NORTH CAROLINA STATE UNIVERSITY

Department of Electrical and Computer Engineering

ECE/CSC 506/406: Architecture of Parallel Computers

Project-2 Coherence Protocols

Report

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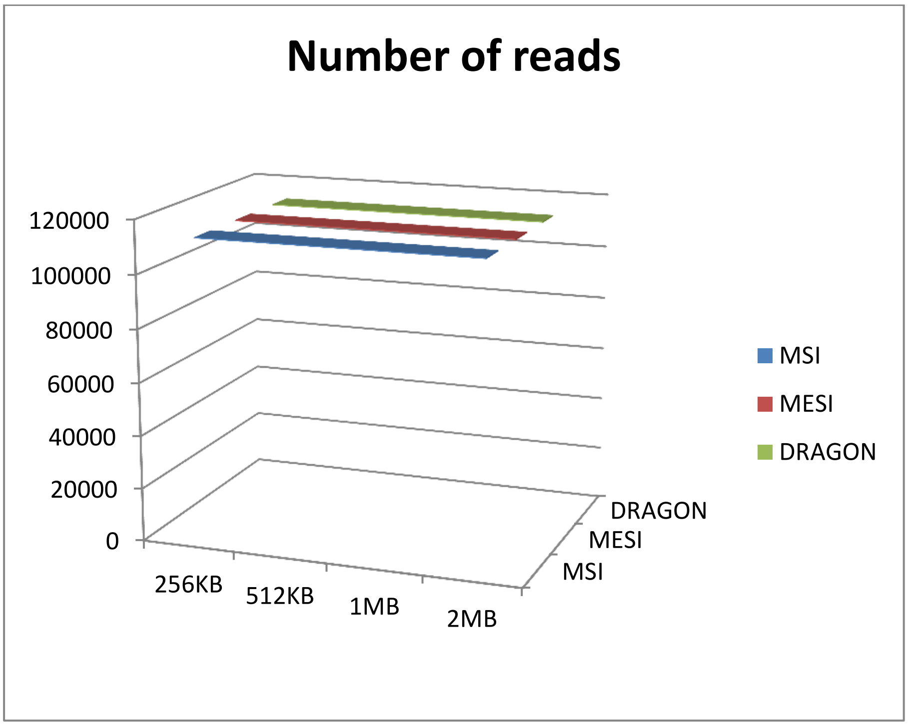
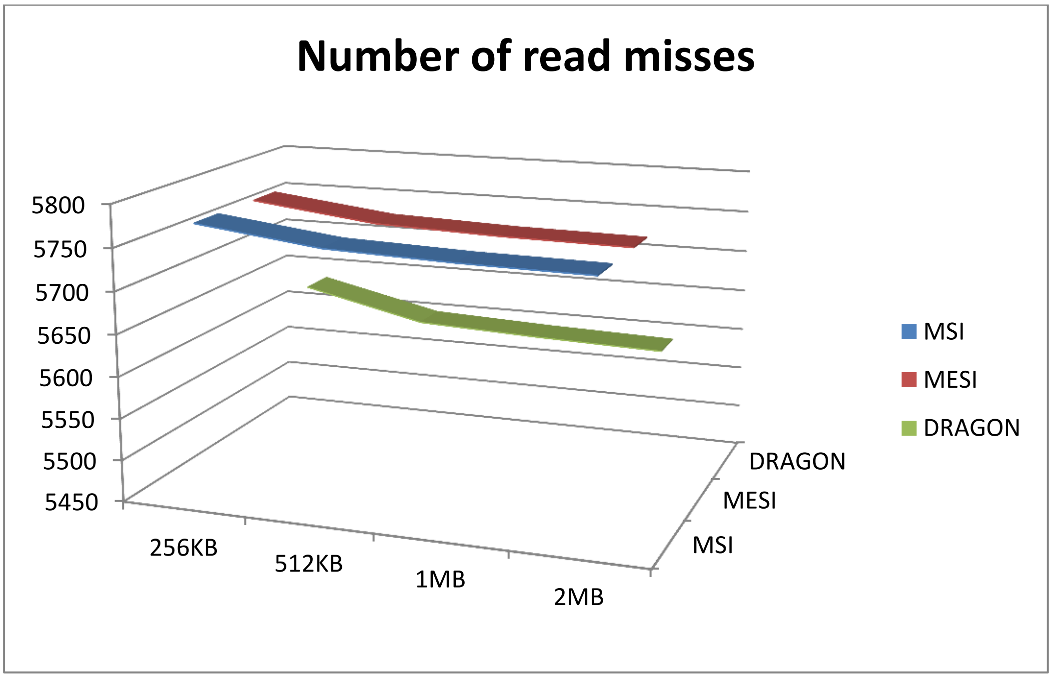
1) Number of reads:



The number of reads is same for MSI, MESI and Dragon for every cache size, block size and associativity since every read request to any of the protocols are counted as the number of reads.

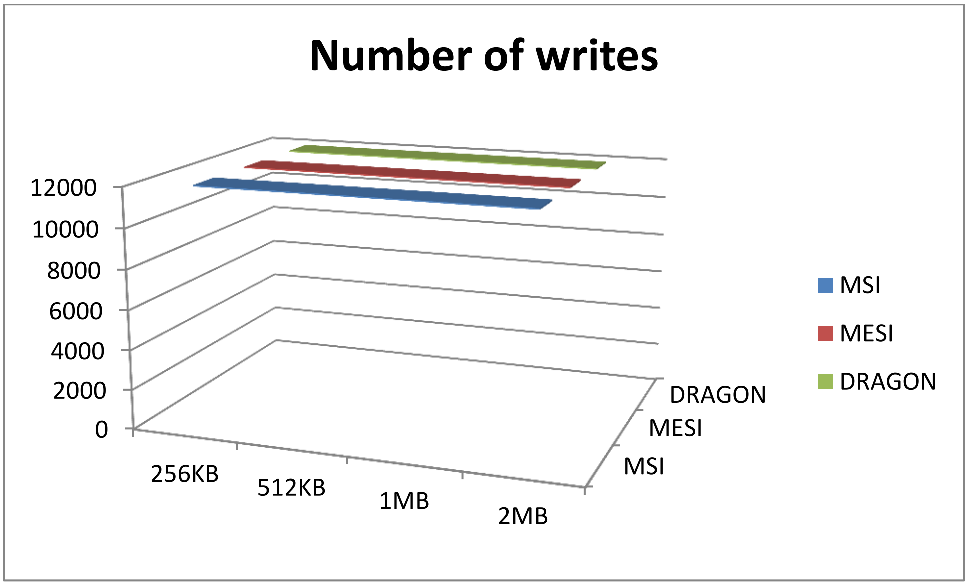
2) Number of read misses:



The number of read misses will be the same for MSI and MESI protocols but lesser for Dragon Protocol due to the existence of shared clean and shared modified. In the case of Invalidation that happens to the other processors in modified state during BusWrite, in the dragon protocol, it remains in the shared modified state which leads to read hit to any incoming processor reads.

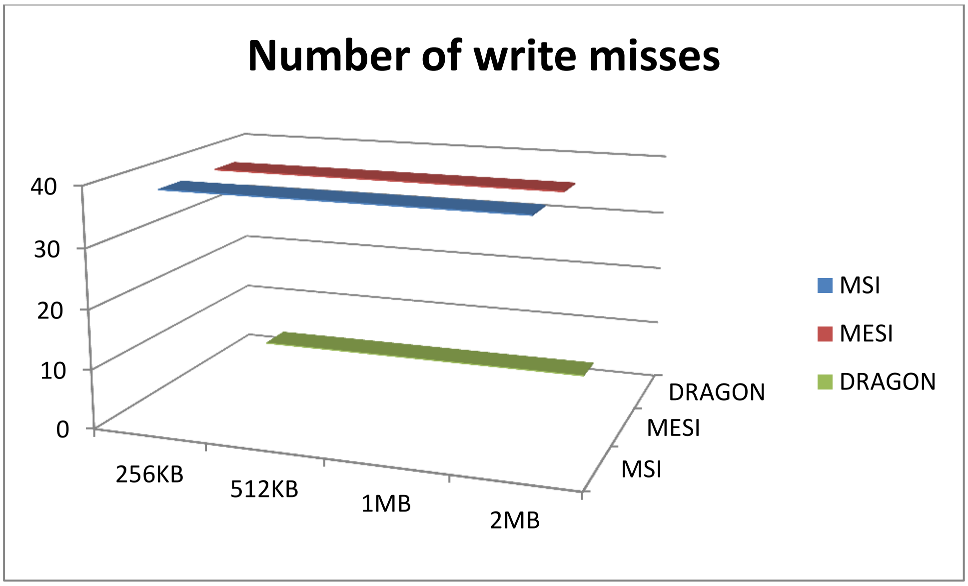
The read misses shows a slightly decreasing trend as cache size increases because conflict and capacity misses decrease.

3) <u>Number of processor writes</u>



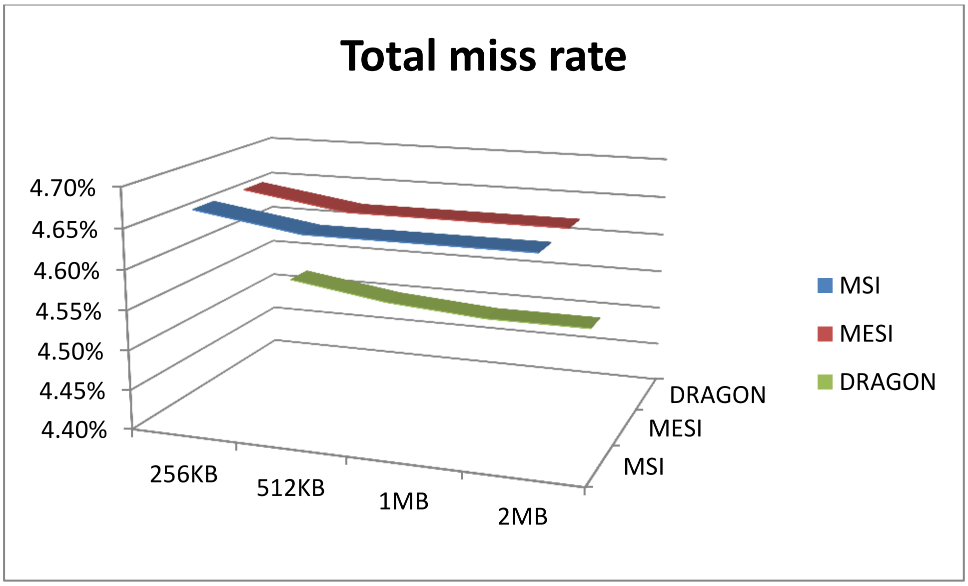
In the case of processor writes, same as the number of reads, all of them would have the same number as every write request to all the protocols would count to the number of writes.

4) Number of write misses



The number of write misses; same as read misses, is the same for MSI and MESI but will be lesser for Dragon because of the existence of shared clean and shared modified state instead of the invalid state that would make it a miss in case of MSI and MESI states. Write misses remain the same across all cache sizes.

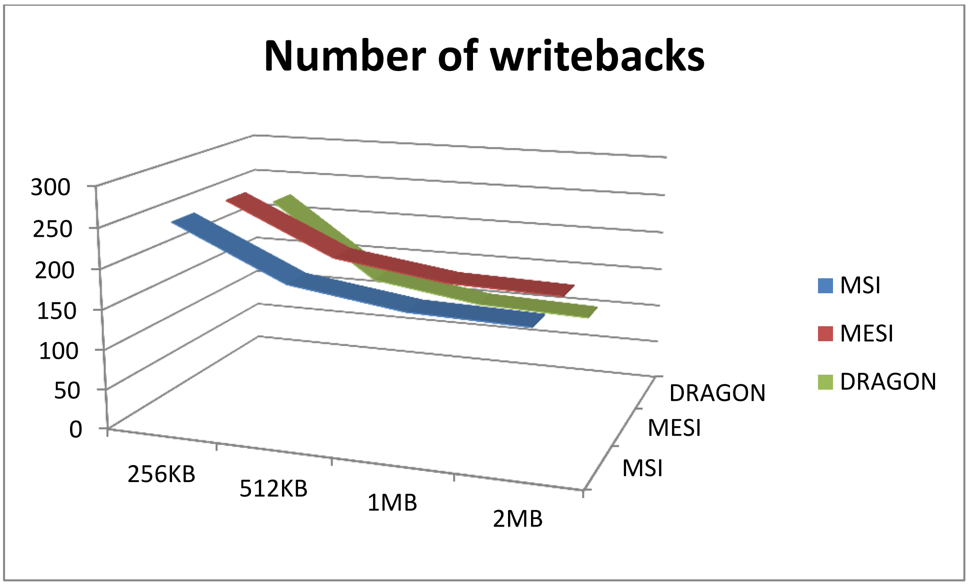
5) Total miss rate



Total miss rates are lesser for Dragon for the same reason as explained for both read and write misses.

Miss rate shows a slightly decreasing trend as cache size increases because conflict and capacity misses decreases with increase in cache size.

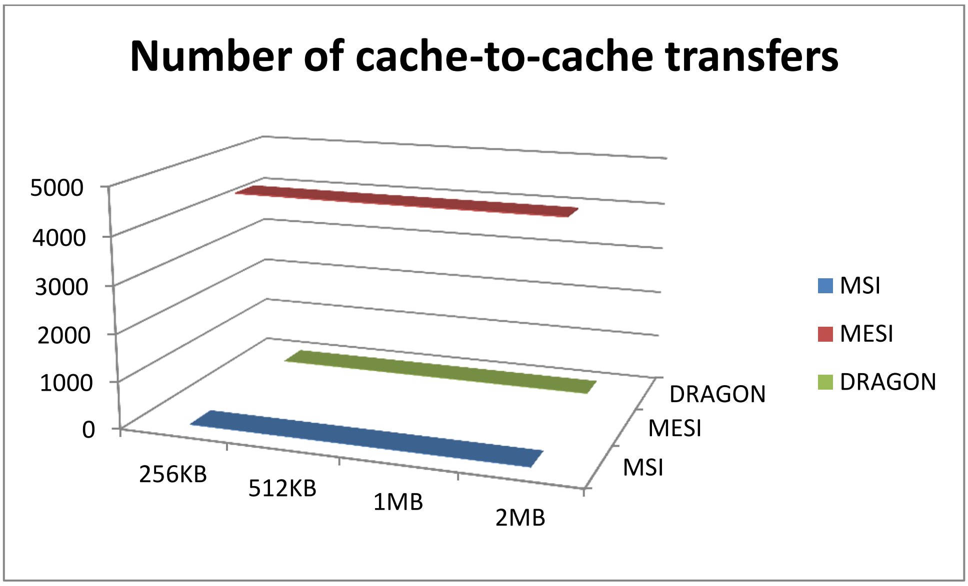
6) **<u>Number of write backs</u>**



Number of writebacks show the same value for MSI and MESI because for both of the cases, the dirty values get written back when it snoops a bus read or a bus upgrade request because of which writeback count is equal for MSI and MESI. However, for Dragon protocol since it goes to only shared states, writeback to main memory does not occur as frequently as in the case of MSI and MESI.

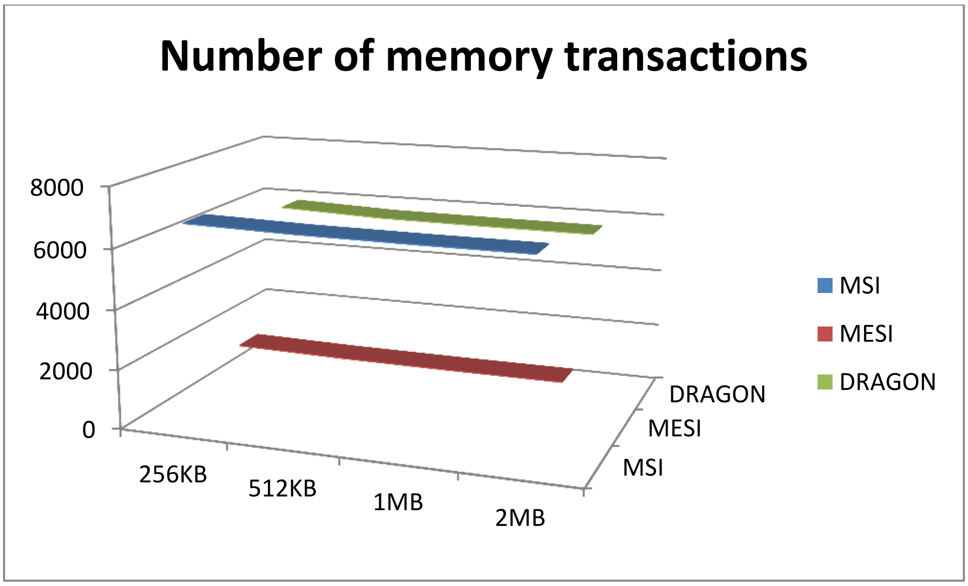
Writebacks shows a decreasing trend as the number of dirty copies in the cache will be lesser as the cache size increases hence there will be lesser writebacks to the main memory.

7) Number of cache- to cache transfer



Since for MESI protocol, miss leads to cache to cache transfers when a clean copy exists in the neighboring processor, and hence it shows a high value for MESI. But since this does not exist for MSI and Dragon, they both have zero values. The trend is constant for all cache sizes as it does not depend on the cache size.

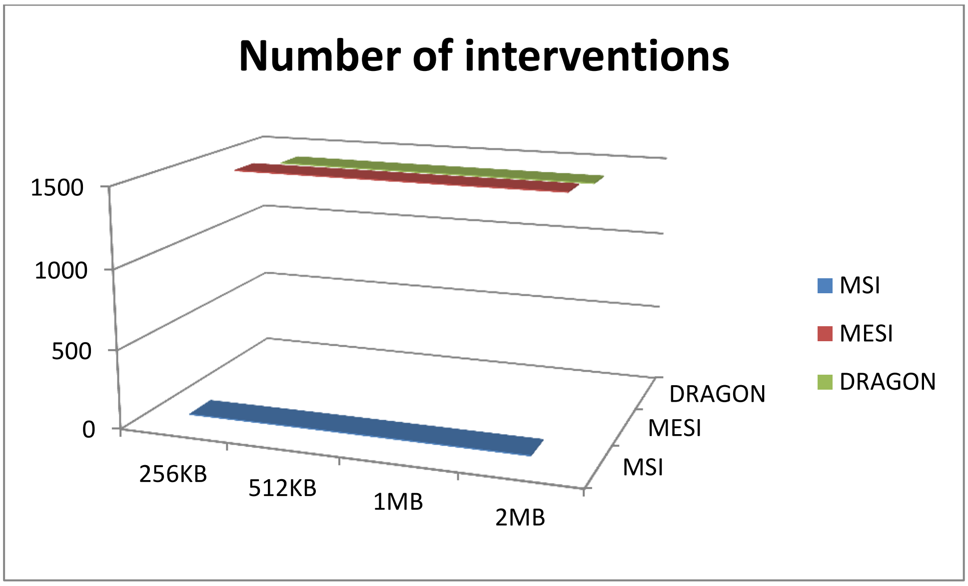
8) Number of memory transactions



Due to cache to cache transfer happening in the MESI protocol, the memory transactions that will be required for MESI will also be lesser than both MSI and Dragon. Dragon protocol has slightly lesser value than MSI due to the existence of shared clean and shared modified concept instead of solely modified and invalid states as in the case of MSI. This reduces the dirty copy increasing the memory transactions.

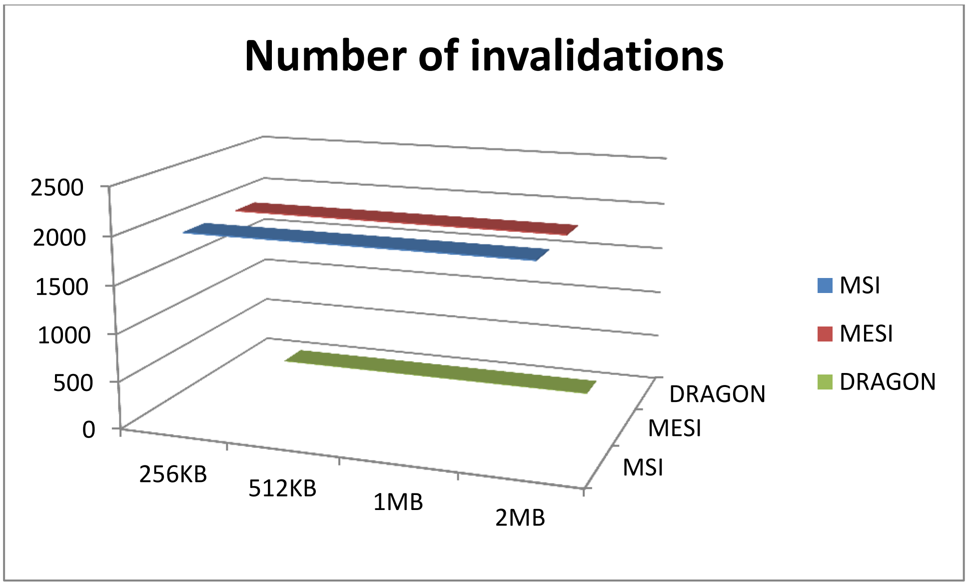
The trend shows a slightly decreasing trend as the number of misses decrease as the cache size increases and therefore the memory transactions decreases.

9) Number of interventions



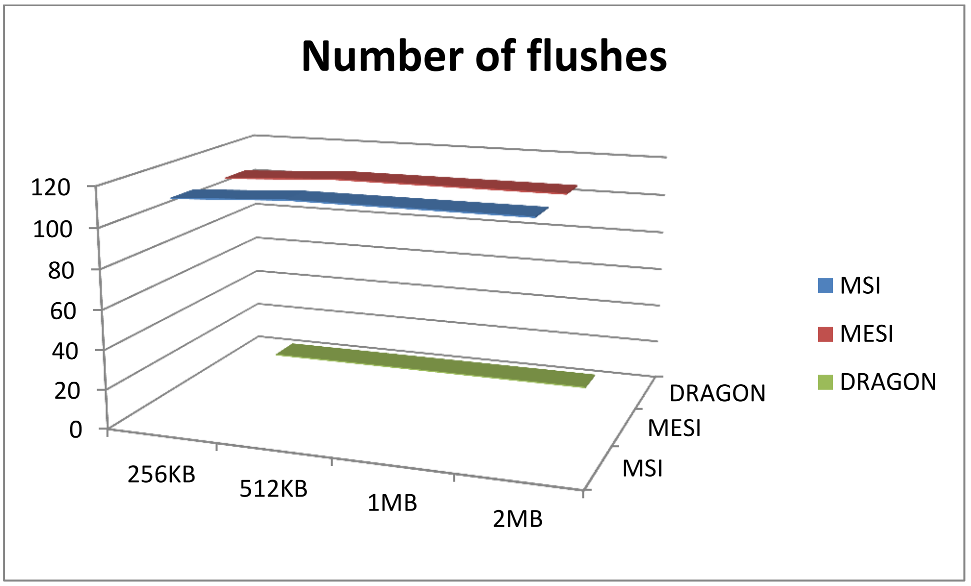
The number of interventions is much lesser for MSI when compared to MESI and Dragon. This is due to the non-existence of exclusive, shared clean or shared modified states in case of MESI and Dragon protocols. There is also a slight decreasing trend that is observed because the miss rates are decreasing and hence lesser evictions as cache size increases.

10) <u>Number of invalidations</u>



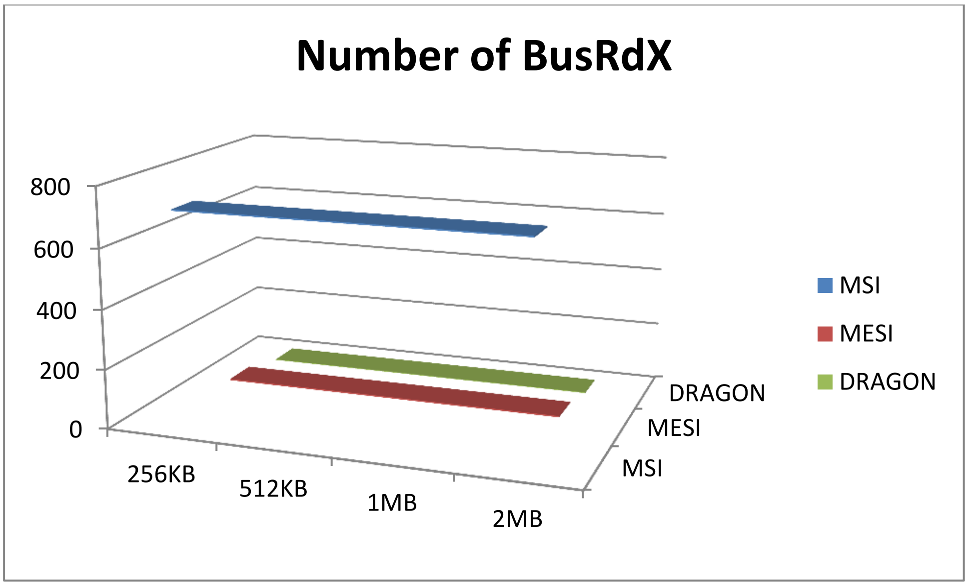
The number of invalidations are the same for both MSI and MESI protocols as they have the same concept of invalidating the shared copy when it snoops a bus write. However, the case is different with Dragon where it goes to shared modified and shared clean states instead of modified states and hence there is no invalidation. The trend is constant for increasing cache sizes as it does not depend on the cache size.

11) Number of flushes



Flushes are observed to be much lesser for the dragon protocol as compared to the other two states. From the graph, it is evident that the updation of the dirty state (when flush occurs in Dragon) is less frequent when compared to the dirty copies getting flushed in MSI and MESI protocols. The flushes shows a slightly increasing trend as the cache size increases since conflict and capacity misses will be lesser as the cache size increases and hence less misses and less invalidations and lesser flushes.

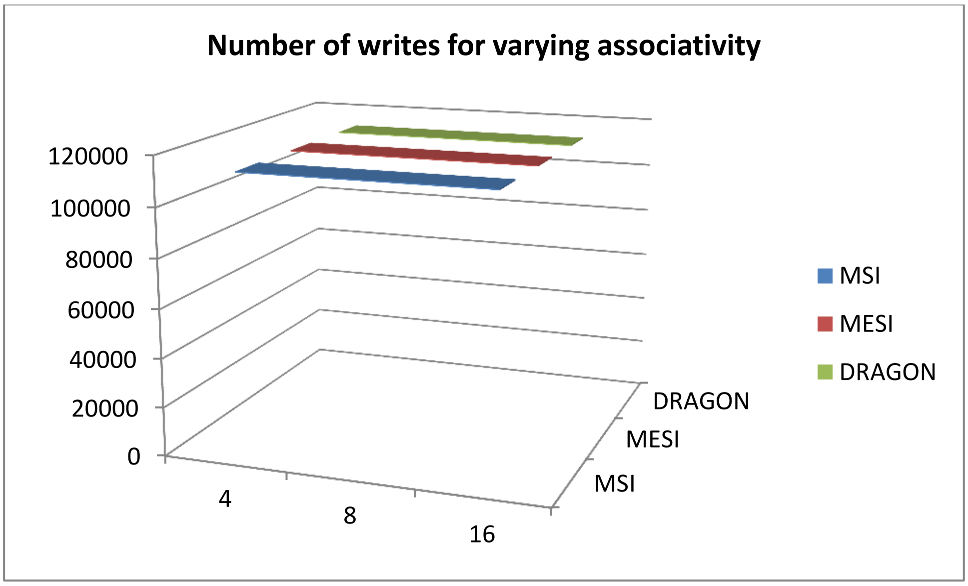
12) Number of Bus ReadX

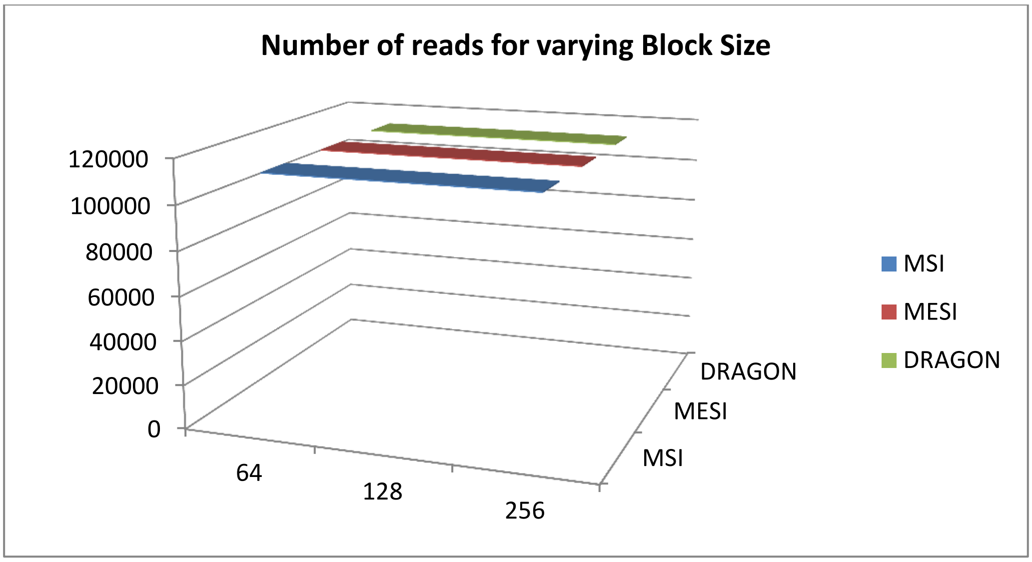


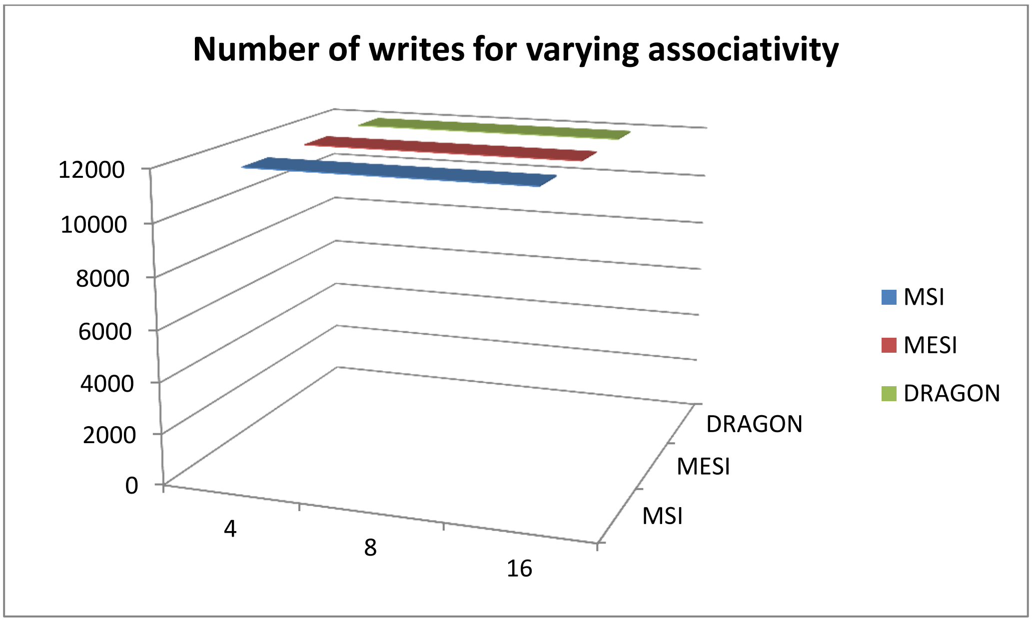
The BusRdX values is more for MSI when compared to Dragon and the value of Dragon is less when compared to MESI. Dragon has no BusRdX values since it does bus upgrade instead of BusRdX.

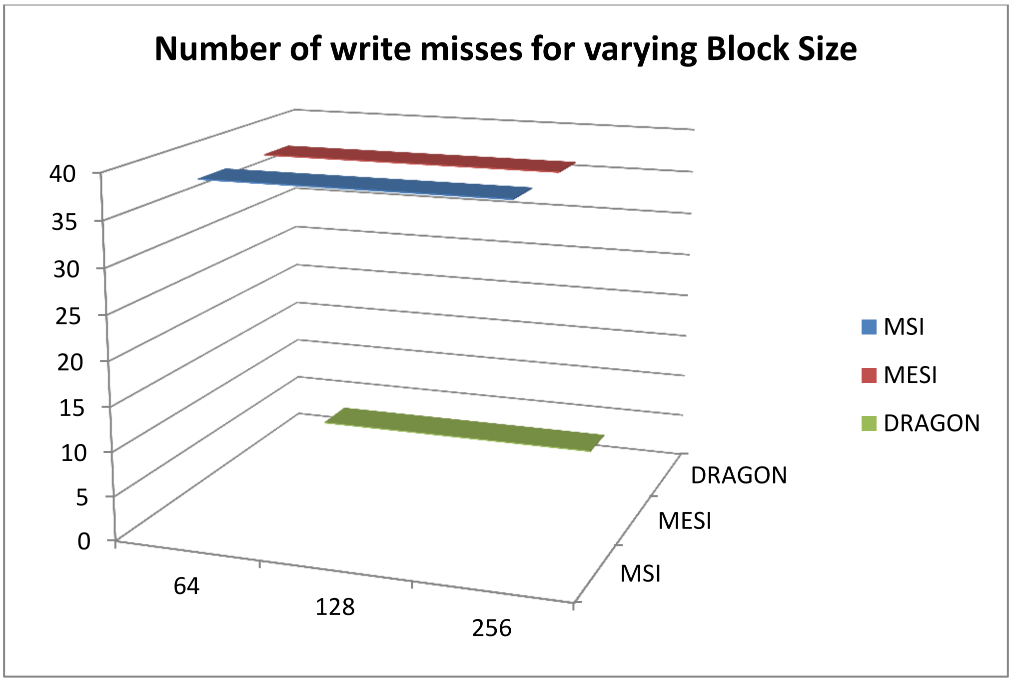
Varying Associativity and Block Size

1) Number of reads and writes



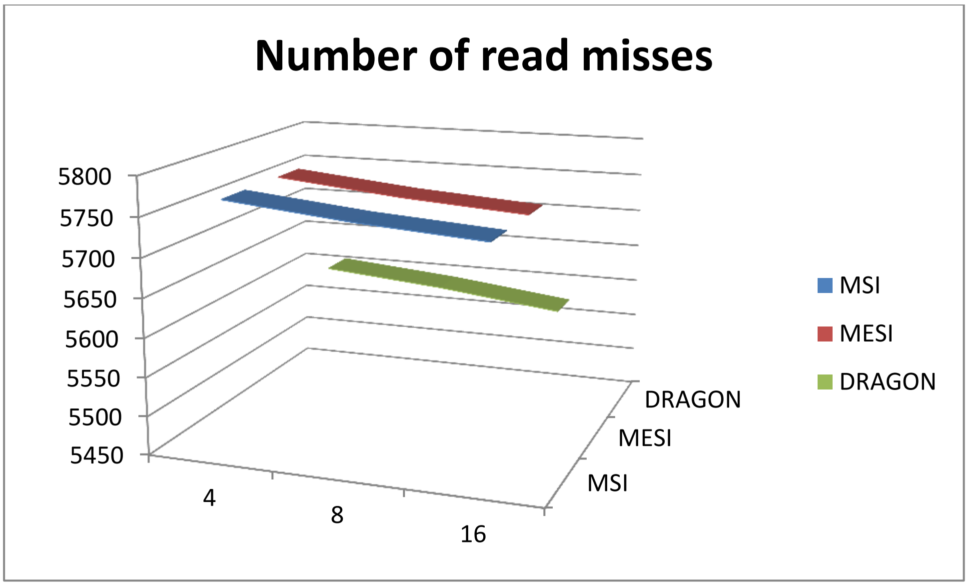

Number of reads for varying Block Size
120000
100000
80000
60000
40000
20000
0
64
128
256
MSI
MESI
DRAGON
MSI
MESI
DRAGON


Number of writes for varying associativity
12000
10000
8000
6000
4000
2000
0
4
8
16
MSI
MESI
DRAGON
MSI
MESI
DRAGON



The number of reads and writes will be the constant value for all the three protocols since every read and write request from the trace file will counted as the read and write value and will remain constant.

2) Number of read misses

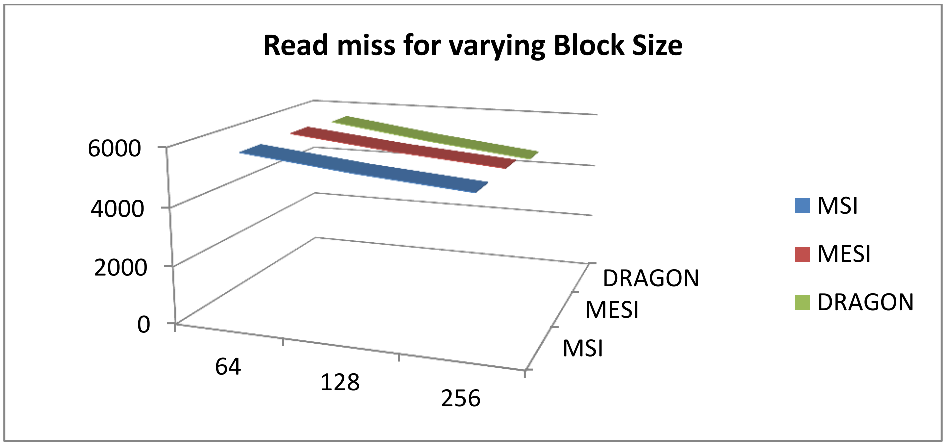


The number same as read misses,

is the same for MSI and MESI but will be lesser for Dragon because of the existence of shared clean and shared modified state instead of the invalid state that would make it a miss in case of MSI and MESI states.

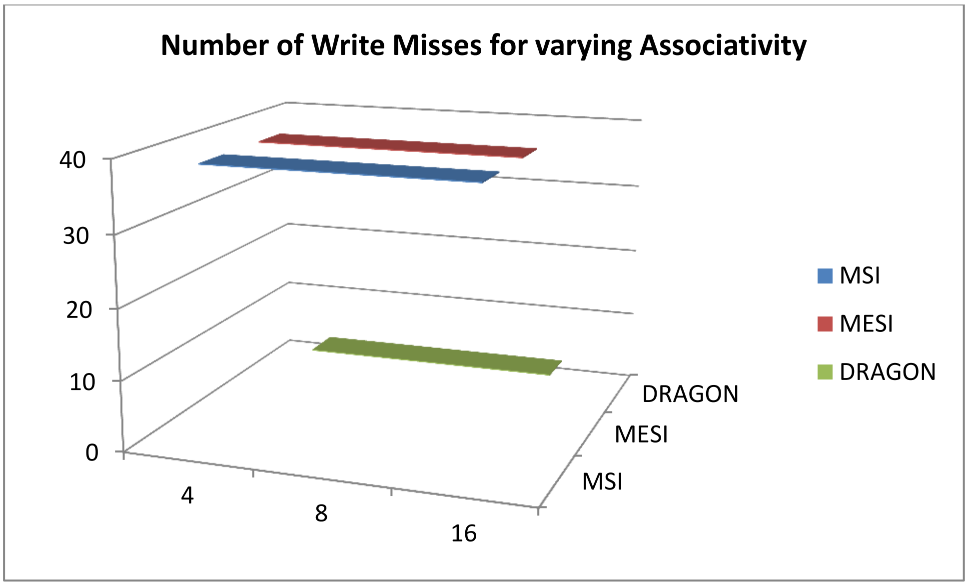
The trend is a decreasing value because conflict misses reduce when the associativity increases and so the number of read misses decrease.

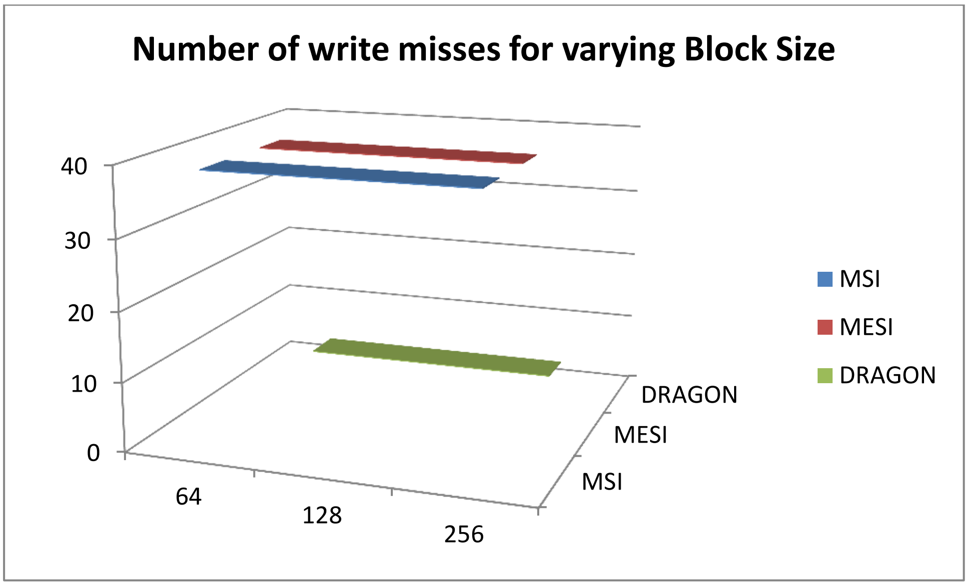
Varying Block Size



The general trend is slight decrease and the value for Dragon is slightly lesser because it invalidates its own cache line.

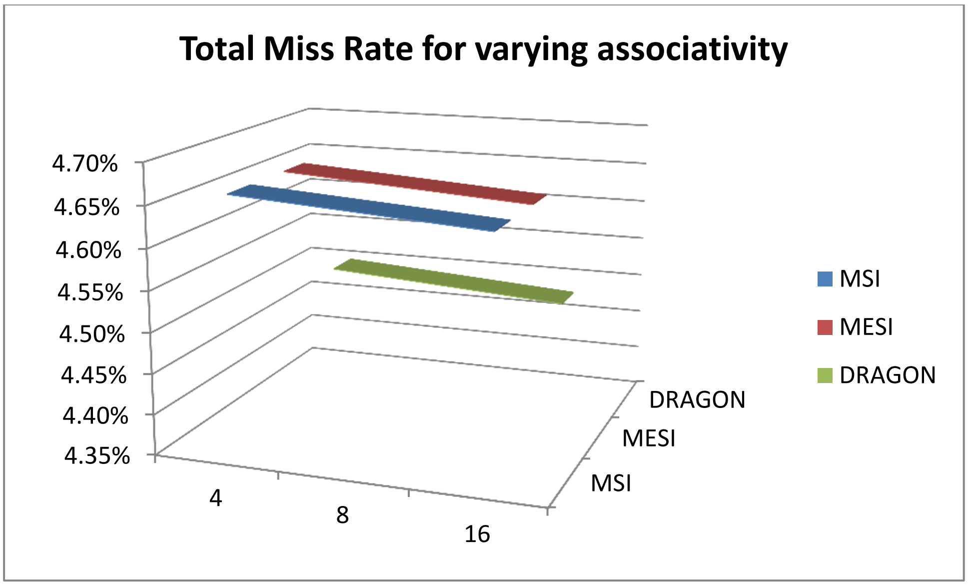
3) Number of write misses

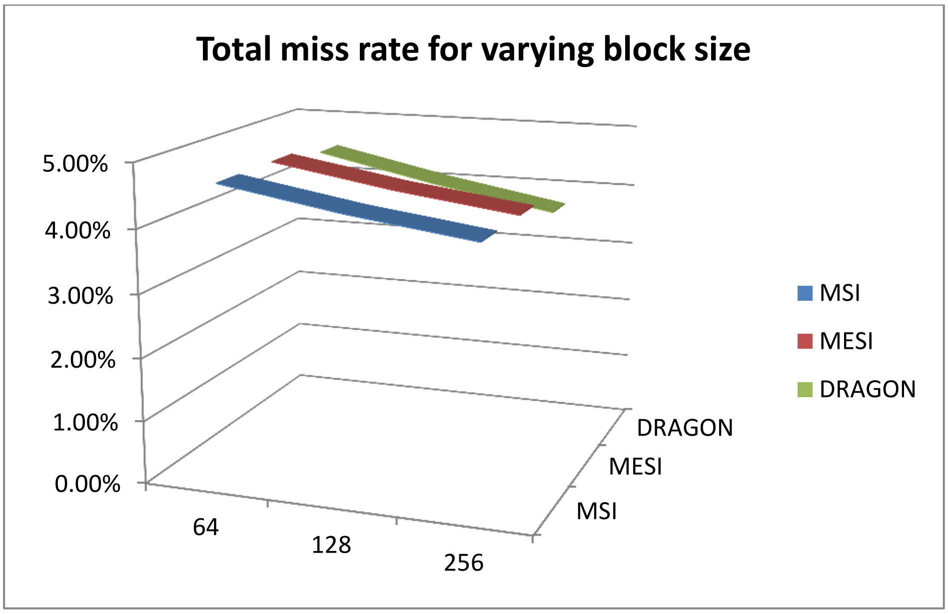




The number of write misses will be the same for MSI and MESI protocols but lesser for Dragon Protocol due to the existence of shared clean and shared modified. In the case of Invalidation that happens to the other processors in modified state during BusWrite, in the dragon protocol, it remains in the shared modified state. The trend remains constant for increasing associativity and block size.

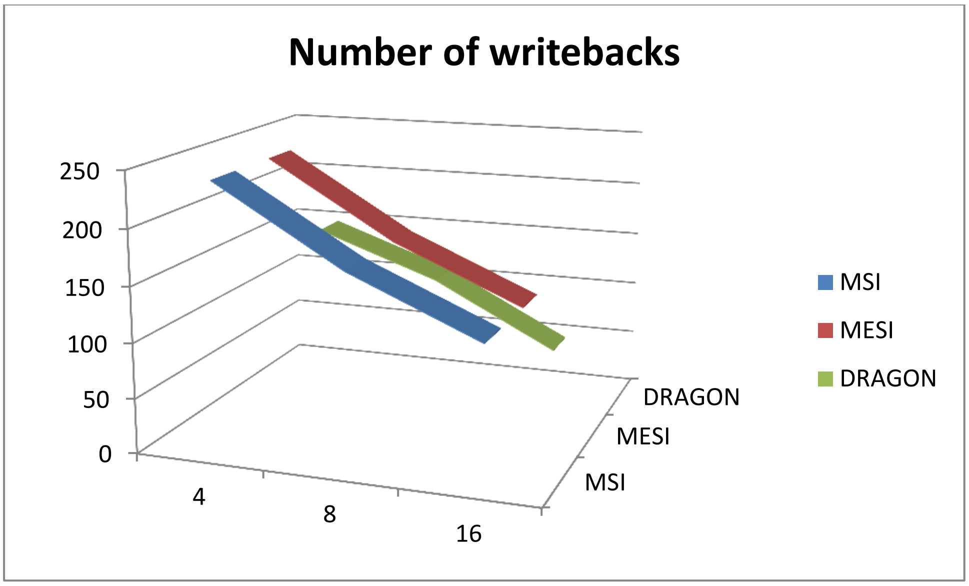
4) **Total Miss Rate**





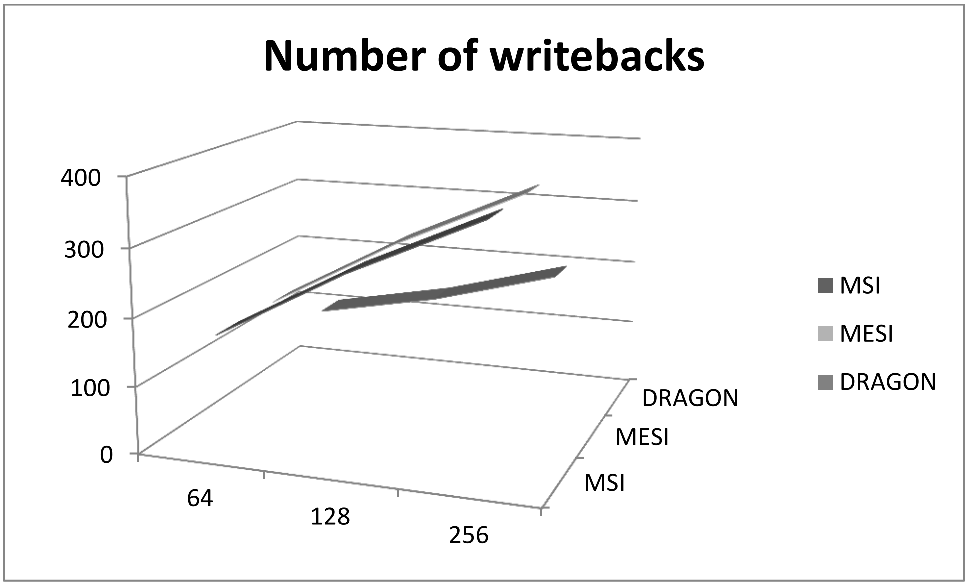
The miss rate will be lesser for Dragon when compared to MSI and MESI for the same reasons as above for read and write misses. For varying block size, if the trace file has values that are close together, then it increases granularity at which spatial locality is observed.

5) Number of writebacks



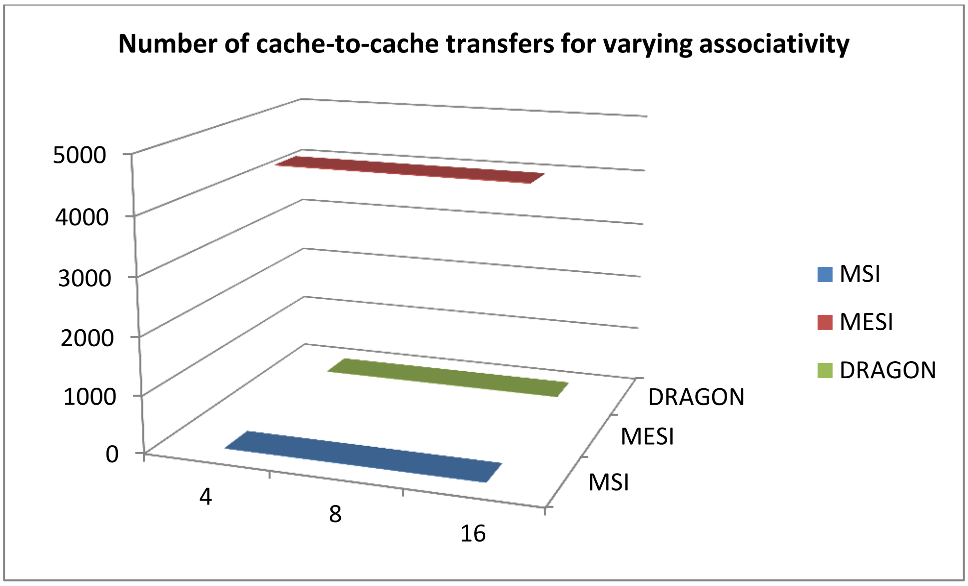
The writebacks is lesser for Dragon when compared to MSI and MESI and it shows a decreasing trend with increasing associativity. As the associativity increases, the eviction of dirty copy will decrease since there will be less conflict misses.

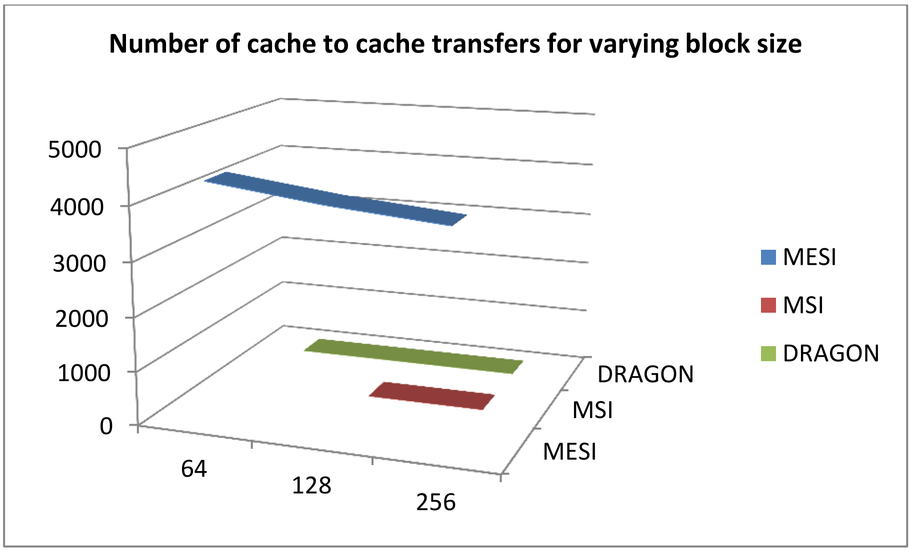
For Varying Block size



The trend observed here is an increase in the amount of writebacks with a bigger block size. An increasing block size causes an increase in the spatial locality bias,

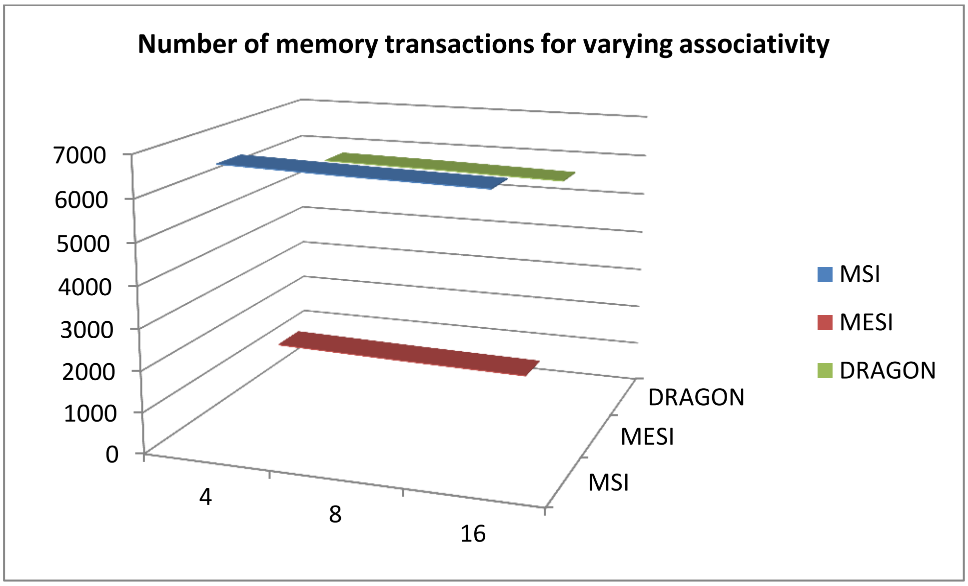
6) **<u>Number of cahe-to-cache transfers</u>**

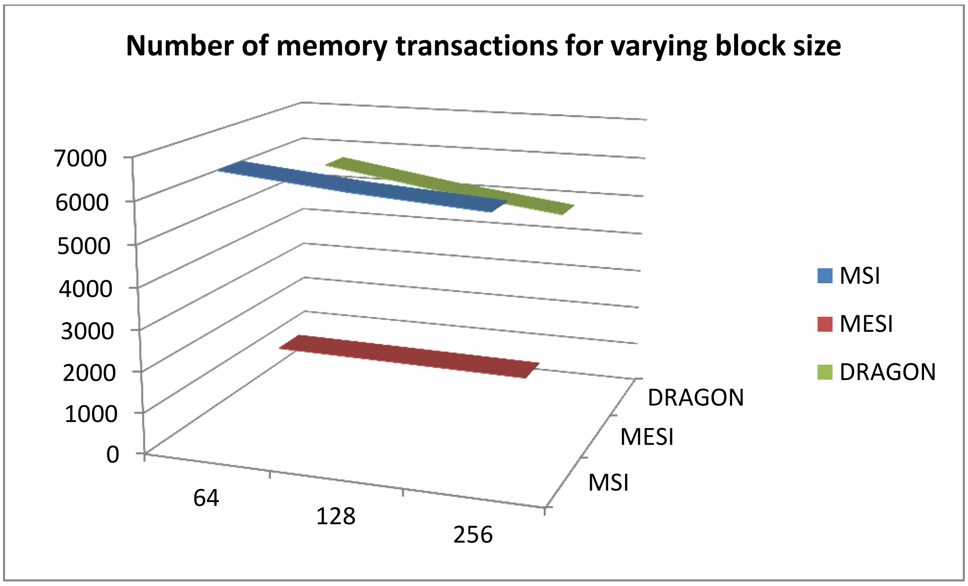




Since for MESI protocol, miss leads to cache to cache transfers when a clean copy exists in the neighboring processor, and hence it shows a high value for MESI. But since this does not exist for MSI and Dragon, they both have zero values. There is a only slight decreasing trend observed here as the associativity increases as compared to the cache size variation because of not enough evictions happening. For decreasing trend observed in varying the block size could be due to more cache hits.

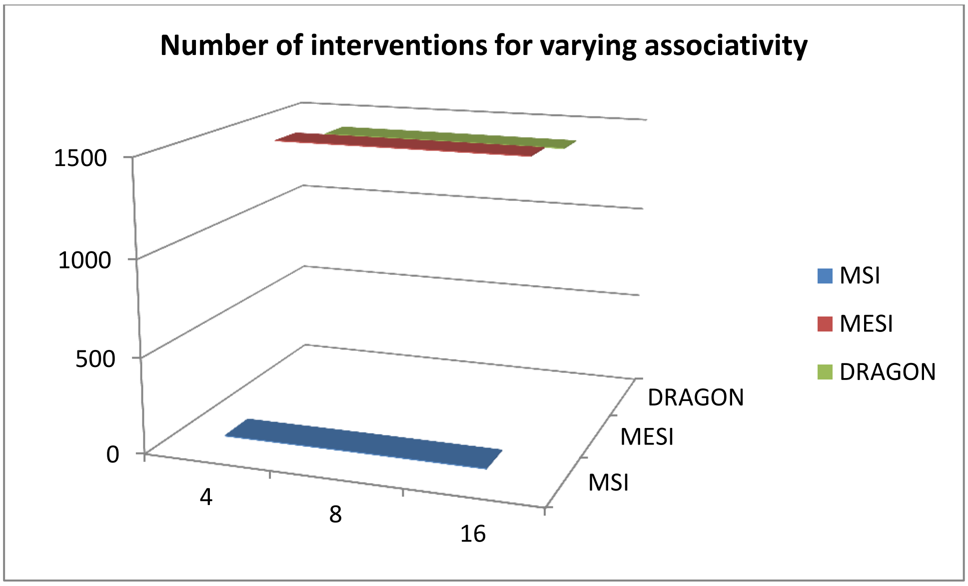
7) **<u>Number of memory transactions</u>**

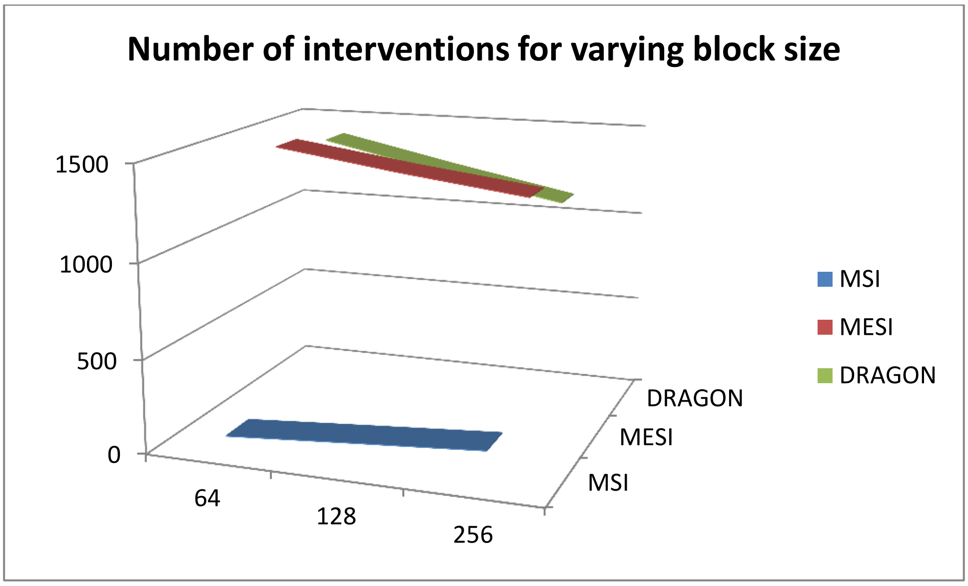




Memory transactions show a slightly decreasing trend as the conflict misses decrease, the memory transactions will decrease too.

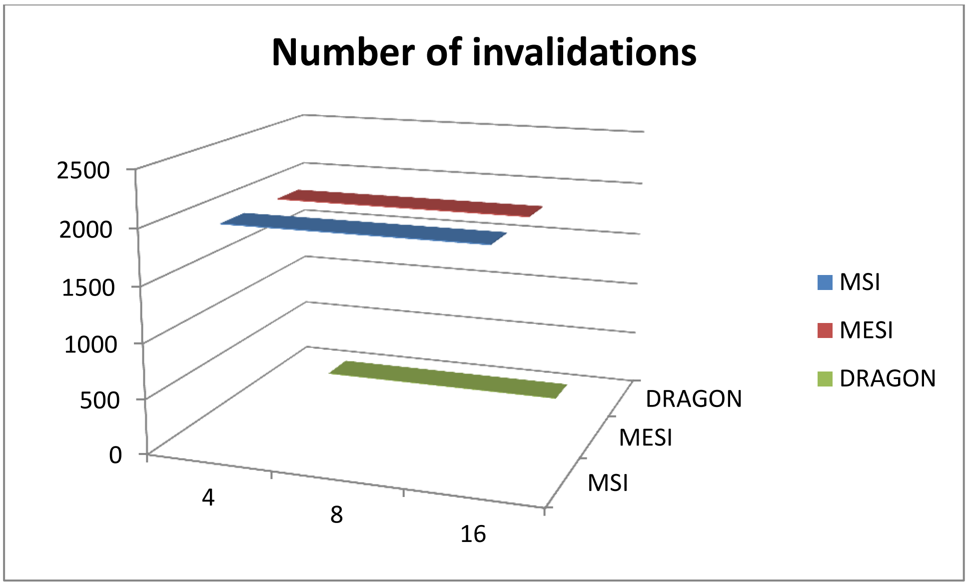
8) <u>Number of interventions</u>

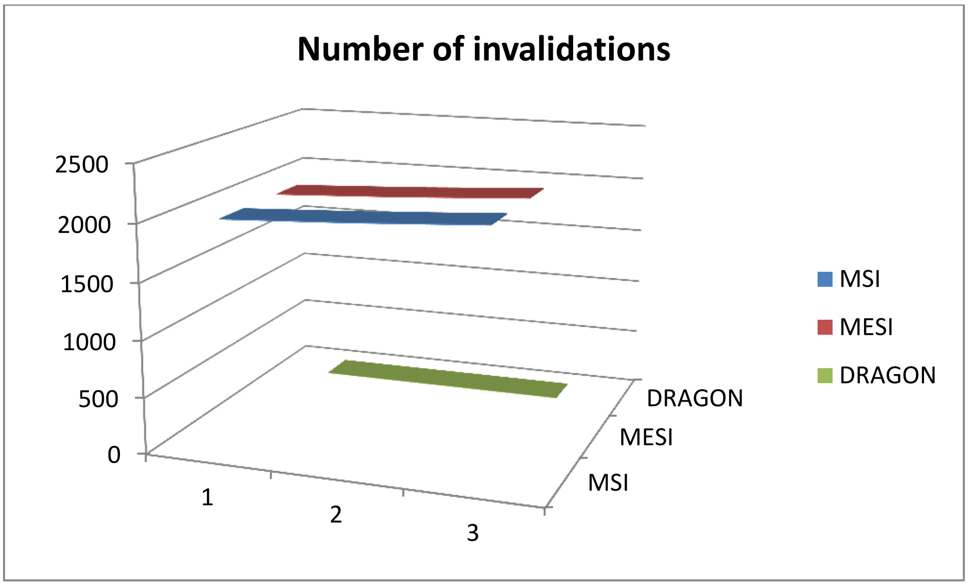




Number of interventions remains almost constant with increasing associativity. MSI has a lower value as it does not have an Exclusive state.

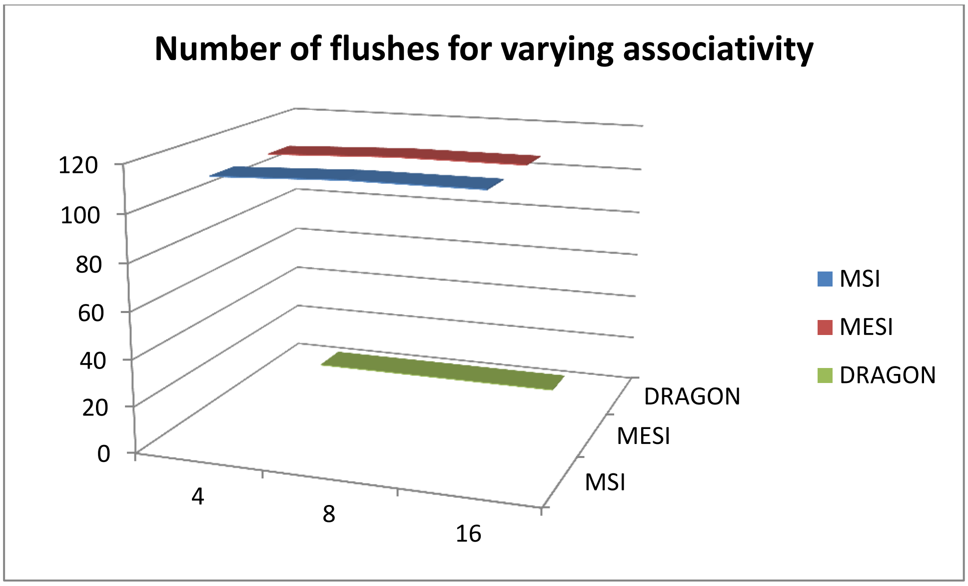
9) Number of invalidations



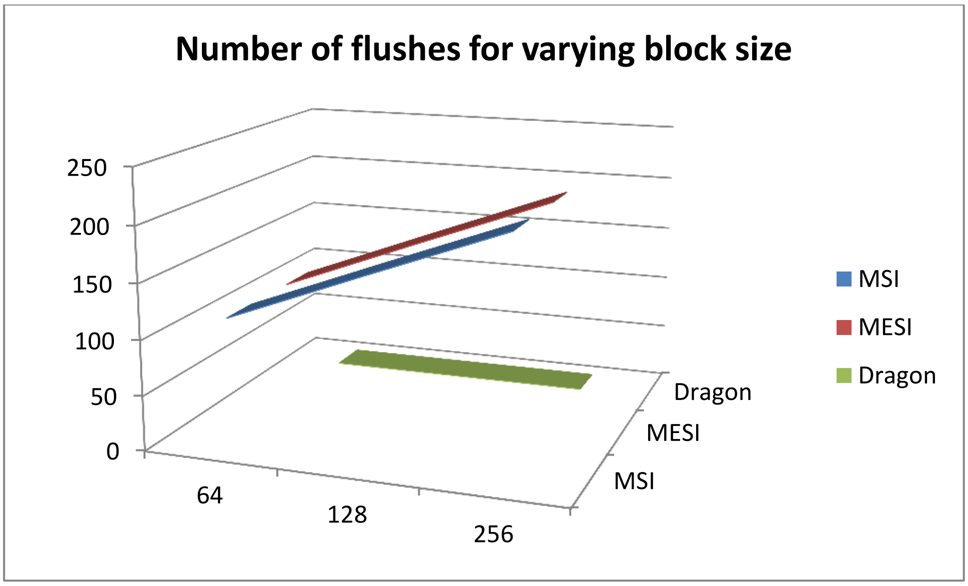


The invalidation here is same as for varying the cache size. It does not exist for Dragon protocol and the value remains constant for varying associativity and block sizes.

10) <u>Number of flushes</u>

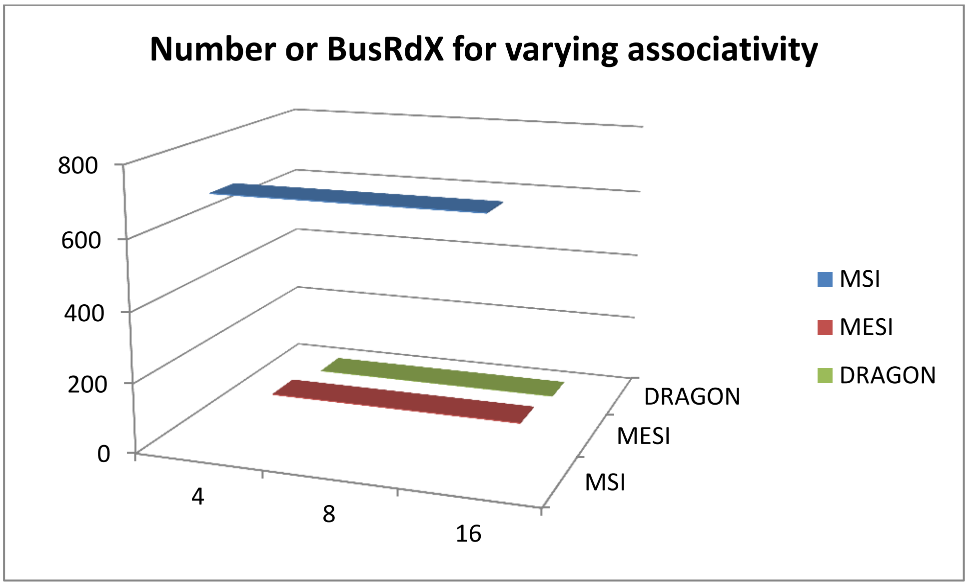


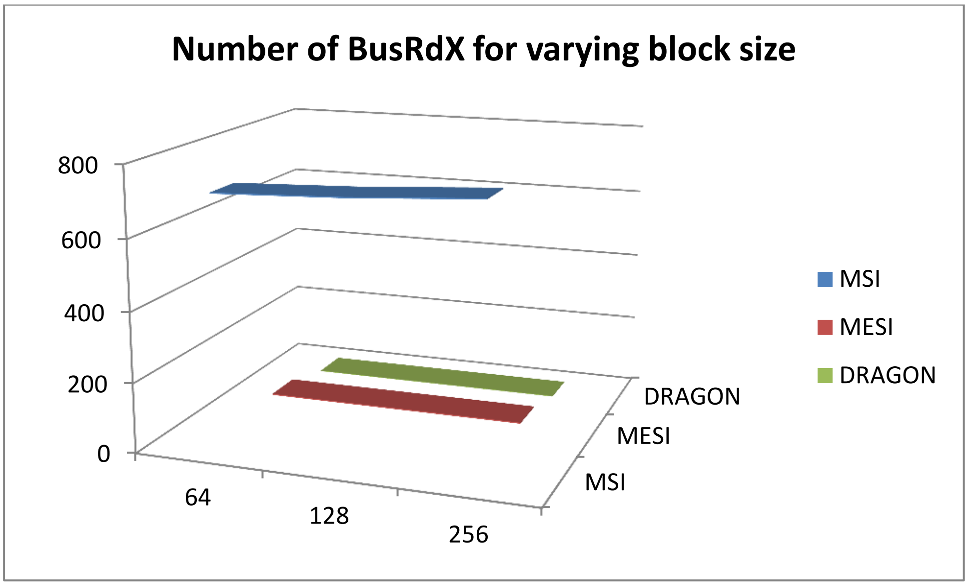
The number of flushes almost remains constant with increasing associativity. It follows the same trend and inference as for varying cache sizes.



Similar to the writeback trend, here it is increasing with block size. The increased amount of evictions is the reason for the increase in flushes.

11) <u>Number of BusRdX</u>





The number of BusRdX almost remains constant with increasing associativity and block size. Again, it follows the same trend and inference as for varying cache sizes.

Values for Varying Block Size

MSI

01. number of reads	64B	128B	256B
c0	112661	112661	112661
c1	110830	110830	110830
c2	114938	114938	114938
c3	113428	113428	113428
02. number of read misses			
c0	5752	5340	5023
c1	5781	5386	5070
c2	5752	5341	5004
c3	5790	5384	5084
03. number of writes			
c0	11942	11942	11942
c1	11710	11710	11710
c2	12383	12383	12383
c3	12108	12108	12108
04. number of write misses			
c0	39	39	39
c1	41	40	40
c2	42	42	42
c3	39	39	39
05. total miss rate			
c0	4.65%	4.32%	4.06%
c1	4.75%	4.43%	4.17%
c2	4.55%	4.23%	3.96%
c3	4.64%	4.32%	4.08%
06. number of writebacks			
c0	170	275	363
c1	155	250	342
c2	186	283	383
c3	157	269	332
07. number of cache-to-cache transfers			
c0	0	0	

c1	0	0	
c2	0	0	
c3	0	0	
08. number of memory transactions			
c0	6638	6344	6137
c1	6636	6347	6147
c2	6663	6369	6167
c3	6661	6386	6159
09. number of interventions			
c0	71	119	166
c1	48	84	133
c2	82	127	192
c3	64	110	145
10. number of invalidations			
c0	2014	2066	2132
c1	2034	2089	2157
c2	2008	2053	2107
c3	2020	2068	2148
11. number of flushes			
c0	116	164	211
c1	93	129	178
c2	121	166	231
c3	89	135	170
12. number of BusRdX			
c0	716	729	751
c1	700	711	735
c2	725	745	780
c3	714	733	743

MESI and Dragon

MESI					DRAGON		
01. number of reads	64B	128B	256B		64B	128B	256B
c0	112661	112661	112661		112661	112661	112661
c1	110830	110830	110830		110830	110830	110830
c2	114938	114938	114938		114938	114938	114938
c3	113428	113428	113428		113428	113428	113428
02. number of read misses							
c0	5752	5340	5023		5595	5069	4628
c1	5781	5386	5070		5604	5080	4633
c2	5752	5341	5004		5604	5080	4630
c3	5790	5384	5084		5611	5086	4640
03. number of writes							
c0	11942	11942	11942		11942	11942	11942
c1	11710	11710	11710		11710	11710	11710
c2	12383	12383	12383		12383	12383	12383
c3	12108	12108	12108		12108	12108	12108
04. number of write misses							
c0	39	39	39		3	3	3
c1	41	40	40		2	1	1
c2	42	42	42		2	2	2
c3	39	39	39		0	0	0
05. total miss rate							
c0	4.65%	4.32%	4.06%		4.49%	4.07%	3.72%
c1	4.75%	4.43%	4.17%		4.57%	4.15%	3.78%
c2	4.55%	4.23%	3.96%		4.40%	3.99%	3.64%
c3	4.64%	4.32%	4.08%		4.47%	4.05%	3.70%
06. number of writebacks							
c0	170	275	363		107	145	198
c1	155	250	342		110	149	200
c2	186	283	383		105	145	185
c3	157	269	332		123	160	196

07. number of cache-to-cache transfers							
c0	4389	4124	3938		0	0	0
c1	4422	4155	3943		0	0	0
c2	4393	4115	3903		0	0	0
c3	4395	4125	3939		0	0	0
08. number of memory transactions							
c0	1572	1530	1487		5705	5217	4829
c1	1555	1521	1509		5716	5230	4834
c2	1587	1551	1526		5711	5227	4817
c3	1591	1567	1516		5734	5246	4836
09. number of interventions							
c0	1464	1367	1283		1398	1256	1125
c1	1428	1337	1284		1387	1266	1175
c2	1464	1377	1321		1387	1257	1143
c3	1474	1385	1309		1417	1287	1176
10. number of invalidations							
c0	2014	2066	2132		0	0	0
c1	2034	2089	2157		0	0	0
c2	2008	2053	2107		0	0	0
c3	2020	2068	2148		0	0	0
11. number of flushes							
c0	116	164	211		3	3	3
c1	93	129	178		9	9	11
c2	121	166	231		6	6	9
c3	89	135	170		6	9	9
12. number of BusRdX							
c0	39	39	39		0	0	0
c1	41	40	40		0	0	0
c2	42	42	42		0	0	0
c3	39	39	39		0	0	0

Varying Associativity

MSI

01. number of reads	4	8	16
c0	112661	112661	112661
c1	110830	110830	110830
c2	114938	114938	114938
c3	113428	113428	113428
	02. number of read misses		
c0	5768	5752	5741
c1	5797	5781	5772
c2	5762	5752	5741
c3	5803	5790	5780
	03. number of writes		
c0	11942	11942	11942
c1	11710	11710	11710
c2	12383	12383	12383
c3	12108	12108	12108
	04. number of write misses		
c0	39	39	39
c1	41	41	41
c2	42	42	42
c3	39	39	39
	05. total miss rate		
c0	4.66%	4.65%	4.64%
c1	4.76%	4.75%	4.74%
c2	4.56%	4.55%	4.54%
c3	4.65%	4.64%	4.64%
	06. number of writebacks		
c0	239	170	120
c1	211	155	101
c2	239	186	130

c3	224	157	98
	07. number of cache-to-cache transfers		
c0	0	0	0
c1	0	0	0
c2	0	0	0
c3	0	0	0
	08. number of memory transactions		
c0	6723	6638	6577
c1	6708	6636	6573
c2	6726	6663	6596
c3	6741	6661	6592
	09. number of interventions		
c0	69	71	71
c1	47	48	48
c2	81	82	83
c3	63	64	64
	10. number of invalidations		
c0	2014	2014	2014
c1	2034	2034	2034
c2	2008	2008	2008
c3	2020	2020	2020
	11. number of flushes		
c0	114	116	116
c1	92	93	93
c2	120	121	122
c3	88	89	89
	12. number of BusRdX		
c0	716	716	716
c1	700	700	700
c2	725	725	725

c3	714	714	714

MESI and Dragon

01. number of reads		MESI				DRAGON	
	4	8	16		4	8	16
c0	112661	112661	112661		112661	112661	112661
c1	110830	110830	110830		110830	110830	110830
c2	114938	114938	114938		114938	114938	114938
c3	113428	113428	113428		113428	113428	113428
02. number of read misses							
c0	5768	5752	5741		5609	5595	5576
c1	5797	5781	5772		5619	5604	5586
c2	5762	5752	5741		5619	5604	5586
c3	5803	5790	5780		5626	5611	5593
03. number of writes							
c0	11942	11942	11942		11942	11942	11942
c1	11710	11710	11710		11710	11710	11710
c2	12383	12383	12383		12383	12383	12383
c3	12108	12108	12108		12108	12108	12108
04. number of write misses							
c0	39	39	39		3	3	3
c1	41	41	41		2	2	2
c2	42	42	42		2	2	2
c3	39	39	39		0	0	0
05. total miss rate							
c0	4.66%	4.65%	4.64%		4.50%	4.49%	4.48%
c1	4.76%	4.75%	4.74%		4.59%	4.57%	4.56%
c2	4.56%	4.55%	4.54%		4.41%	4.40%	4.39%
c3	4.65%	4.64%	4.64%		4.48%	4.47%	4.46%
06. number of writebacks							
c0	239	170	120		148	107	47

c1	211	155	101		149	110	43
c2	239	186	130		142	105	62
c3	224	157	98		158	123	57
07. number of cache-to-cache transfers							
c0	4402	4389	4379		0	0	0
c1	4434	4422	4415		0	0	0
c2	4401	4393	4386		0	0	0
c3	4401	4395	4386		0	0	0
08. number of memory transactions							
c0	1644	1572	1521		5760	5705	5626
c1	1615	1555	1499		5770	5716	5631
c2	1642	1587	1527		5763	5711	5650
c3	1665	1591	1531		5784	5734	5650
09. number of interventions							
c0	1465	1464	1463		1400	1398	1395
c1	1431	1428	1426		1392	1387	1382
c2	1465	1464	1461		1388	1387	1383
c3	1480	1474	1473		1424	1417	1411
10. number of invalidations							
c0	2014	2014	2014		0	0	0
c1	2034	2034	2034		0	0	0
c2	2008	2008	2008		0	0	0
c3	2020	2020	2020		0	0	0
11. number of flushes							
c0	114	116	116		3	3	3
c1	92	93	93		9	9	9
c2	120	121	122		6	6	6
c3	88	89	89		6	6	6
12. number of BusRdX							
c0	39	39	39		0	0	0

c1	41	41	41		0	0	0
c2	42	42	42		0	0	0
c3	39	39	39		0	0	0

Varying Cache Size

MSI

256KB	512KB	1MB	2MB
01. number of reads			
112661	112661	112661	112661
110830	110830	110830	110830
114938	114938	114938	114938
113428	113428	113428	113428
02. number of read misses			
5775	5757	5752	5750
5805	5792	5781	5779
5771	5756	5752	5751
5813	5796	5790	5789
03. number of writes			
11942	11942	11942	11942
11710	11710	11710	11710
12383	12383	12383	12383
12108	12108	12108	12108
04. number of write misses			
39	39	39	39
41	41	41	41
42	42	42	42
39	39	39	39
05. total miss rate			
4.67%	4.65%	4.65%	4.65%
4.77%	4.76%	4.75%	4.75%
4.57%	4.55%	4.55%	4.55%
4.66%	4.65%	4.64%	4.64%

06. number of writebacks			
254	190	170	166
235	170	155	143
278	205	186	176
234	171	157	152
07. number of cache-to-cache transfers			
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
08. number of memory transactions			
6745	6663	6638	6632
6740	6662	6636	6622
6774	6686	6663	6652
6761	6681	6661	6655
09. number of interventions			
68	71	71	71
47	47	48	48
81	82	82	82
63	63	64	64
10. number of invalidations			
2014	2014	2014	2014
2034	2034	2034	2034
2008	2008	2008	2008
2020	2020	2020	2020
11. number			

of flushes				
113	116	116	116	
92	92	93	93	
120	121	121	121	
88	88	89	89	
12. number of BusRdX				
716	716	716	716	
700	700	700	700	
725	725	725	725	
714	714	714	714	

<u>Varying MESI and Dragon</u>

	MESI					DRAGON		
01. number of reads	256KB	512KB	1MB	2MB		256KB	512KB	1MB
c0	112661	112661	112661	112661		112661	112661	112661
c1	110830	110830	110830	110830		110830	110830	110830
c2	114938	114938	114938	114938		114938	114938	114938
c3	113428	113428	113428	113428		113428	113428	113428
02. number of read misses								
c0	5775	5757	5752	5750		5635	5601	5595
c1	5805	5792	5781	5779		5646	5610	5604
c2	5771	5756	5752	5751		5644	5610	5604
c3	5813	5796	5790	5789		5652	5617	5611
03. number of writes								
c0	11942	11942	11942	11942		11942	11942	11942
c1	11710	11710	11710	11710		11710	11710	11710
c2	12383	12383	12383	12383		12383	12383	12383
c3	12108	12108	12108	12108		12108	12108	12108
04. number of write misses								
c0	39	39	39	39		3	3	3

c1	41	41	41	41		2	2	2
c2	42	42	42	42		2	2	2
c3	39	39	39	39		0	0	0
05. total miss rate								
c0	4.67%	4.65%	4.65%	4.65%		4.52%	4.50%	4.49%
c1	4.77%	4.76%	4.75%	4.75%		4.61%	4.58%	4.57%
c2	4.57%	4.55%	4.55%	4.55%		4.43%	4.41%	4.40%
c3	4.66%	4.65%	4.64%	4.64%		4.50%	4.47%	4.47%
06. number of writebacks								
c0	254	190	170	166		226	128	107
c1	235	170	155	143		243	127	110
c2	278	205	186	176		232	135	105
c3	234	171	157	152		234	141	123
07. number of cache-to-cache transfers								
c0	4405	4392	4389	4387		0	0	0
c1	4441	4431	4422	4420		0	0	0
c2	4406	4396	4393	4392		0	0	0
c3	4411	4400	4395	4394		0	0	0
08. number of memory transactions								
c0	1663	1594	1572	1568		5864	5732	5705
c1	1640	1572	1555	1543		5891	5739	5716
c2	1685	1607	1587	1577		5878	5747	5711
c3	1675	1606	1591	1586		5886	5758	5734
09. number of interventions								
c0	1468	1466	1464	1464		1405	1400	1398
c1	1432	1429	1428	1428		1396	1388	1387
c2	1469	1465	1464	1464		1398	1389	1387
c3	1479	1474	1474	1474		1430	1418	1417
10. number								

of invalidations								
c0	2014	2014	2014	2014		0	0	0
c1	2034	2034	2034	2034		0	0	0
c2	2008	2008	2008	2008		0	0	0
c3	2020	2020	2020	2020		0	0	0
11. number of flushes								
c0	113	116	116	116		3	3	3
c1	92	92	93	93		9	9	9
c2	120	121	121	121		6	6	6
c3	88	88	89	89		9	6	6
12. number of BusRdX								
c0	39	39	39	39		0	0	0
c1	41	41	41	41		0	0	0
c2	42	42	42	42		0	0	0
c3	39	39	39	39		0	0	0