Note: Using a VM for measurement and testing (may have affected some results)

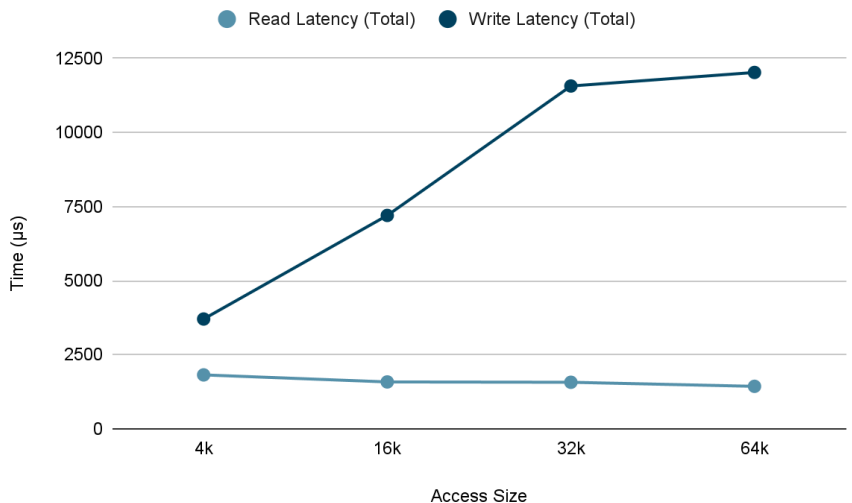
Effect of Data Access Size on Latency:

- Fixed Parameters: Read/Write Ratio: 50% Read / 50% Write, I/O Queue Depth: 16
- Varied Parameter: Data Access Size
- Command used:

fio --filename=testfile --size=10G --rw=randrw --rwmixread=50 --bs=[Variable] --iodepth=16 --time_based --runtime=60 --name=test

Data Access Size	Read Latency (total) lat(µs)			Read Latency (Submission) lat(us)			Read Latency (Completion) lat(ns)		
	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
4k	1820.3	7	206848	28.51	2	59147	1791k	500	20624k
16k	1582.84	210	133349	34.38	2	10025	1582.84	3	133339
32k	1571.52	76	210530	39.9	2	21597	1531.61	9	210521
64k	1434.52	120	125485	130.07	3	16139	1390	77	125466

Data Access Size	Write Latency (total) lat(µs)			Write Latency (Submission) lat(us)			Write Latency (Completion) lat(ns)		
	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
4k	3705.32	6	406369	54.17	2	12863	3651k	375	406365k
16k	7200.72	21	1117.6k	76.07	2	14546	7124k	583	1117.6M
32k	11567.48	26	6354.1k	76.15	3	123153	11481k	26	6354.1k
64k	12025.18	68	1368.6k	77.14	4	123919	11948k	542	1368.6M



Effect of Read/Write Intensity Ratio on Latency:

- Fixed Parameters: Data Access Size: 4KB, I/O Queue Depth: 16
- Varied Parameter: Read/Write Ratio
- Command used:

fio --filename=testfile --size=10G --rw=randrw --rwmixread=[Variable] --bs=4k --iodepth=16 --time_based --runtime=60 --name=test

Read/Write Ratio	Read Latency (total) lat(µs)			Read Latency (Submission) lat(us)			Read Latency (Completion) lat(ns)		
	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
100/0	1933.88	5	177804	33.76	2	36583	2381k	417	114059k
50/50	1238.85	5	216730	25.81	2	8830	9430k	458	20597k
70/30	2799.12	5	157738	40.36	2	27483	4456k	750	224058k
0/100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Read/Write Ratio	Write Latency (total) lat(µs)			Write Latency (Submission) lat(us)			Write Latency (Completion) lat(ns)		
	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
100/0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
50/50	3860.89	7	1479.3k	40.24	2	7305	3505.92	8	1221.4k
70/30	4791.80	6	24741k	143.77	3	110850	1177380	458	2311.7M
0/100	3760.5	6	737085	21.93	2	1532k	4321k	625	1503M

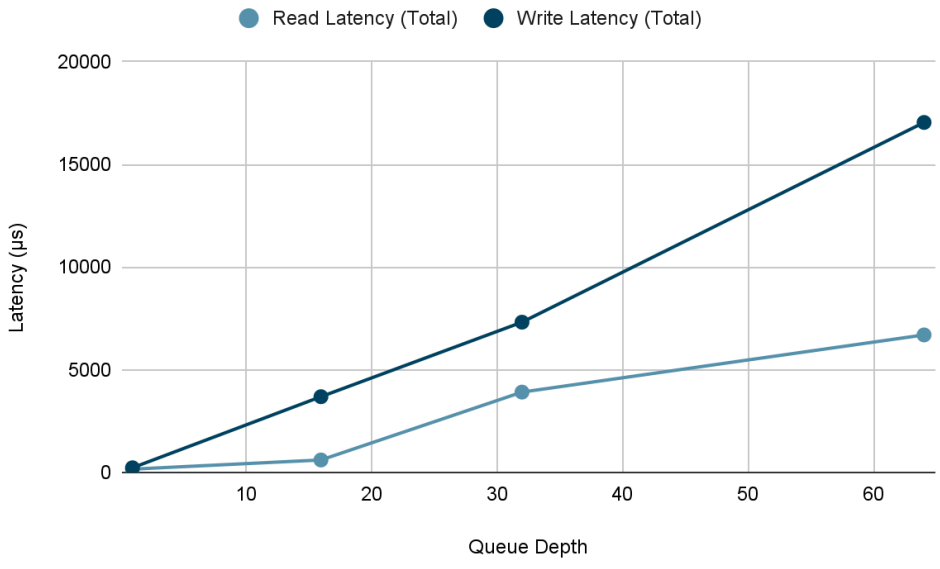
Effect of I/O Queue Depth on Latency:

- Fixed Parameters: Data Access Size: 4KB, Read/Write Ratio: 50% Read / 50% Write
- Varied Parameter: I/O Queue Depth
- Command used:

fio --filename=testfile --size=10G --rw=randrw --rwmixread=50 --bs=4k --iodepth=[Variable] --time_based --runtime=60 --name=test

I/O Queue Depth	Read Latency (total) lat(µs)			Read Latency (Submission) lat(us)			Read Latency (Completion) lat(ns)		
	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
1	160.73	6	315679	53.59	4	26703	107141	333	315546k
16	606.32	5	11143	26.77	2	4427	579547	458	11109k
32	3912.23	20	139048	25.54	2	13369	3886689	959	139007k
64	6697.31	6	387141	119.86	2	21254	6664577	625	387124k

I/O Queue Depth	Write Latency (total) lat(µs)			Write Latency (Submission) lat(us)			Write Latency (Completion) lat(ns)		
	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
1	227.7	12	1233.8k	71	4	20509	156704	375	1233.7M
16	3688.62	6	1755.3k	35.13	2	5309	3653393	458	1755.3M
32	7317.65	7	473617	54.93	2	12799	7262722	538	473605k
64	17045.72	6	547625	59.02	2	14225	16997696	667	54759k

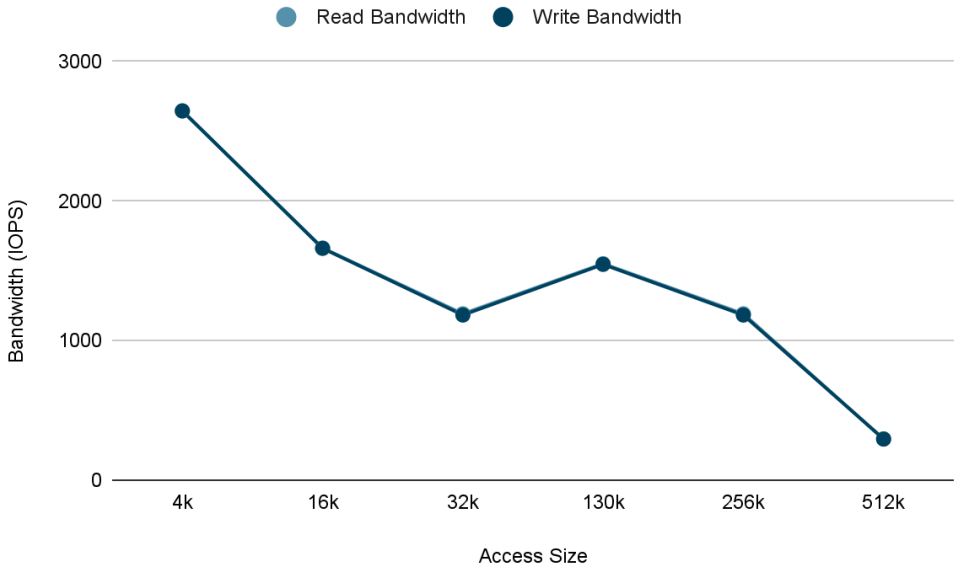


Effect of Data Access Size on Bandwidth:

- Fixed Parameters: Read/Write Ratio: 50% Read / 50% Write, I/O Queue Depth: 16
- Varied Parameter: Data Access Size
- Command used:

fio --filename=testfile --size=10G --rw=randrw --rwmixread=50 --bs=[Variable] --iodepth=16 --time_based --runtime=60 --name=test

Data Access Size	Read Bandwidth (IOPS)	Write Bandwidth (IOPS)
4k	2645	2646
16k	1663	1661
32k	1192	1183
130k	1551	1546
256k	1192	1183
512k	294	295
Large Access Size (MB/s)		
130k	24.2	24.2
256k	37.3	36
512k	147	148

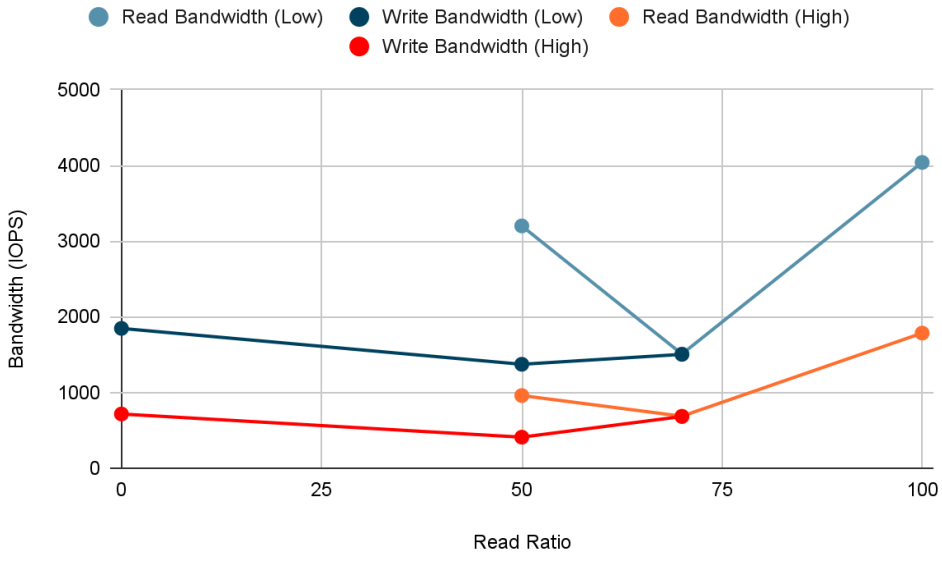


Effect of Read/Write Intensity Ratio on Bandwidth:

- Fixed Parameters: Data Access Size: 4KB, I/O Queue Depth: 16
- Varied Parameter: Read/Write Ratio
- Command used:

fio --filename=testfile --size=10G --rw=randrw --rwmixread=[Variable] --bs=4k --iodepth=16 --time_based --runtime=60 --name=test

Data Access Size	Read/Write Ratio	Read Bandwidth (IOPS)	Write Bandwidth (IOPS)
16k	100/0	4040	n/a
16k	50/50	1508	1504
16k	70/30	3201	1373
16k	0/100	n/a	1847
130k	100/0	1785	n/a
130k	50/50	687	683
130k	70/30	960	410
130k	0/100	n/a	716
Large Access Size (MB/s)			
130k	100/0	230	n/a
130k	50/50	87.3	86.8
130k	70/30	122	52.2
130k	0/100	n/a	90

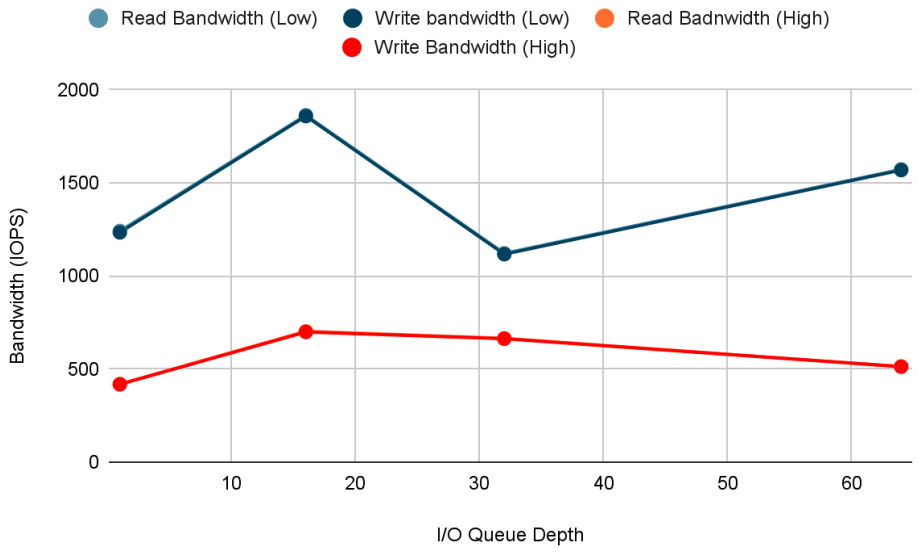


Effect of I/O Queue Depth on Bandwidth:

- Fixed Parameters: Data Access Size: 4KB, Read/Write Ratio: 50% Read / 50% Write
- Varied Parameter: I/O Queue Depth
- Command used:

fio --filename=testfile --size=10G --rw=randrw --rwmixread=50 --bs=4k --iodepth=[Variable] --time_based --runtime=60 --name=test

Data Access Size	I/O Queue Depth	Read Bandwidth (IOPS)	Write Bandwidth (IOPS)
16k	1	1242	1234
16k	16	1864	1859
16k	32	1122	1117
16k	64	1573	1569
130k	1	419	418
130k	16	703	699
130k	32	665	663
130k	64	513	513
Large Access Size (MB/s)			
130k	1	53.2	53.2
130k	16	89.3	88.8
130k	32	84.4	84.2
130k	64	65.2	65.2



Analysis: 50pts

Effect of Data Acces of Size on Latency:

Observed trend:

- Small data size: latency is lower because smaller data sizes are processed quickly
- Larger data size: latency increases because more time is needed to read/write data

Reason:

- Small data size: faster read/write operations which means lower latency. SSD is more efficient due to less data transfer per operation
- Large data size: I/O takes longer to complete as data size increases. Large data blocks require more time to read/write to storage cells

Effect of Read/Write on Latency:

Observed trend:

- Read only: latency is lower for read operations because reading is faster than writing
- Write only: latency is higher for write operations due do needing to storage modification
- Read/Write: latency falls in between read only and write only

Reason:

- Read only: reading SSD is faster because it only needs to retrieve data with no modifying cells
- Write only: writing data requires reading, erasing, and programming cells which takes more time and higher latency
- Read/Write: latency falls between read only and write only - higher read ratio means lower latency

Effect of I/O Queue Depth on Latency:

Observed trend:

- Low queue depth: latency is lower because fewer I/O operations
- Moderate queue depth: latency increases as queue depth grows
- High queue depth: latency becomes higher as queue depth exceeds SSD capacity (when capacity is reached latency increases)

Reason:

- Low queue depth: with fewer I/O operations in the queue each operation can be processed quickly, which leads to lower latency
- Moderate queue depth: as queue depth increases, more I/O operations are waiting to be processed, which leads to increased waiting time and increased latency
- Higher queue depth: when queue depth exceeds SSD capacity, latency increases due to an increasing number of queued operations

Effect of Data Acces of Size on Bandwidth:

Observed trend:

- For small data sizes measured with IOPS, bandwidth tends to be higher due to the small number of I/O operations
- For large data sizes, bandwidth will increase but will hit a point where it will level out or decrease due to SSD ability to handle large chunks of data

Reason:

- For small data sizes, SSD can handle large amounts of small I/O operations. This is because small data sizes require less time to read/write (SSD can handle multiple operations in parallel)
- For large data sizes, each I/O operation takes more time due to the size. The bandwidth will increase until the SSD internal bandwidth is reached (this will cause the bandwidth to either level out of decrease)

Effect of Read/Write on Bandwidth:

Observed trend:

- Read only: read operations are faster than write, so there is a higher bandwidth
- Write only: Slower than read operations, so lower bandwidth
- Read/Write: the bandwidth values fall between read and write bandwidth values

Reason:

- Read only: Read operations are faster because SSD doesn't need to modify storage cells
- Write only: Writing data makes SSD erase and reprogram cells which takes up more bandwidth
- Read/Write: falls between read only and write only. If the read ratio is higher the bandwidth will be higher

Effect of I/O Queue Depth on Bandwidth:

Observed trend:

- Low queue depth (1): bandwidth is lower because SSD is not fully used
- Moderate queue depth (16, 32): bandwidth increase as SSD can handle more I/O operations in parallel (better utilization of SSD)
- High queue depth (64): bandwidth increases but will level out/decrease as operations exceed SSD bandwidth capabilities

Reason:

- Lower queue depth: few I/O operations cause SSD to be underutilized - controller spends more time waiting for new operations
- Moderate queue depth: SSD processes more I/O operations simultaneously which improves bandwidth
- High queue depth: SSD becomes overwhelmed due to increased need for management and resources needed