Persistent Memory Performance Benchmarking & Comparison

Real World GPS Navigation Portal v Synthetic SQL Workload
Direct Attached Test: PM v NVMe
Fabric Test: NVMe-oF & Remote PM

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John Kim, Mellanox Technologies, Inc.

PM Benchmarking & Comparison

- Part 1: Test Plan & Workloads – Eden Kim of Calypso
- Part 2: Direct Attached PM & NVMe - Eden Kim of Calypso
- Part 3: Remote PM & NVMe-oF – John Kim of Mellanox
- Part 4: Conclusions – John Kim of Mellanox & Eden Kim of Calypso
- Questions & Answers

Part 1: Test Plan & Workloads

A. Test Plan

B. Real World Workload Source Captures

C. Test Workloads

A: Test Plan - Steps

Step	Description	Reference
Select & Define Workloads	Synthetic SQL Workload Real World GPS Nav Portal	SNIA SSS PTS v2.0.1 TestMyWorkload.com Demo #7 SNIA RWSW PTS v1.0.7
Run Direct Attached Tests	PM–N NVMe U.2–H NVMe U.2-I	SQL DIRTH - RND 8K RW65 GPS Nav Auto DIRTH – 9 IO Stream Replay - Native & Scaled Individual Streams – Steady State
Run Fabric/Remote Tests	PM–N NVMe U.2–H NVMe U.2-I	RoCE on 100 Gb/s Ethernet

A. Test Plan - Sample Pool

Sample	Description	Capacity
PM-N	NVDIMM-N	Single 16 GB NVDIMM-N Module
NVMe U.2-H	U.2x4 SSD	2.5" U.2x4 SFF 8639 3200 GB
NVMe U.2-I	U.2x4 SSD	2.5" U.2x4 SFF 8639 2000 GB

A: Test Plan - Platforms

Device Under Test	Platform	Description
PM–N - Direct	Smart Modular Supermicro X11 DRI	Ubuntu; DDR4 16GB RAM; 24 Core 2.1 GHz CPU
NVMe U.2–H NVMe U.2-I	Calypso RTP 5 Supermicro X10 DRI	CentOS 7x; DDR4 32GB RAM; Dual 24 Core Intel E5 2660 v4 2.0 GHz CPU; PCIe Gen 3
PM–N - Remote	Smart Modular Supermicro X11 DRI	Ubuntu; DDR4 16GB RAM; 24 Core 2.1 GHz CPU
Fabric	Mellanox 100Gb/s	Linux Open Source RoCE ConnectX-4 VPI 100Gb/s ConnectX-5 EN 100Gb/s
Test Software	Calypso CTS	CTS 6.5

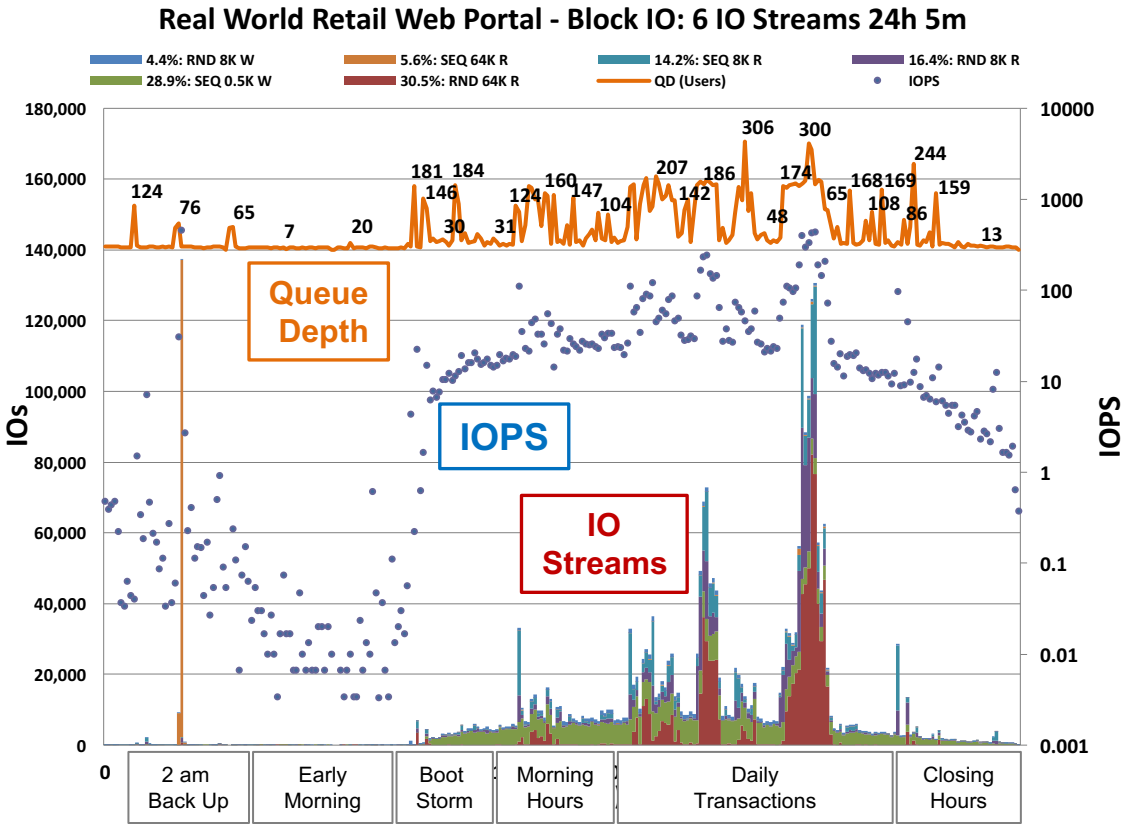
B: Real World Source Captures

Item	Description	Reference
SSSI Reference Captures	Synthetic Benchmarks Real World Workloads	SNIA RWSW PTS v1.0.7 TestMyWorkload.com
PM Summit 2018	2,000 Outlet Retail Web Portal Workload 24 hr/5 min resolution Drive0 Block IO Varied Activity/QD – Coarser Grain	TestMyWorkload.com/demo_5
PM Summit 2019	GPS Navigation Portal Workload 30 min/1 sec resolution Drive0 Block IO Homogenous Activity – Finer Grain	TestMyWorkload.com/demo_7

B. PM Summit 2018 – TestMyWorkload.com/demo_5

Retail Web Portal

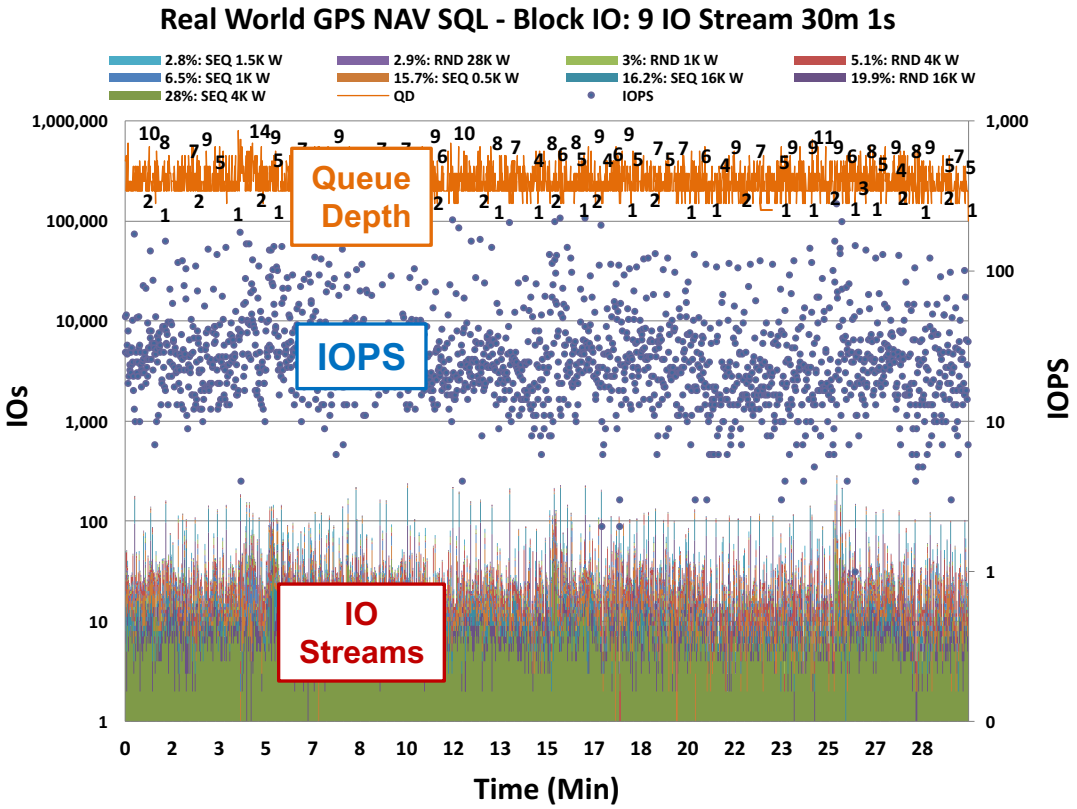
- Block IO Drive0
- Fewer IO Streams (6)
  - 30.5% RND 64K W
  - 28.9% SEQ 0.5K W
  - 16.4% RND 8K W
  - 14.2% SEQ 8K R
  - 5.6% SEQ 64K R
  - 4.4% RND 8K W
- QD (Users)
  Higher Range 1-306
- Coarser Grain (5 min)
- More Activities & Spikes
- Lower IOPS Range
- Larger Block Sizes
- Read & Write IOs



B. PM Summit 2019 – TestMyWorkload.com/demo_7

GPS Nav Portal

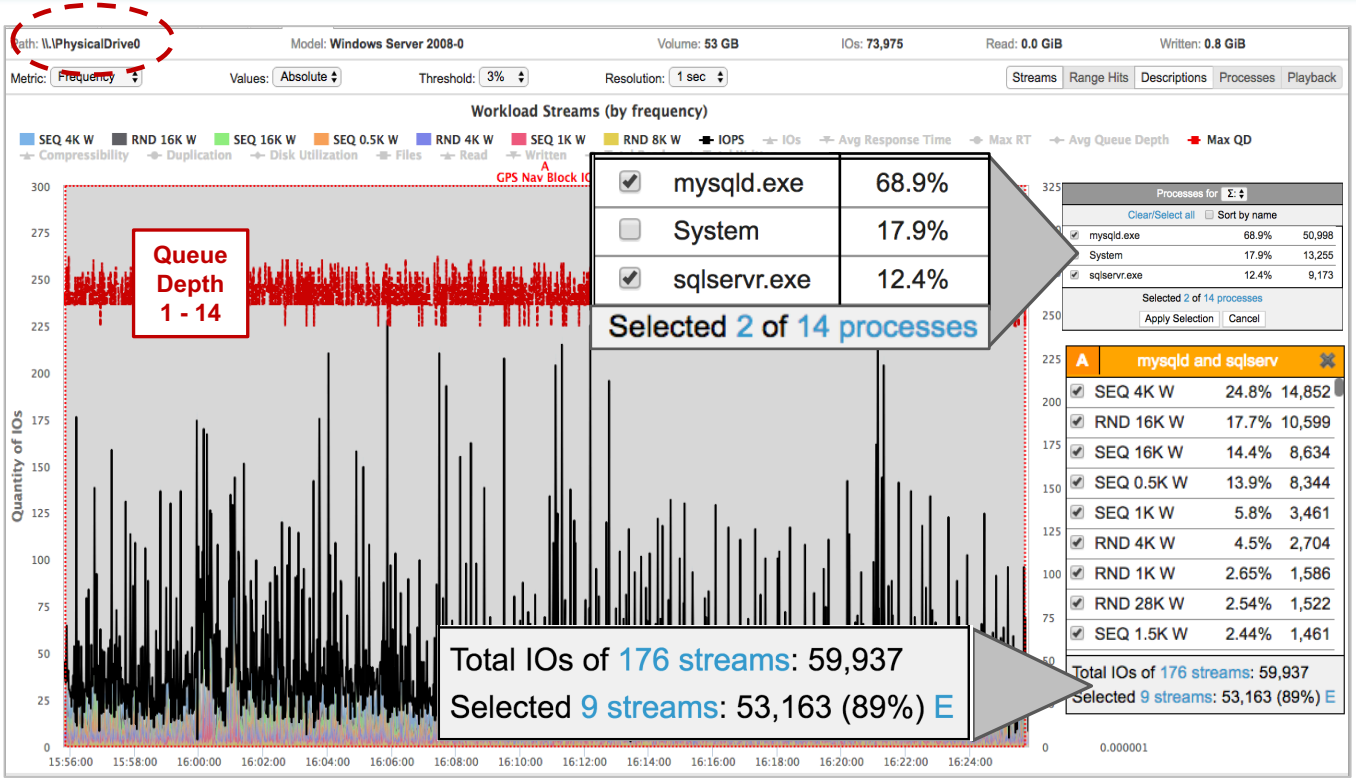
- Block IO Drive0
- More IO Streams (9)
  - 28.0% SEQ 4K W
  - 19.9% RND 16K W
  - 16.2% SEQ 16K W
  - 15.7% SEQ 0.5K W
  - 6.5% SEQ 1K W
  - 5.1% RND 4K W
  - 3.0% RND 1K W
  - 2.9% RND 28K W
  - 2.8% SEQ 1.5K W
- QD (Users)
  Lower Range 1-14
- Finer Grain (1 sec)
- Fewer Activities
- Higher IOPS Range
- Smaller Block Sizes
- All Write IOs



Source Workload: GPS Nav Portal - TestMyWorkload.com/Demo_7

GPS Nav Portal Source Capture

- TestMyWorkload.com Demo No. 7
- Block IO – Drive0
- 30 min Duration 1 sec Resolution
- 14 Processes 176 IO Streams
- 9 IO Streams 89%of Total IOs
- 2 Process IDs (PIDs): mysqld.exe sqlservr.exe
- QD Range: 1-14

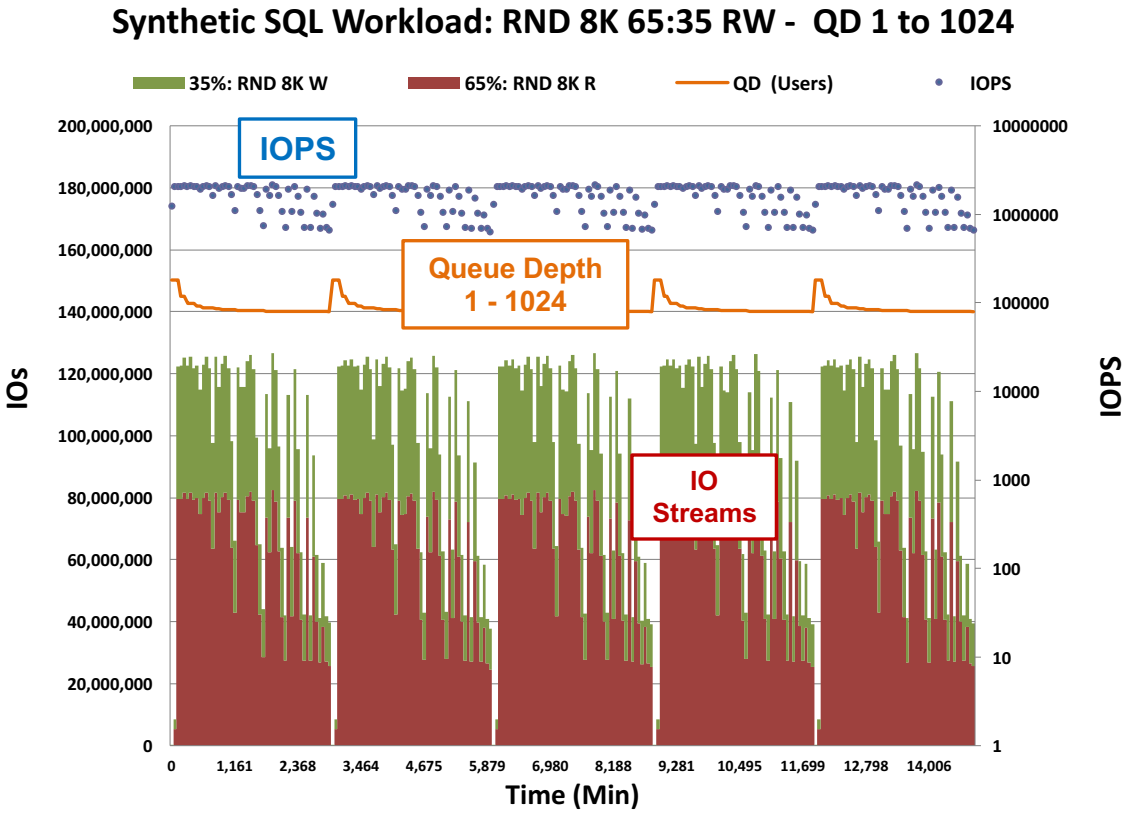


C: Test Workloads

Test	Test Flow Description	Reference
Synthetic SQL – DIRTH Fixed Synthetic Workload	Demand Intensity Response Time Histogram Fixed 2 IO Stream Composite with a QD Range 1-1024 Run the Fixed Workload to Steady State Apply Thread Count/Queue Depth Loop (T32Q32 – T1Q1)	SNIA SSS PTS 2.0.1 Section 14 page 80 www.snia.org/pts#
GPS Nav – Auto DIRTH Fixed Real World Workload	GPS Nav Portal: 9 IO Stream – 30min / 1sec capture Fixed 9 IO Stream Composite with a QD Range 1-1024 Run the Fixed Workload to Steady State Apply Thread Count/Queue Depth Loop (T32Q32 – T1Q1)	TestMyWorkload.com Demo No. 7 RWSW PTS 1.0.7, Section 10 page 63 www.snia.org/rwsw#
Replay – Native Dynamic Real World Workload	Replay the Sequence of IO Stream Combinations & QDs from the Original GPS Nav Portal Workload Capture The GPS Nav Portal has a Native QD Range 1-14	RWSW PTS 1.0.7, Section 7 page 39 www.snia.org/rwsw#
Replay – Scaled Dynamic Real World Workload	Run the GPS Nav Replay Native IO Stream Combinations Scale the Native QDs by x2, x4, x8, x16, x32 Native QD Range 1-14 is Multiplied by the Scaling Factor	RWSW PTS 1.0.7, Section 7 page 39 www.snia.org/rwsw#
Individual Streams Fixed Real World Workload	Run the 9 IO Individual Streams of the GPS Nav Portal Workload to Steady State and Report	RWSW PTS 1.0.7, Section 9 page 54 www.snia.org/rwsw#

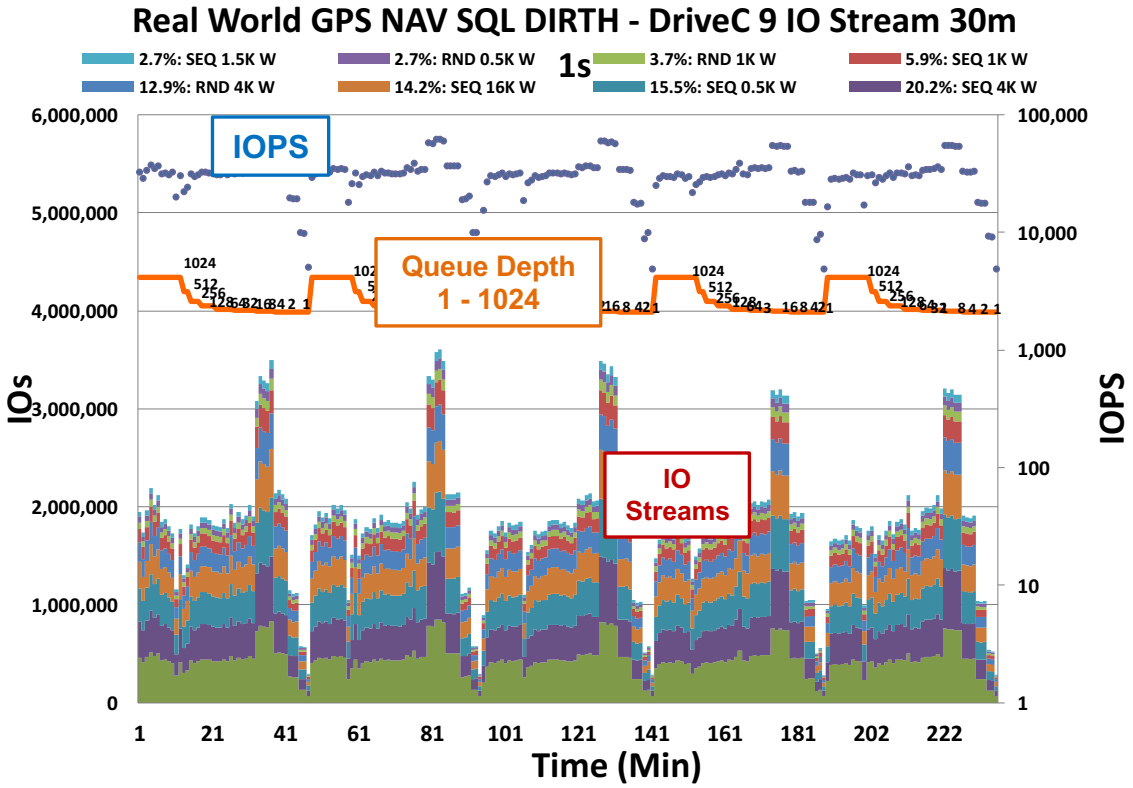
C. Synthetic SQL – DIRTH RND 8K RW65

- DIRTH – Demand Intensity Response Time Histogram
- 2 IO Streams: RND 8K RW65
- Fixed & Constant Synthetic Workload
- 2 IO Streams
  - 65% RND 8K R
  - 35% RND 8K W
- Outstanding IO (OIO) Loop T32Q32 – T1Q1
- QD (Users) Range 1-1024



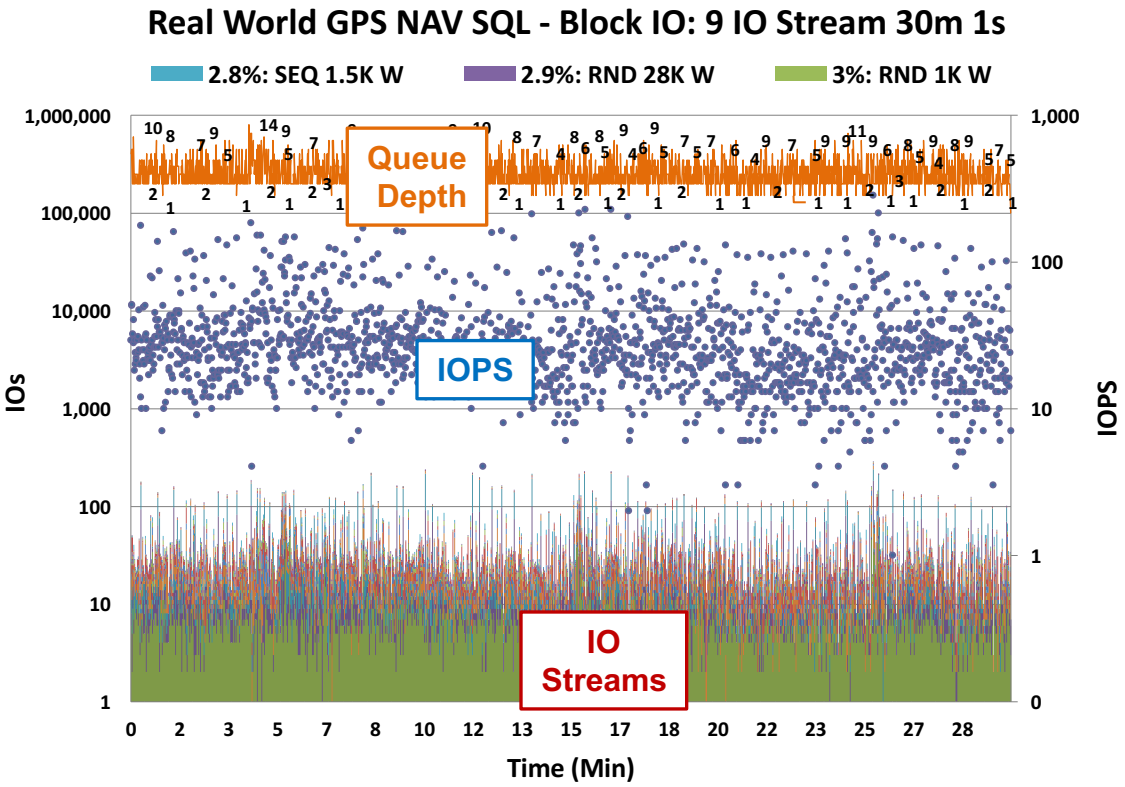
C. Real World SQL: DIRTH GPS Nav. Portal

- Auto DIRTH – 9 IO Stream GPS Nav Portal
- Fixed & Constant Workload
- Same 9 IO Streams for each Test Step
  - 22.2% RND 16K W
  - 20.2% SEQ 4K W
  - 15.5% SEQ 0.5K W
  - 14.2% SEQ 16K W
  - 12.9% RND 4K W
  - 5.9% SEQ 1K W
  - 3.7% RND 1K W
  - 2.7% RND 0.5K W
  - 2.7% SEQ 1.5K W
- Outstanding IO Loop T32Q32 – T1Q1
- QD (Users) Range 1-1024



C. Real World Replay – GPS Nav. Portal

- Replay IO Streams & QD for each Test Step
- Dynamic Sequence of IO Streams & QD
- 9 IO Streams
  - 28.0% SEQ 4K W
  - 19.9% RND 16K W
  - 16.2% SEQ 16K W
  - 15.7% SEQ 0.5K W
  - 6.5% SEQ 1K W
  - 5.1% RND 4K W
  - 3.0% RND 1K W
  - 2.9% RND 28K W
  - 2.8% SEQ 1.5K W
- QD (Users) Range 1-14
- Replay Original Capture IO Streams & QD for each Test Step



C. Replay: Replay Sequence of IO Streams & QDs

- **Replay Test – Play the Same Sequence of IO Stream & QDs from the Original Capture**
- **Dynamically changing IO & QD combinations**
- **Different IO Streams for each test step**
- **1800 1s Test Steps (30m Dur x 1s Res)**

IO Stream & QD Combinations

IO Streams at 15:55:47
- SEQ 4K W: 4
- RND 16K W: 5
- SEQ 0.5K W: 10
- RND 4K W: 8

~ IOPS: 45

IO Streams at 16:00:47
- SEQ 4K W: 8
- RND 16K W: 3
- SEQ 16K W: 1
- SEQ 0.5K W: 1
- RND 4K W: 5
- RND 8K W: 3

~ IOPS: 31

IO Streams at 16:05:47
- SEQ 4K W: 8
- RND 16K W: 4
- SEQ 16K W: 2
- SEQ 0.5K W: 10
- RND 4K W: 3
- SEQ 1K W: 2
- RND 8K W: 2

~ IOPS: 45

IO Streams at 16:10:47
- SEQ 4K W: 10
- RND 16K W: 9
- SEQ 16K W: 5
- SEQ 0.5K W: 2
- RND 4K W: 2
- SEQ 1K W: 1
- RND 8K W: 1

~ IOPS: 35

IO Streams at 16:15:47
- SEQ 4K W: 23
- RND 16K W: 3
- SEQ 0.5K W: 9
- RND 4K W: 3
- SEQ 1K W: 5
- RND 8K W: 1

~ IOPS: 55

IO Streams at 16:20:48
- SEQ 4K W: 7
- RND 16K W: 1
- SEQ 16K W: 1
- SEQ 0.5K W: 2
- RND 4K W: 9
- SEQ 1K W: 1
- RND 8K W: 4

~ IOPS: 30

IO Streams at 16:25:48
- SEQ 4K W: 3
- RND 16K W: 3

~ IOPS: 9.0

Part 2: Direct Attached Block IO Test

A. DIRTH: Synthetic SQL v Real World GPS Nav

B. Real World: GPS Nav DIRTH v Replay

C. Replay: Scaled QD x1, x2, x4, x8, x16, x32

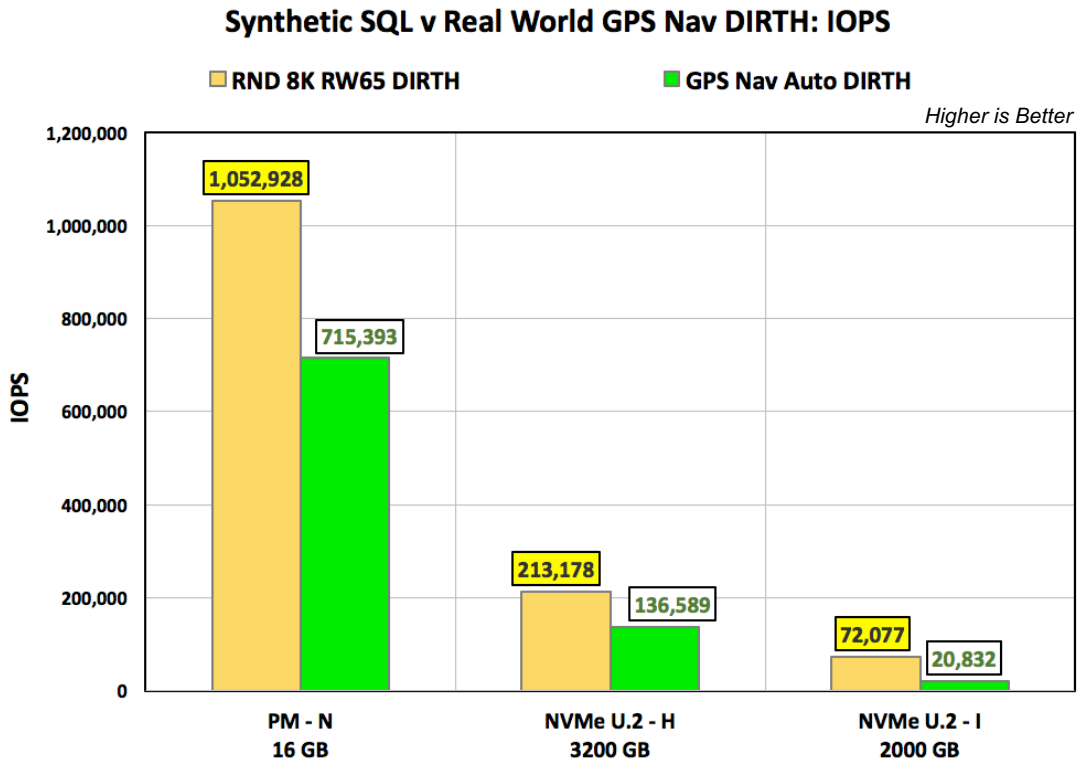
A. DIRTH: Synthetic SQL v Real World GPS - IOPS

Syn SQL DIRTH - RND 8K RW65
Fixed Synthetic - 2 IO Streams

A0	Synthetic SQL DIRTH	
RND 8K R	65.0%	65.0
RND 8K W	35.0%	35.0

GPS Nav Auto DIRTH –
Fixed Real World - 9 IO Streams

A0	GPS Nav Auto DIRTH	
SEQ 4K W	24.8%	28.0
RND 16K W	17.7%	19.9
SEQ 16K W	14.4%	16.2
SEQ 0.5K W	13.9%	15.7
SEQ 1K W	5.8%	6.5
RND 4K W	4.5%	5.1
RND 1K W	2.65%	2.98
RND 28K W	2.54%	2.86
SEQ 1.5K W	2.44%	2.75



A. DIRTH: Syn. SQL – IOPS, ART, QoS (5 9s RT – 99.999%)

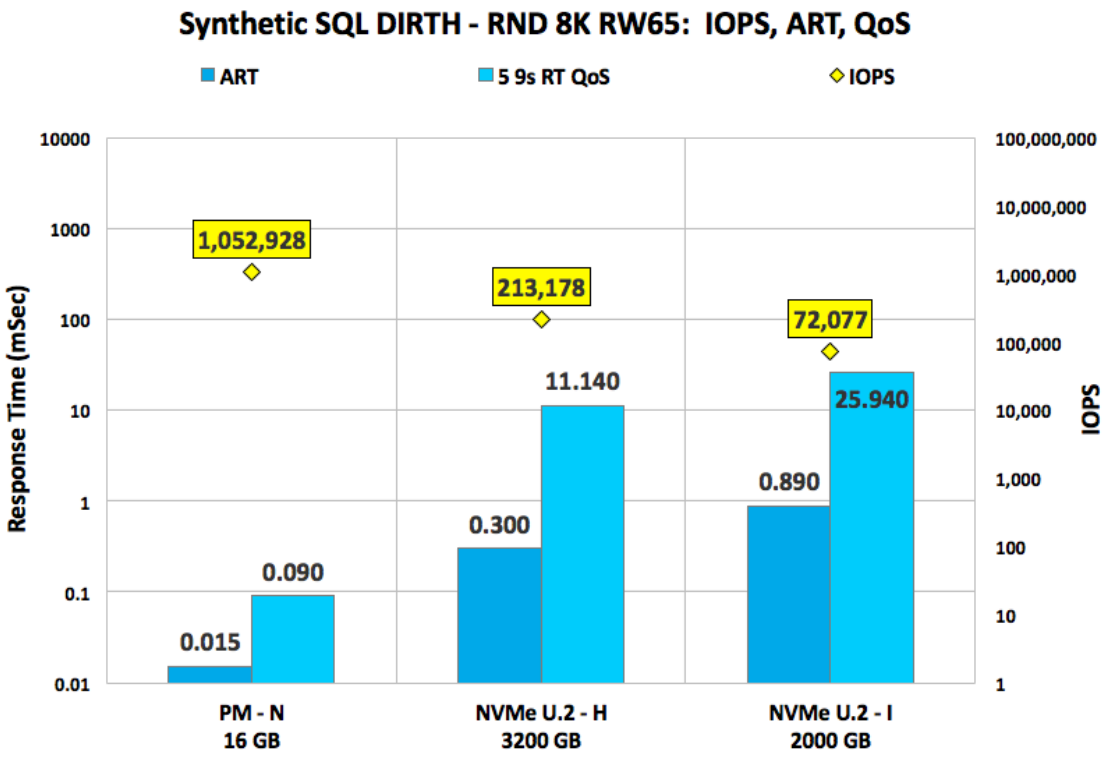
Syn SQL DIRTH – RND 8K RW65
Fixed Synthetic - 2 IO Streams

QD (Users) Range 1-1024

A0	Synthetic SQL DIRTH	
RND 8K R	65.0%	65.0
RND 8K W	35.0%	35.0

	PM-N
IOPS	1,052,928
ART	0.015 mS
QoS	0.090 mS

	U.2-H	U.2-I
IOPS	213,178	72,077
ART	0.300 mS	0.890 mS
QoS	11.140 mS	29.940 mS

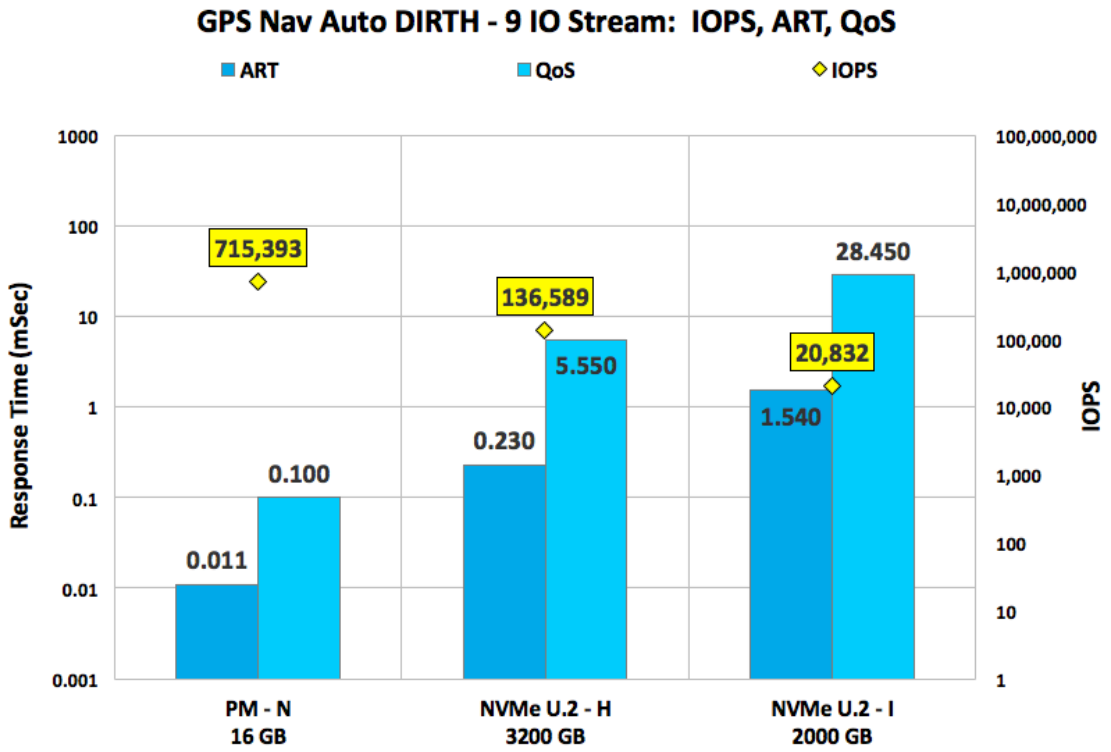


B. GPS Nav: Auto DIRTH – IOPS, ART, QoS (5 9s RT – 99.999%)

A0	GPS Nav Auto DIRTH	
SEQ 4K W	24.8%	28.0
RND 16K W	17.7%	19.9
SEQ 16K W	14.4%	16.2
SEQ 0.5K W	13.9%	15.7
SEQ 1K W	5.8%	6.5
RND 4K W	4.5%	5.1
RND 1K W	2.65%	2.98
RND 28K W	2.54%	2.86
SEQ 1.5K W	2.44%	2.75

	PM-N
IOPS	715,393
ART	0.011 mS
QoS	0.100 mS

	U.2-H	U.2-I
IOPS	135,589	20,832
ART	0.230 mS	1.540 mS
QoS	5.550 mS	28.450 mS



B. GPS Nav: Auto DIRTH v Replay - IOPS

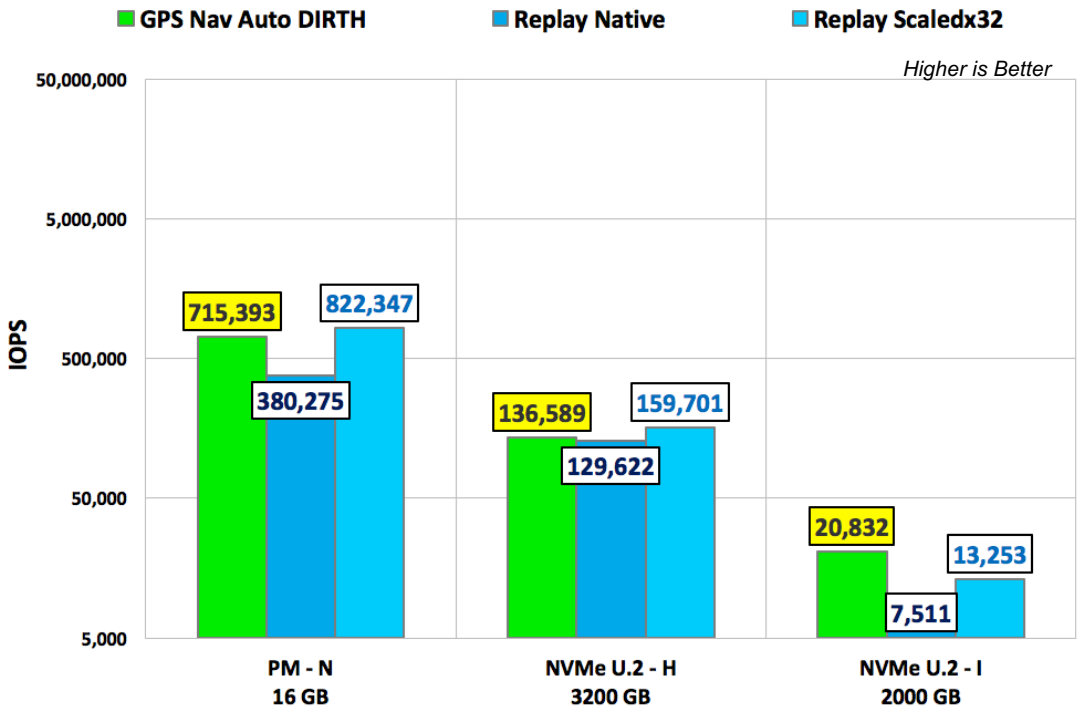
GPS Nav Replay – Replay Native & Scaled

A0	GPS Nav Replay
Replay Native QD Range 1-14	
Replay Scaled QD x32	

GPS Nav Auto DIRTH: 9 IO Streams

A0	GPS Nav Auto DIRTH	
SEQ 4K W	24.8%	28.0
RND 16K W	17.7%	19.9
SEQ 16K W	14.4%	16.2
SEQ 0.5K W	13.9%	15.7
SEQ 1K W	5.8%	6.5
RND 4K W	4.5%	5.1
RND 1K W	2.65%	2.98
RND 28K W	2.54%	2.86
SEQ 1.5K W	2.44%	2.75

Real World GPS Nav v Replay Native/Scaled: DIRTH IOPS



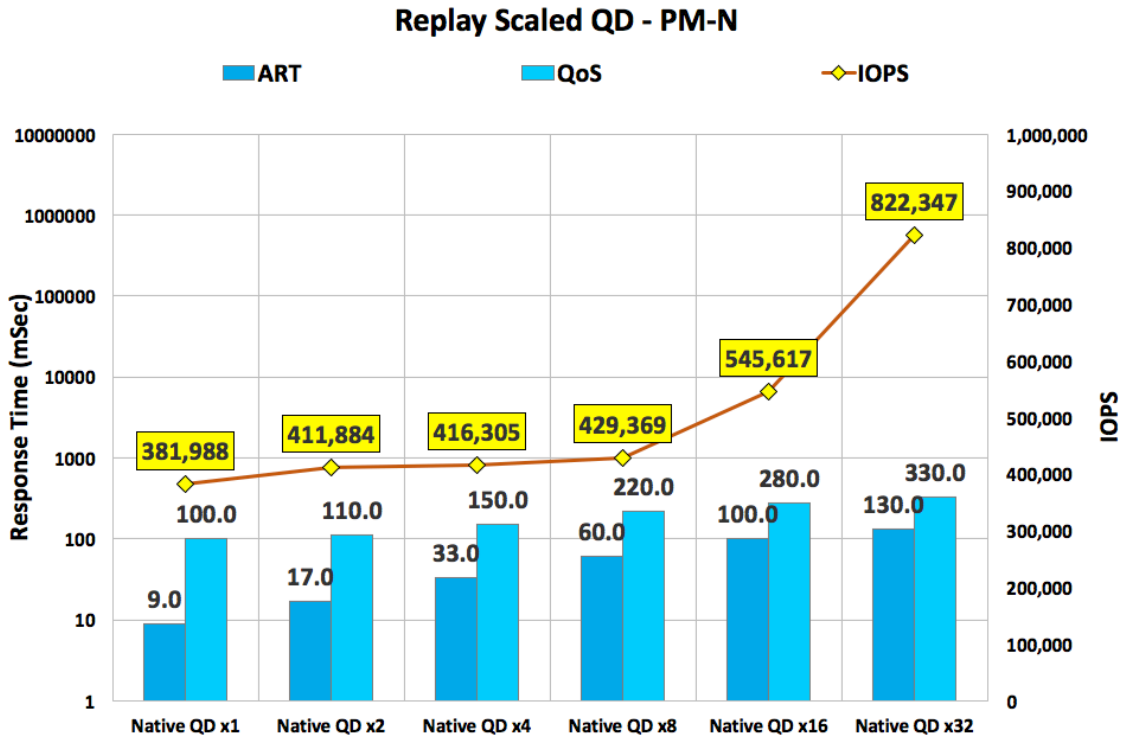
C. Replay: PM-N – IOPS, ART, QoS (5 9s RT – 99.999%)

GPS Nav Replay – Scaled QD

A0	GPS Nav Replay
Replay Native QD Range 1-14	
Replay Scaled: Native QD x2-x32	

	Scaled QD x1	Scaled QD x32
IOPS	381,988	822,347
ART	9.0 mS	130 mS
QoS	100 mS	330 mS

- Lowest Response Times at QDx1
- Highest IOPS Spike at QDx32
- Response Times Increase Linearly



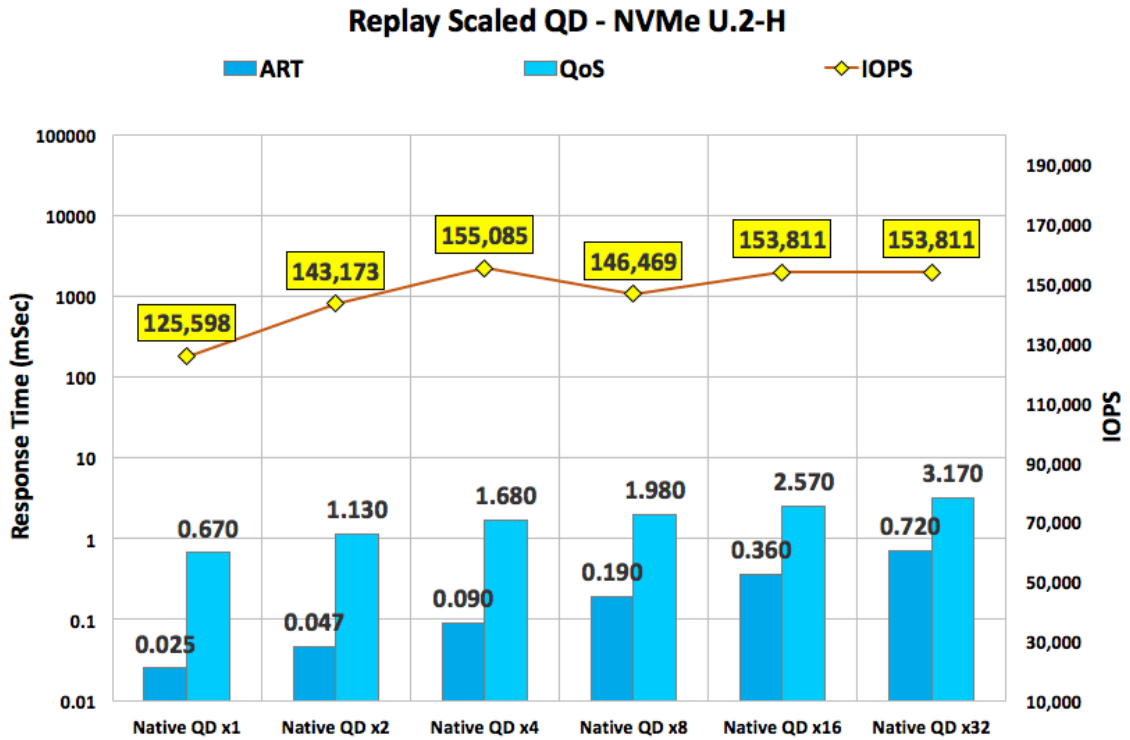
C. Replay: NVMe U.2-H – IOPS, ART, QoS (5 9s RT – 99.999%)

GPS Nav Replay – Scaled QD

A0	GPS Nav Replay
Replay Native QD Range 1-14	
Replay Scaled: Native QD x2-x32	

	QD x1	QD x4
IOPS	125,598	155,085
ART	0.025 mS	0.090 mS
QoS	0.670 mS	1.680 mS

- Lowest Response Times at QDx1
- Highest IOPS at QDx4, Decrease at QDx8
- Response Times begin to Spike at QDx8



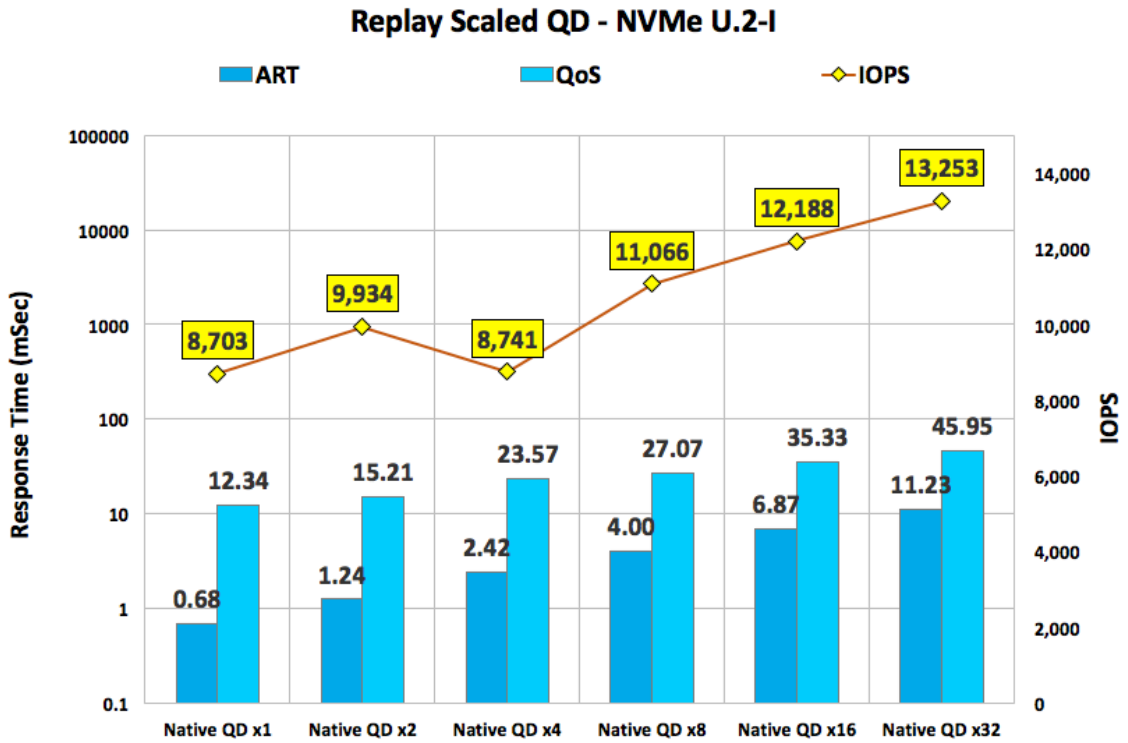
C. Replay: NVMe U.2-I – IOPS, ART, QoS (5 9s RT – 99.999%)

GPS Nav Replay – Scaled QD

A0	GPS Nav Replay
Replay Native QD Range 1-14	
Replay Scaled: Native QD x2-x32	

	QD x1	QD x2
IOPS	8,703	9,934
ART	0.68 mS	1.24 mS
QoS	12.34 mS	15.21 mS

- Lowest Response Times at QDx1
- Highest IOPS at QDx2, Decrease at QDx4
- Response Times Increase Linearly

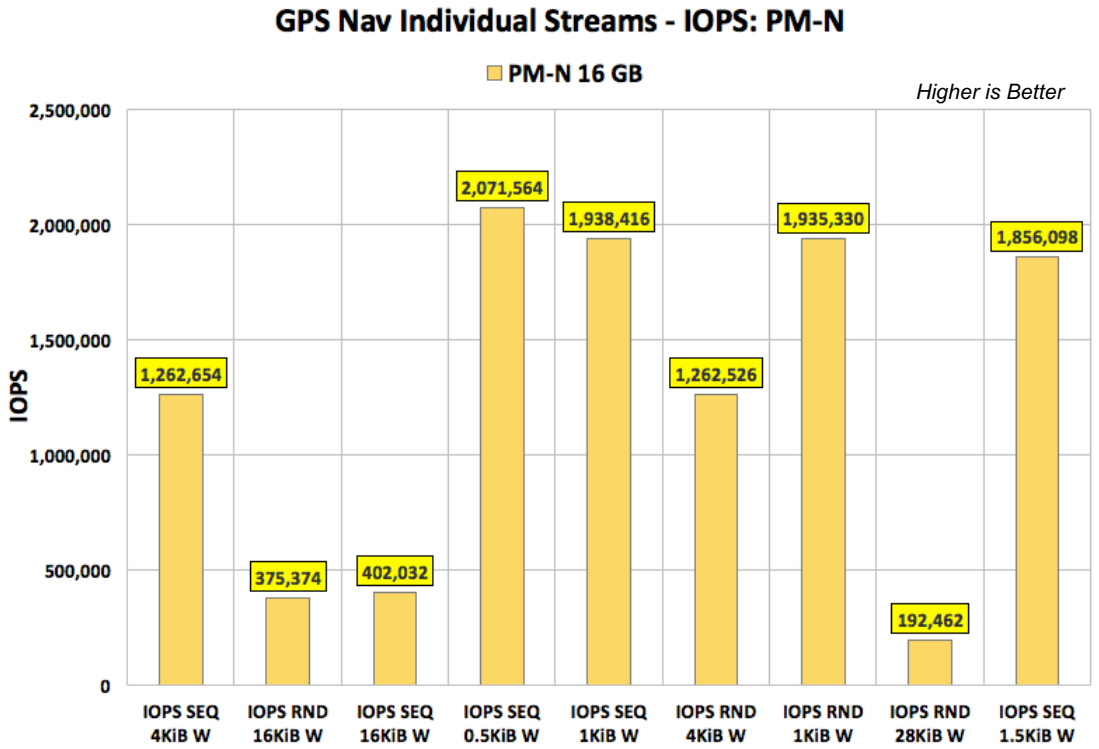


D. Ind Streams: PM-N – 9 IO Streams

GPS Nav – Individual Streams
9 IO Streams to Steady State

A0	GPS Nav Ind Streams
SEQ 4K W	28.0%
RND 16K W	19.9%
SEQ 16K W	16.2%
SEQ 0.5K W	15.7%
SEQ 1K W	6.5%
RND 4K W	5.1%
RND 1K W	2.98%
RND 28K W	2.86%
SEQ 1.5K W	2.75%

- **PM-N IOPS are Higher than at smaller transfer sizes**
- **Weighted IO Stream Mix determines workload performance**

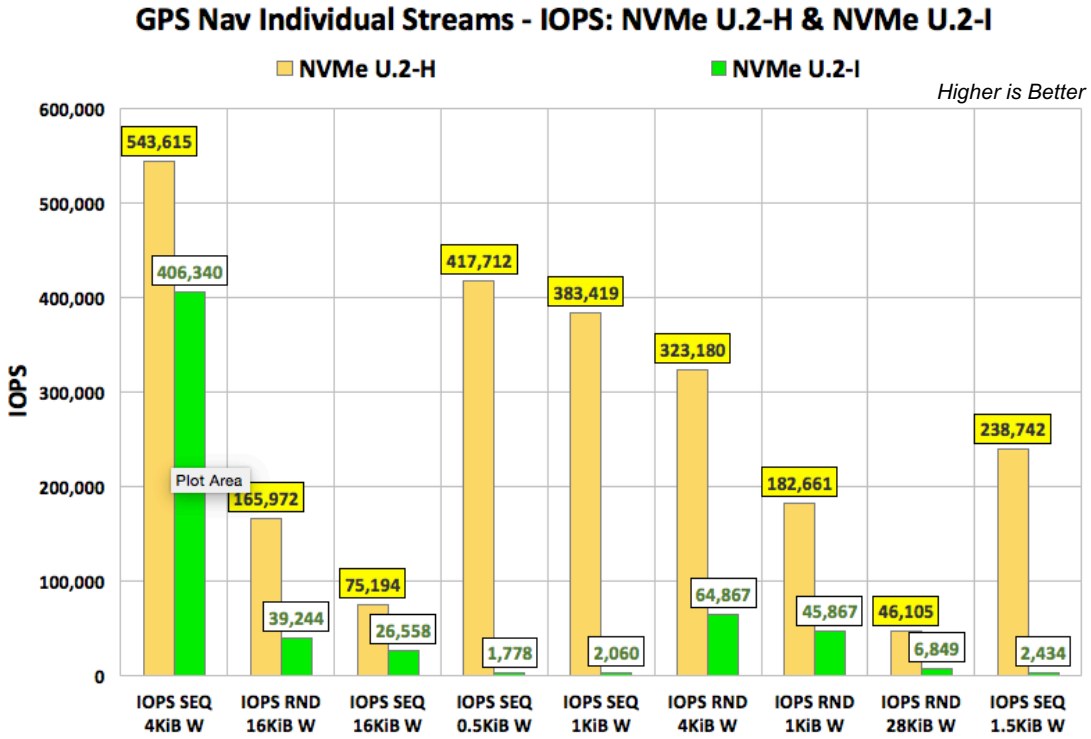


D. Ind Streams: U.2-H v U.2-I – 9 IO Streams

GPS Nav – Individual Streams
9 IO Streams to Steady State

A0	GPS Nav Ind Streams
SEQ 4K W	28.0%
RND 16K W	19.9%
SEQ 16K W	16.2%
SEQ 0.5K W	15.7%
SEQ 1K W	6.5%
RND 4K W	5.1%
RND 1K W	2.98%
RND 28K W	2.86%
SEQ 1.5K W	2.75%

- **NVMe U.2-H IOPS are Higher than NVMe U.2-I IOPS at all transfer sizes**

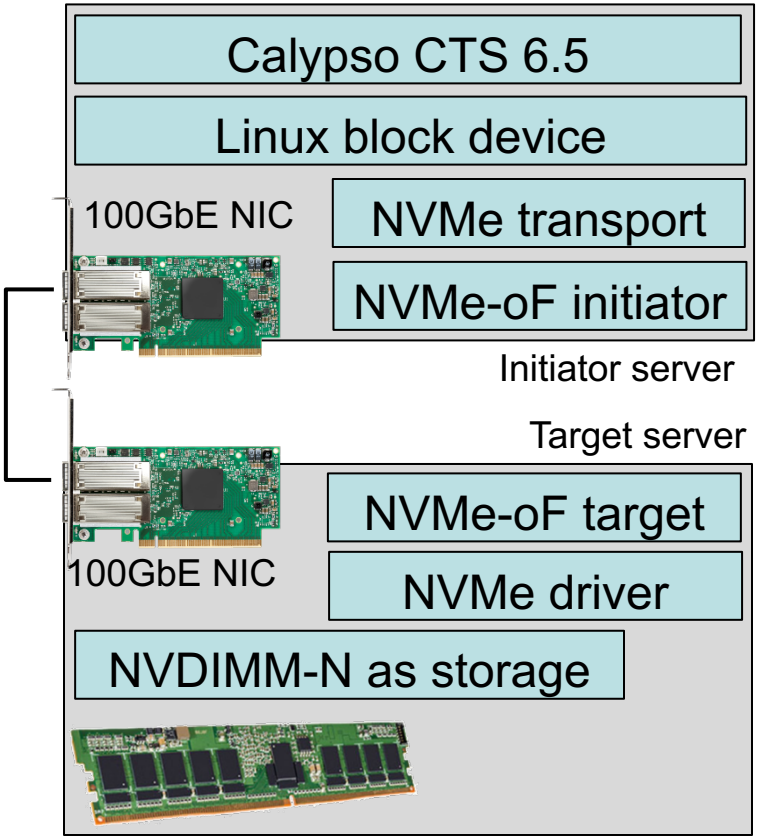


Part 3: Direct v Fabric

1. Direct Attached v Remote Fabric
2. Direct PM v Remote PM
   A. Synthetic SQL DIRTH
   B. Real World Auto DIRTH
   C. Individual Streams WSAT
3. Direct NVMe v NVMe-oF
   A. Synthetic SQL DIRTH
   B. Real World Auto DIRTH
   C. Individual Streams WSAT

1. Direct v Fabric: Architectures – DAS v NMVe-oF

- Fabric enables remote access
  - This test used RDMA/RoCE on 100GbE
  - Also can use FC, IB, TCP/IP
- Fabric always adds latency
  - But not always noticeable
  - Effect depends on workload and media latency
  - RDMA improves network efficiency, reduces fabric latency



A. PM v RPM: Syn. DIRTH – IOPS, ART, QoS (5 9s RT – 99.999%)

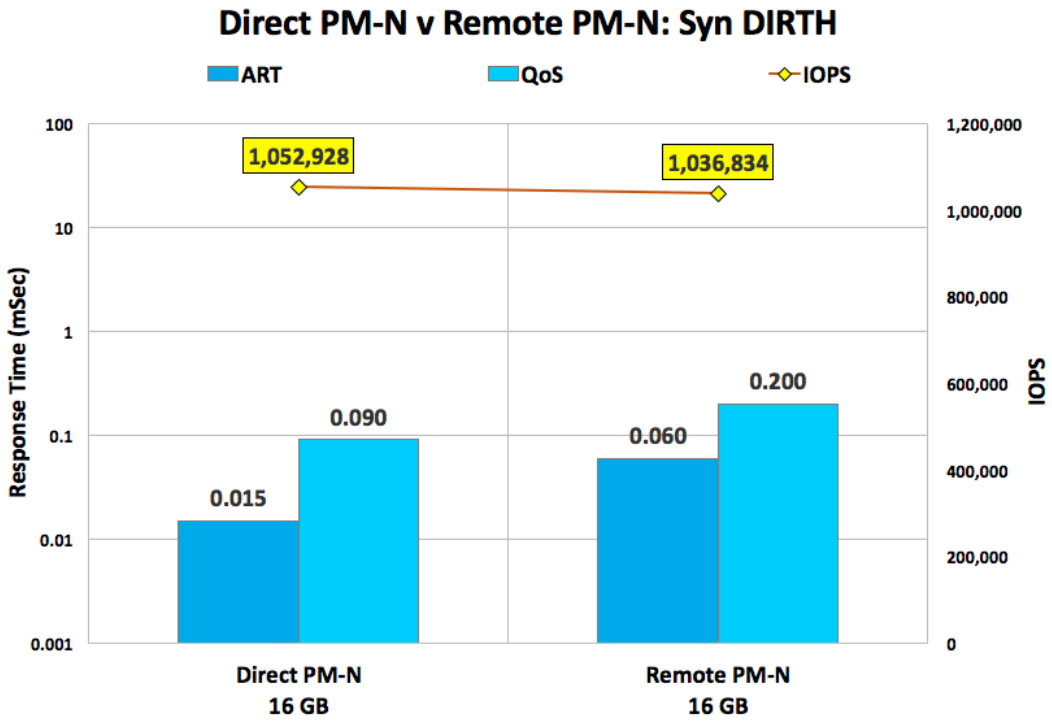
Syn SQL DIRTH – Fixed RND 8K RW65

QD (Users) Range 1-1024

A0	Synthetic SQL DIRTH	
RND 8K R	65.0%	65.0
RND 8K W	35.0%	35.0

	Direct	Remote
IOPS	1,052,928	1,036,834
ART	0.015 mS	0.060 mS
QoS	0.090 mS	0.200 mS

- **PM-N IOPS are Higher than RPM-N IOPS**
- **PM-N RTs are Lower than RPM-N RTs**



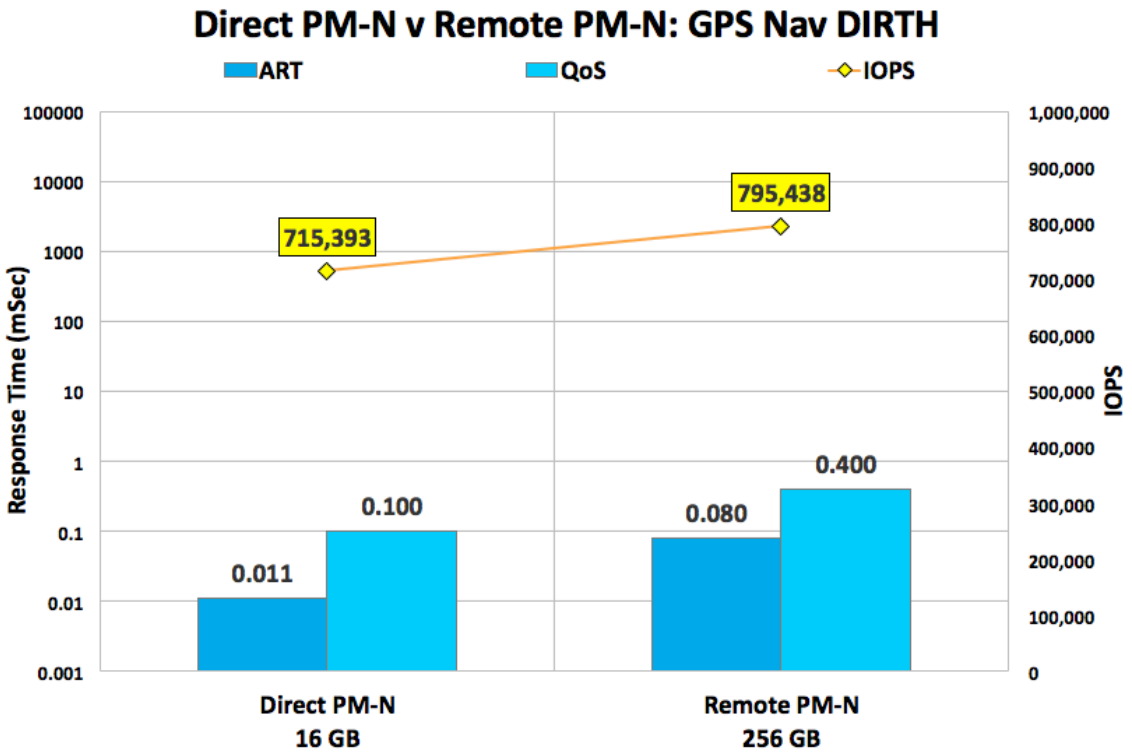
B. PM v RPM: GPS Nav. DIRTH – IOPS, ART, QoS (5 9s RT – 99.999%)

GPS Nav Auto DIRTH – Fixed 9 IO Streams

A0	GPS Nav Auto DIRTH	
SEQ 4K W	24.8%	28.0
RND 16K W	17.7%	19.9
SEQ 16K W	14.4%	16.2
SEQ 0.5K W	13.9%	15.7
SEQ 1K W	5.8%	6.5
RND 4K W	4.5%	5.1
RND 1K W	2.65%	2.98
RND 28K W	2.54%	2.86
SEQ 1.5K W	2.44%	2.75

	Direct	Remote
IOPS	715,393	795,438
ART	0.011 mS	0.080 mS
QoS	0.100 mS	0.400 mS

- **PM-N IOPS are Lower than RPM-N**
- **PM-N RTs are Lower than RPM-N**

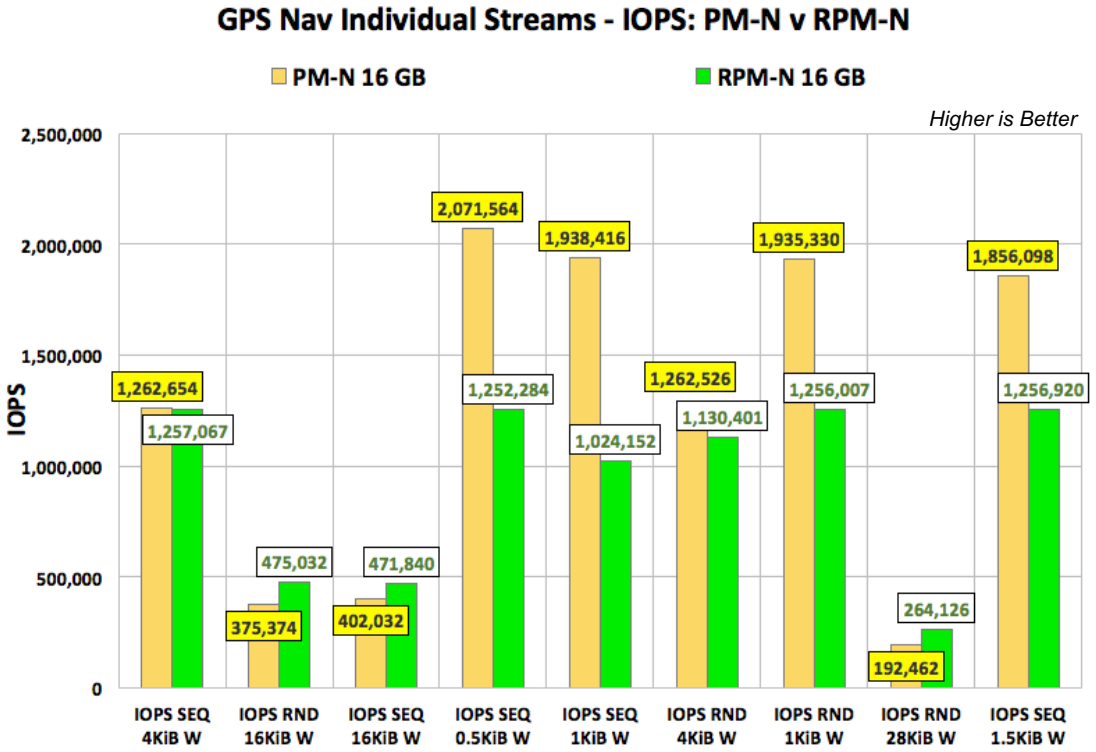


C. PM v RPM: Individual Streams - IOPS

GPS Nav – Individual Streams
9 IO Streams to Steady State

A0	GPS Nav Ind Streams
SEQ 4K W	28.0%
RND 16K W	19.9%
SEQ 16K W	16.2%
SEQ 0.5K W	15.7%
SEQ 1K W	6.5%
RND 4K W	5.1%
RND 1K W	2.98%
RND 28K W	2.86%
SEQ 1.5K W	2.75%

- **RPM-N IOPS are Higher than PM-N IOPS at transfer sizes < 4K**
- **Weighted IO Stream Mix determines workload performance**

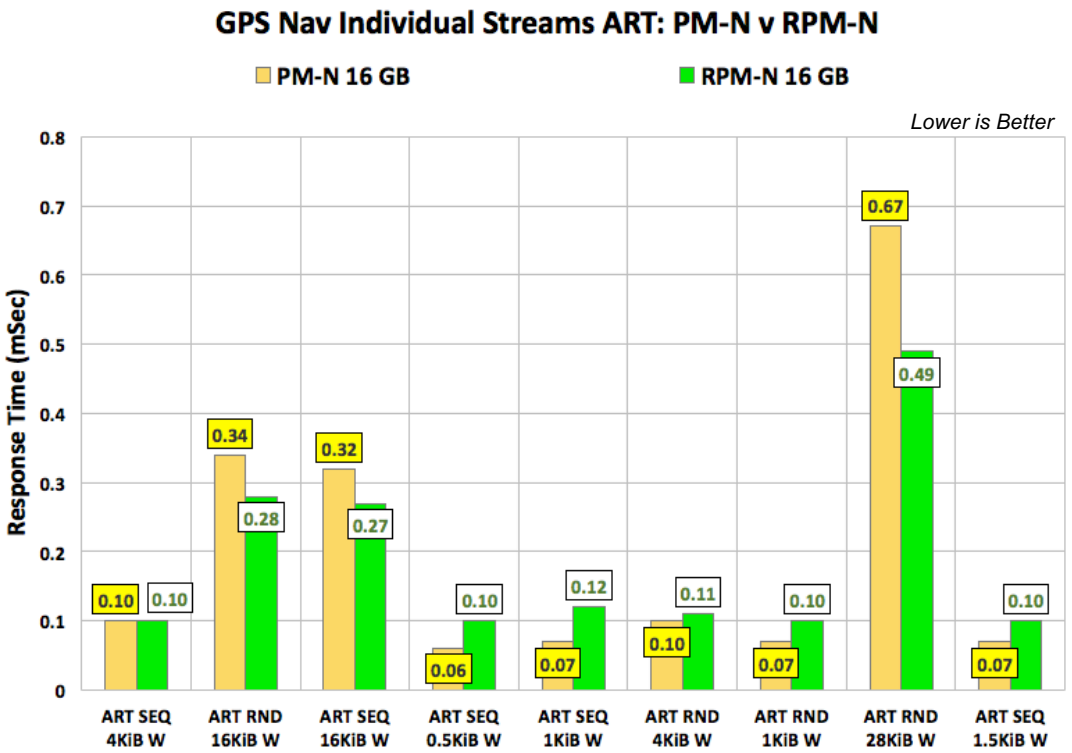


C. PM v RPM: Individual Streams – Average Response Times

GPS Nav – Individual Streams
9 IO Streams to Steady State

A0	GPS Nav Ind Streams
SEQ 4K W	28.0%
RND 16K W	19.9%
SEQ 16K W	16.2%
SEQ 0.5K W	15.7%
SEQ 1K W	6.5%
RND 4K W	5.1%
RND 1K W	2.98%
RND 28K W	2.86%
SEQ 1.5K W	2.75%

- **RPM-N RTs are Lower than PM-N RTs at transfer sizes < 4K, the same at 4K and higher > 4K**
- **Weighted IO Stream Mix determines workload performance**



A. NVMe v NVMe-oF – U.2-H: Synthetic DIRTH

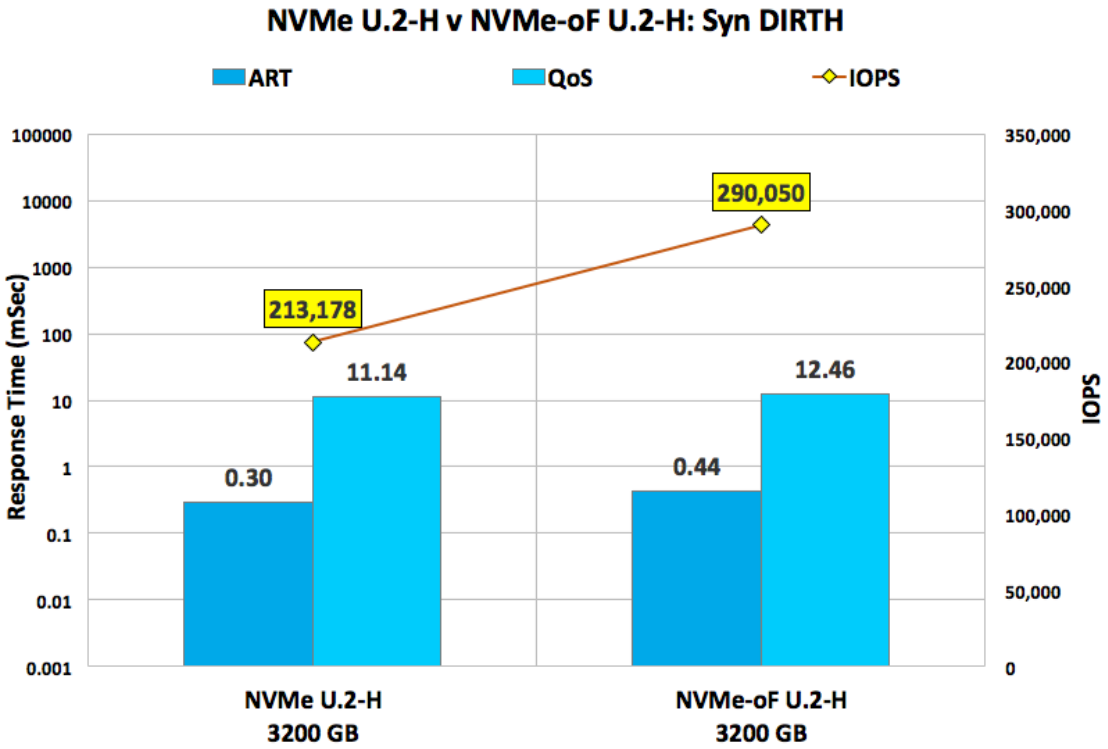
Syn SQL DIRTH – Fixed RND 8K RW65

QD (Users) Range 1-1024

A0	Synthetic SQL DIRTH	
RND 8K R	65.0%	65.0
RND 8K W	35.0%	35.0

	NVMe	NVMe-oF
IOPS	213,178	290,050
ART	0.30 mS	0.44 mS
QoS	11.14 mS	12.46 mS

- **NVMe U.2-H IOPS are Lower than NVMe-oF U.2-H**
- **NVMe U.2-H RTs are Lower than NVMe-oF U.2-H**



A. NVMe v NVMe-oF – U.2-I: Synthetic DIRTH

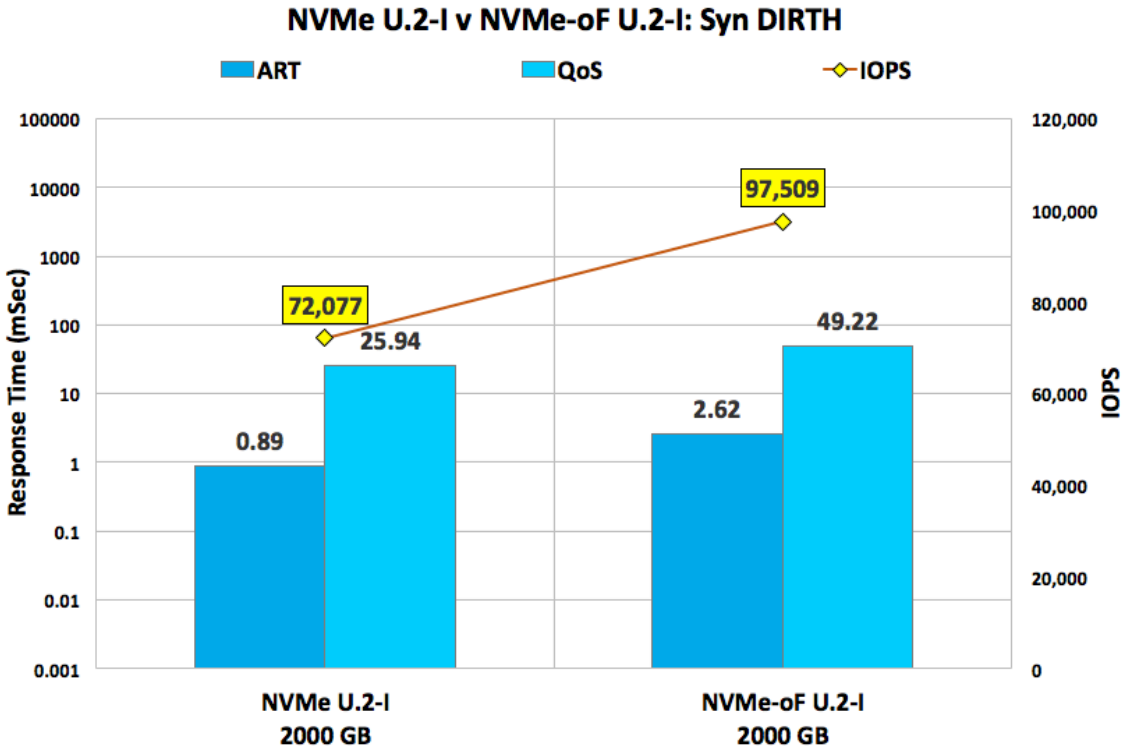
Syn SQL DIRTH – Fixed RND 8K RW65

QD (Users) Range 1-1024

A0	Synthetic SQL DIRTH	
RND 8K R	65.0%	65.0
RND 8K W	35.0%	35.0

	NVMe	NVMe-oF
IOPS	72,077	97,509
ART	0.89 mS	2.62 mS
QoS	25.94 mS	49.22 mS

- **NVMe U.2-I IOPS are Lower than NVMe-oF U.2-I**
- **NVMe U.2-I RTs are Lower than NVMe-oF U.2-I**



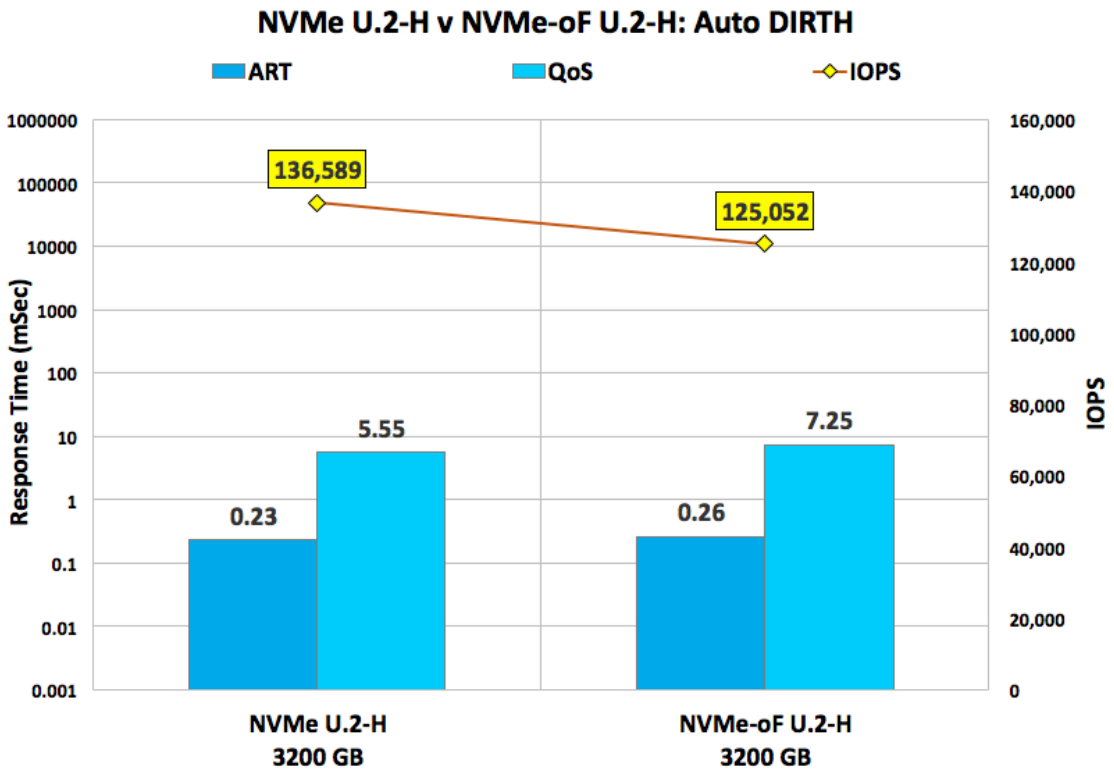
B. NVMe v NVMe-oF – U.2-H: Auto DIRTH

GPS Nav Auto DIRTH – Fixed 9 IO Streams

A0	GPS Nav Auto DIRTH	
SEQ 4K W	24.8%	28.0
RND 16K W	17.7%	19.9
SEQ 16K W	14.4%	16.2
SEQ 0.5K W	13.9%	15.7
SEQ 1K W	5.8%	6.5
RND 4K W	4.5%	5.1
RND 1K W	2.65%	2.98
RND 28K W	2.54%	2.86
SEQ 1.5K W	2.44%	2.75

	NVMe	NVMe-oF
IOPS	136,589	125,052
ART	0.23 mS	0.26 mS
QoS	5.55 mS	7.25 mS

- **NVMe U.2-H IOPS are Higher than NVMe-oF U.2-H**
- **NVMe U.2-H RTs are Lower than NVMe-oF U.2-H**



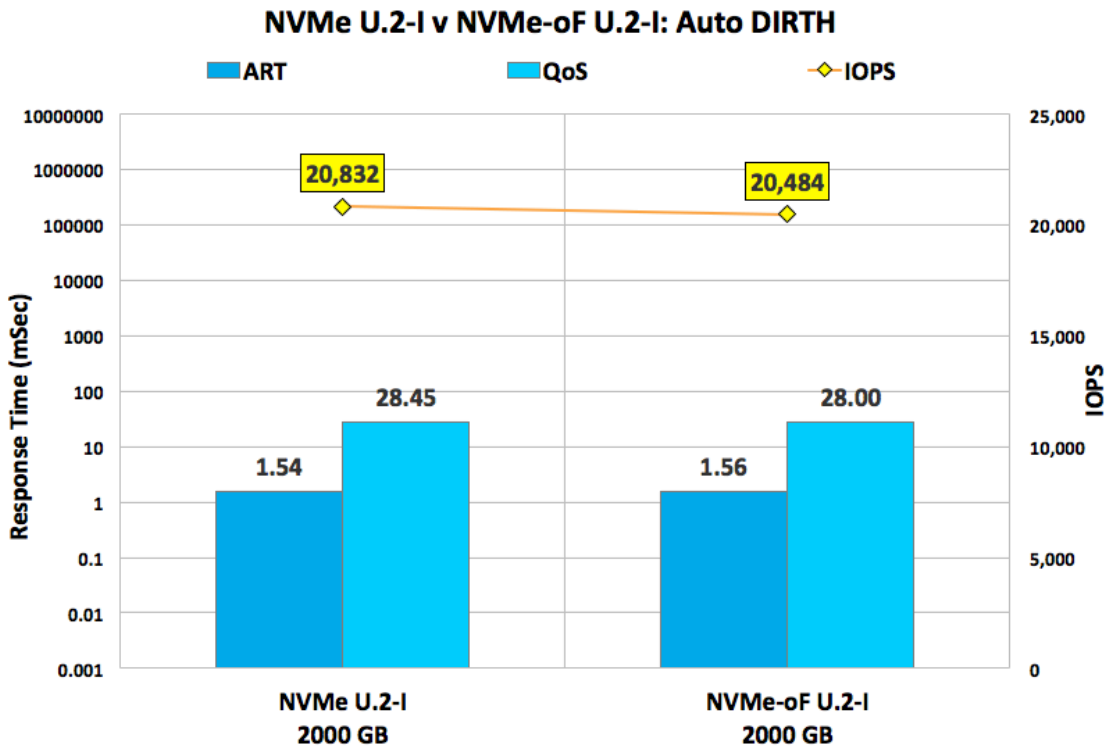
B. NVMe v NVMe-oF – U.2-I: Auto DIRTH

GPS Nav Auto DIRTH – Fixed 9 IO Streams

A0	GPS Nav Auto DIRTH	
SEQ 4K W	24.8%	28.0
RND 16K W	17.7%	19.9
SEQ 16K W	14.4%	16.2
SEQ 0.5K W	13.9%	15.7
SEQ 1K W	5.8%	6.5
RND 4K W	4.5%	5.1
RND 1K W	2.65%	2.98
RND 28K W	2.54%	2.86
SEQ 1.5K W	2.44%	2.75

	NVMe	NVMe-oF
IOPS	20,832	20,484
ART	1.54 mS	1.56 mS
QoS	28.45 mS	28.00 mS

- **NVMe U.2-I IOPS are substantially the same as NVMe-oF U.2-I**
- **NVMe U.2-I RTs are substantially the same NVMe-oF U.2-I RTs**

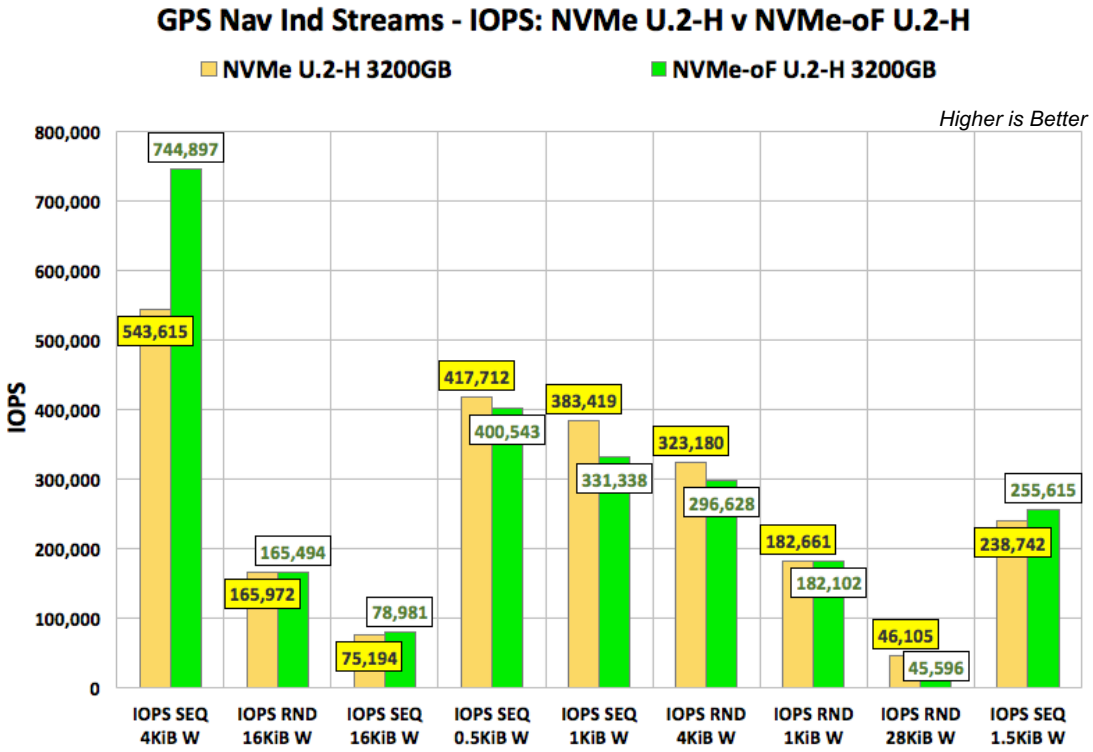


C. NVMe v NVMe-oF – U.2-H: Ind. Streams - IOPS

GPS Nav – Individual Streams
9 IO Streams to Steady State

A0	GPS Nav Ind Streams
SEQ 4K W	28.0%
RND 16K W	19.9%
SEQ 16K W	16.2%
SEQ 0.5K W	15.7%
SEQ 1K W	6.5%
RND 4K W	5.1%
RND 1K W	2.98%
RND 28K W	2.86%
SEQ 1.5K W	2.75%

- **NVMe U.2-H IOPS are Higher than NVMe-oF U.2-H at most transfer sizes**
- **NVMe-oF U.2-H SEQ 4K W IOPS are Higher than NVMe U.2-H**

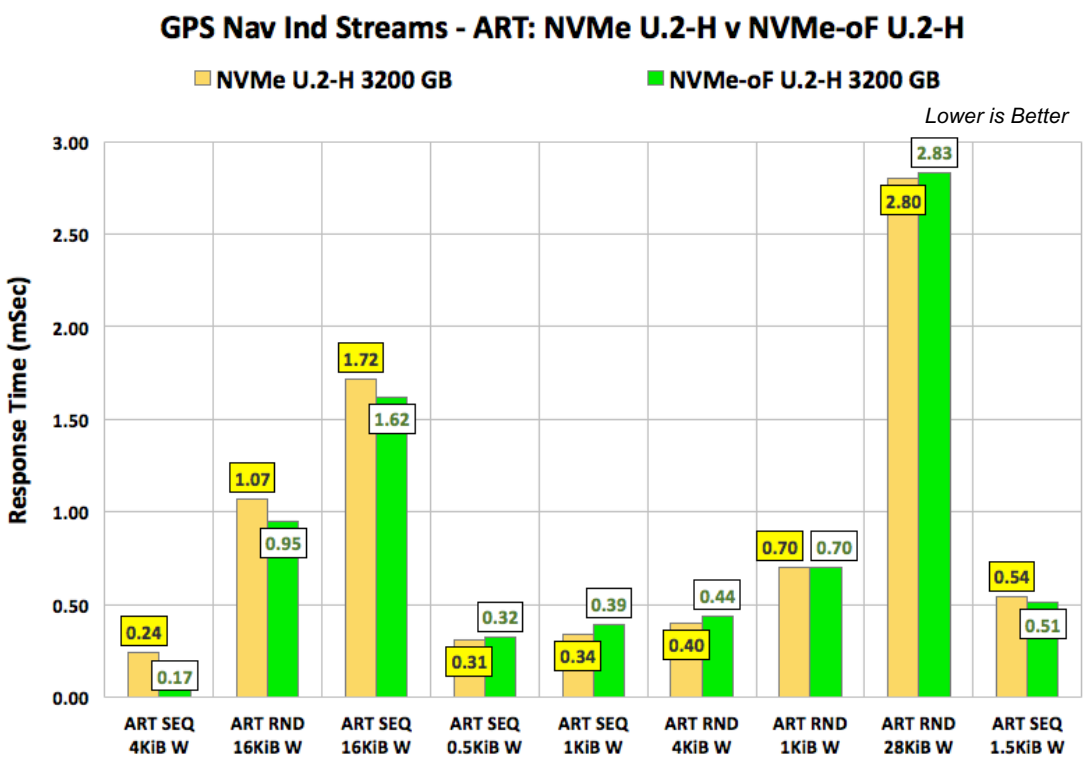


C. NVMe v NVMe-oF – U.2-H: Ind. Streams - ART

GPS Nav – Individual Streams
9 IO Streams to Steady State

A0	GPS Nav Ind Streams
SEQ 4K W	28.0%
RND 16K W	19.9%
SEQ 16K W	16.2%
SEQ 0.5K W	15.7%
SEQ 1K W	6.5%
RND 4K W	5.1%
RND 1K W	2.98%
RND 28K W	2.86%
SEQ 1.5K W	2.75%

- **NVMe U.2-H ART generally are Higher than NVMe-oF U.2-H at larger transfer sizes**
- **NVMe U.2-H ART generally are Lower than NVMe-oF U.2-H at smaller transfer sizes**

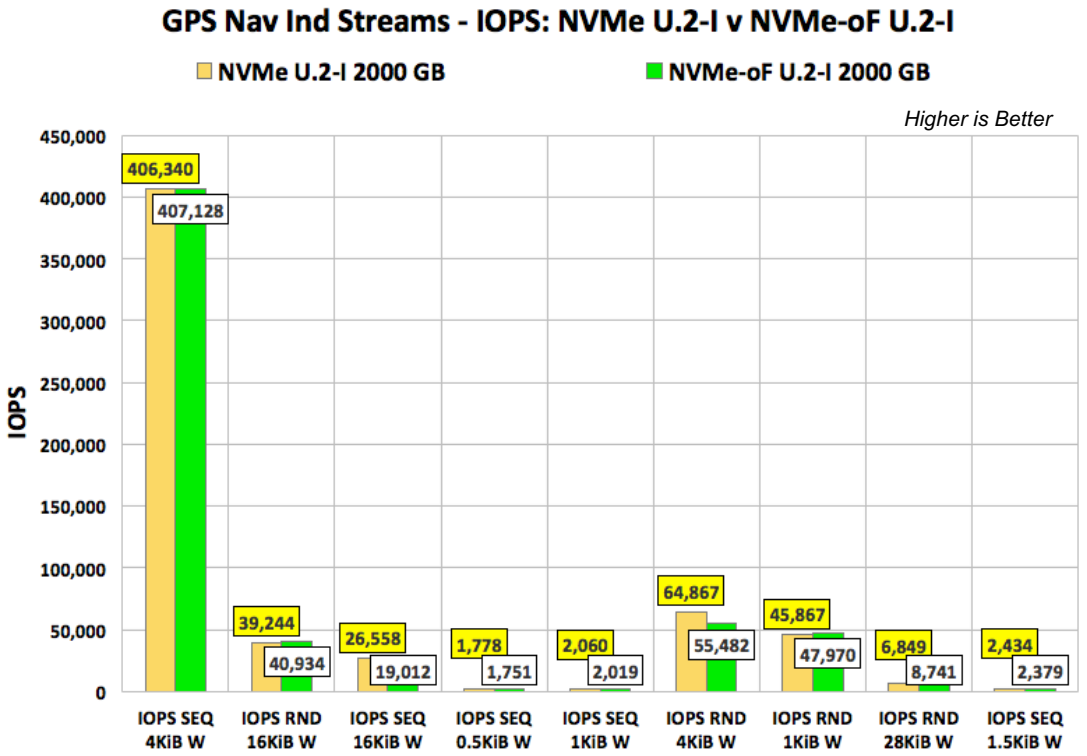


C. NVMe v NVMe-oF – U.2-I: Ind. Streams - IOPS

GPS Nav – Individual Streams
9 IO Streams to Steady State

A0	GPS Nav Ind Streams
SEQ 4K W	28.0%
RND 16K W	19.9%
SEQ 16K W	16.2%
SEQ 0.5K W	15.7%
SEQ 1K W	6.5%
RND 4K W	5.1%
RND 1K W	2.98%
RND 28K W	2.86%
SEQ 1.5K W	2.75%

- **NVMe U.2-I IOPS are substantially similar to NVMe-oF U.2-I IOPS**

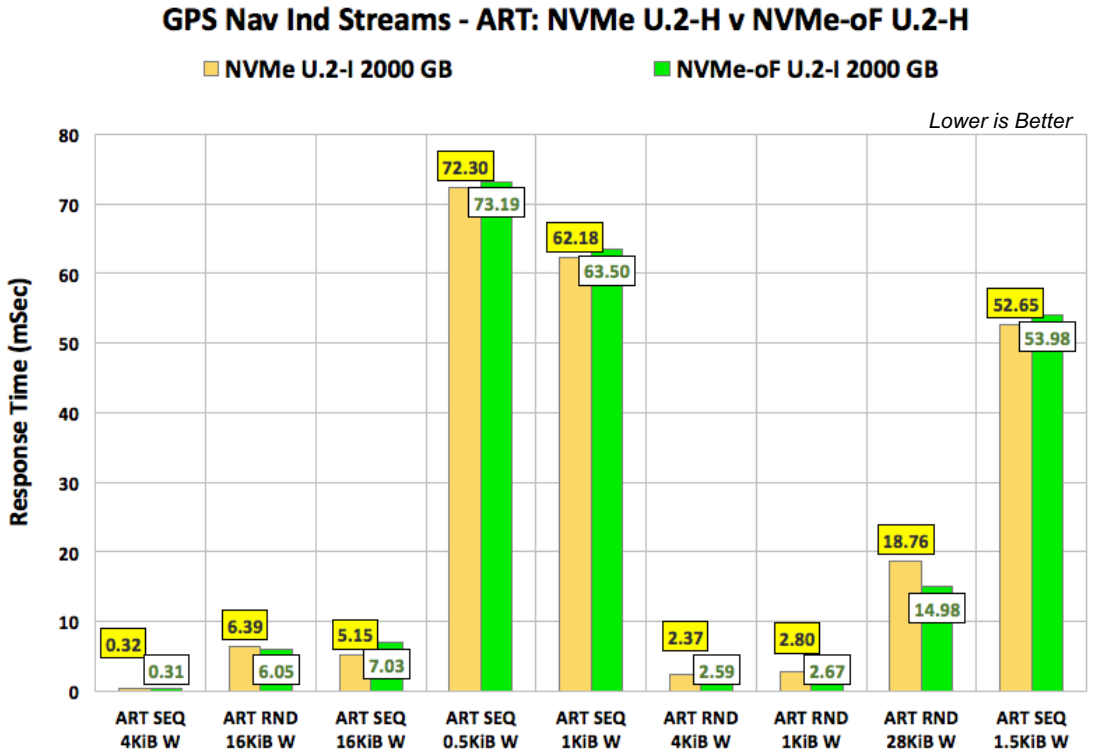


C. NVMe v NVMe-oF – U.2-I: Ind. Streams - ART

GPS Nav – Individual Streams
9 IO Streams to Steady State

A0	GPS Nav Ind Streams
SEQ 4K W	28.0%
RND 16K W	19.9%
SEQ 16K W	16.2%
SEQ 0.5K W	15.7%
SEQ 1K W	6.5%
RND 4K W	5.1%
RND 1K W	2.98%
RND 28K W	2.86%
SEQ 1.5K W	2.75%

- NVMe U.2-I ART are substantially similar to NVMe-oF U.2-I ART
- ART are Very High for SEQ 0.5KW and SEQ 1K W for NVMe U.2-I and NVMe-oF U.2-I



Conclusions

A. PM - Faster IOPS & lower RTs by order(s) magnitude over NVMe

B. Synthetic SQL – Higher Demand Intensity, 65% R workload = Higher performance

C. Real World Replay - Lower Demand Intensity & Write workload = Lower performance

D. Scaled Replay – Increases IOPS and Response Times

E. Fabric – Adds Response Time Overhead

F. NVMe-oF – Slower U.2 shows Equivalent Performance for Direct and Fabric NVMe Storage

G. Performance – Affected by Workload, Demand Intensity, Storage Type and Inter connect

Questions?

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