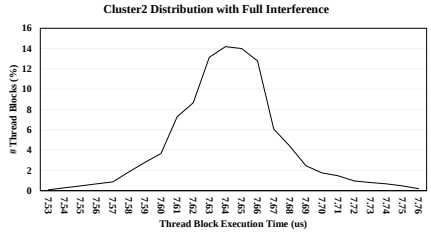
(c) Cluster3 No Interference



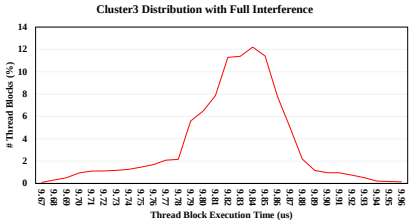
(d) Cluster4 No Interference



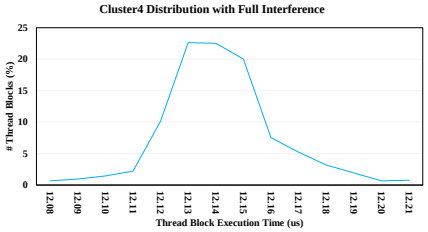
(e) Cluster1 Full Interference



(f) Cluster2 Full Interference

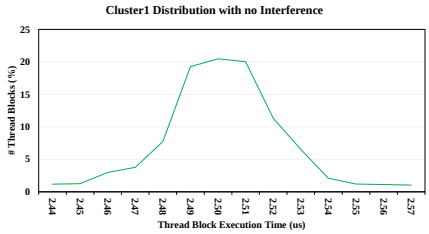


(g) Cluster3 Full Interference

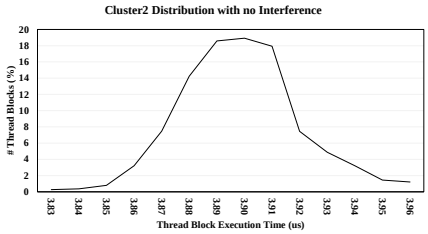


(h) Cluster4 Full Interference

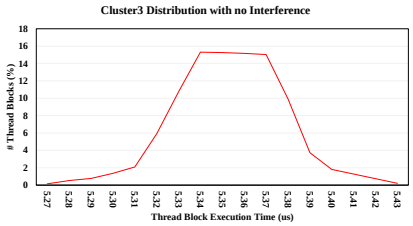
Fig. 7: Distribution of block execution times for stencil benchmark



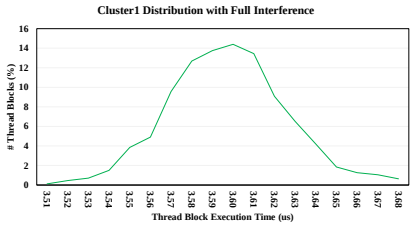
(a) Cluster1 No Interference



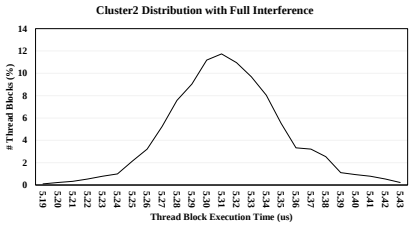
(b) Cluster2 No Interference



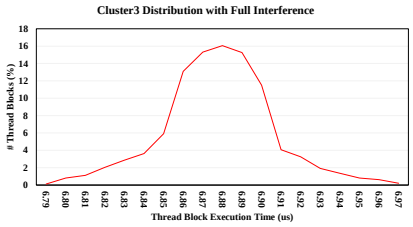
(c) Cluster3 No Interference



(d) Cluster1 Full Interference



(e) Cluster2 Full Interference



(f) Cluster3 Full Interference

Fig. 8: Distribution of block execution times for spmv benchmark