QSAN
Official Document

NVMe-oF

White Paper

October 2025

ANNOUNCEMENT

Copyright

© Copyright 2025 QSAN Technology, Inc. All rights reserved. No part of this document may be reproduced or transmitted without written permission from QSAN Technology, Inc.

QSAN believes the information in this publication is accurate as of its publication date. The information is subject to change without notice.

Trademarks

- QSAN, the QSAN logo, QSAN.com, XCubeFAS, XCubeSAN, XCubeNXT, XCubeNAS, XCubeDAS, XEVO, SANOS, and QSM are trademarks or registered trademarks of QSAN Technology, Inc.
- Microsoft, Windows, Windows Server, and Hyper-V are trademarks or registered trademarks of Microsoft Corporation in the United States and/or other countries.
- Linux is a trademark of Linus Torvalds in the United States and/or other countries.
- UNIX is a registered trademark of The Open Group in the United States and other countries.
- Mac and OS X are trademarks of Apple Inc., registered in the U.S. and other countries.
- Java and all Java-based trademarks and logos are trademarks or registered trademarks of Oracle and/or its affiliates.
- VMware, ESXi, and vSphere are registered trademarks or trademarks of VMware, Inc. in the United States and/or other countries.
- Citrix and Xen are registered trademarks or trademarks of Citrix Systems, Inc. in the United States and/or other countries.
- Other trademarks and trade names used in this document to refer to either the entities claiming the marks and names or their products are the property of their respective owners.

TABLE OF CONTENTS

Announcement i
Notices v
Preface vi
Technical Support vi
Information, Tip, and Caution vi
1. Introduction 8
1.1. What is NVMe-oF 8
1.2. Key Features of NVMe-oF 9
2. Theory of Operations 10
2.1. Mechanism of NVMe-oF 10
2.2. Transport Options 11
3. NVMe-oF Configuration 12
4. Test Results – NVMe/TCP 13
4.1. NVMe/TCP Test Configuration 14
5. Test Results – NVMe/RoCE 15
5.1. NVMe/RoCE Test Configuration 15
6. Conclusion 16
7. Appendix 17
7.1. Apply To 17
7.2. Reference 17

©2025 QSAN Technology, Inc. All rights reserved.

FIGURES

Figure 1-1 NVMe-oF Data Transfer Diagram 8
Figure 2-1 Data I/O Task under NVMe-oF 10

Announcement
©2025 QSAN Technology, Inc. All rights reserved.
www.qsan.com

TABLES

Table 4-1 XN4226D NVMe/TCP Test Matrix 14
Table 5-1 XN4226D NVMe/RoCE Protocol Test Matrix 15

Announcement
©2025 QSAN Technology, Inc. All rights reserved.
www.qsan.com

NOTICES

Information contained in this document has been reviewed for accuracy. But it could include typographical errors or technical inaccuracies. Changes are made to the document periodically. These changes will be incorporated in new editions of the publication. QSAN may make improvements or changes in the products. All features, functionality, and product specifications are subject to change without prior notice or obligation. All statements, information, and recommendations in this document do not constitute a warranty of any kind, express or implied.

Any performance data contained herein was determined in a controlled environment. Therefore, the results obtained in other operating environments may vary significantly. Some measurements may have been made on development-level systems and there is no guarantee that these measurements will be the same on generally available systems. Furthermore, some measurements may have been estimated through extrapolation. Actual results may vary. Users of this document should verify the applicable data for their specific environment.

This information contains examples of data and reports used in daily business operations. To illustrate them as completely as possible, the examples include the names of individuals, companies, brands, and products. All these names are fictitious and any similarity to the names and addresses used by an actual business enterprise is entirely coincidental.

©2025 QSAN Technology, Inc. All rights reserved.

PREFACE

Technical Support

Do you have any questions or need help trouble-shooting a problem? Please contact QSAN Support, we will reply to you as soon as possible.

- Via the Web: https://www.qsan.com/technical_support
- Via Telephone: +886-2-77206355
- (Service hours: 09:30 - 18:00, Monday - Friday, UTC+8)
- Via Skype Chat, Skype ID: qsan.support
- (Service hours: 09:30 - 02:00, Monday - Friday, UTC+8, Summer time: 09:30 - 01:00)
- Via Email: support@qsan.com

Information, Tip, and Caution

This document uses the following symbols to draw attention to important safety and operational information.



INFORMATION

INFORMATION provides useful knowledge, definition, or terminology for reference.



TIP

TIP provides helpful suggestions for performing tasks more effectively.

©2025 QSAN Technology, Inc. All rights reserved.



CAUTION

CAUTION indicates that failure to take a specified action could result in damage to the system.

©2025 QSAN Technology, Inc. All rights reserved.

1. INTRODUCTION

This document provides technical guidance for NVMe over Fabrics (NVMe-oF), a protocol designed to extend the performance and efficiency of NVMe beyond local PCIe connections into a variety of network fabrics. By transporting NVMe commands over high-speed networks, NVMe-oF enables remote storage to perform as if it were locally attached, delivering ultra-low latency and scalable throughput that meets the demands of modern applications.

1.1. What is NVMe-oF

NVMe-oF (Non-Volatile Memory Express over Fabrics) is an extension of the NVMe protocol that allows a host to access remote NVMe devices across a network fabric with the same efficiency as a direct PCIe connection. Unlike legacy storage protocols such as iSCSI or Fibre Channel carrying SCSI commands, NVMe-oF transmits native NVMe commands directly through supported transports like Fibre Channel (FC), RDMA-based Ethernet (RoCE), InfiniBand, and TCP/IP.

By mapping NVMe queues onto the transport layer, NVMe-oF minimizes protocol overhead and achieves microsecond-level latency. This design allows enterprises to unlock the full potential of NVMe SSDs not only within a server, but across a distributed IT environment, making it an essential technology for next-generation infrastructures such as AI, virtualization, real-time analytics, and media production.

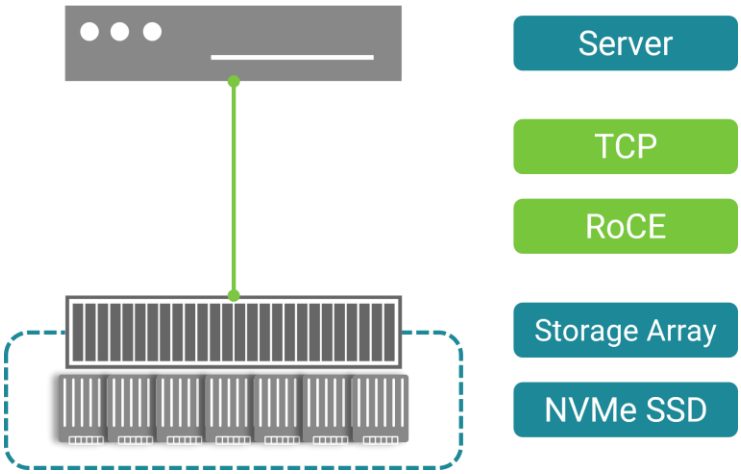


Figure 1-1 NVMe-oF Data Transfer Diagram

©2025 QSAN Technology, Inc. All rights reserved.

1.2. Key Features of NVMe-oF

NVMe-oF introduces several critical features that differentiate it from traditional block storage protocols:

- **Lower Latency and Higher IOPS**
  NVMe-oF reduces the command processing path by eliminating SCSI translation layers. Combined with parallel NVMe queues, this architecture delivers microsecond-level latency and millions of IOPS, significantly outperforming iSCSI-based storage.
- **Flexible Transport Options**
  NVMe-oF is transport-agnostic, supporting multiple network options to meet different infrastructure needs. Among these, **NVMe/TCP** and **NVMe/RoCE** are widely adopted and fully supported in QSAN storage solutions:
  - **NVMe/TCP**: Offers broad compatibility and simple deployment on standard Ethernet infrastructure without requiring special hardware or lossless networks. It delivers higher performance than iSCSI with lower cost and complexity, making it ideal for enterprises seeking rapid adoption.
  - **NVMe/RoCE**: Leverages RDMA technology to bypass kernel and CPU overhead, providing ultra-low latency and efficient data transfers. It is especially suited for demanding workloads such as AI/ML training, HPC, and high-frequency databases where every microsecond matters.



INFORMATION

When adopting an NVMe-oF environment, please check your storage, Ethernet, and the host configuration in terms of compatibility.

©2025 QSAN Technology, Inc. All rights reserved.

2. THEORY OF OPERATIONS

This chapter introduces the operational theory of NVMe-oF and explains how its transport mechanisms enable remote NVMe storage to deliver near-local performance.

2.1. Mechanism of NVMe-oF

NVMe-oF enables communication between a host and a remote NVMe storage target by encapsulating NVMe commands within a chosen transport protocol. Unlike legacy block storage protocols such as iSCSI that translate SCSI commands over TCP/IP, NVMe-oF transmits NVMe commands natively across a fabric. This direct command mapping removes translation overhead and preserves the full efficiency of NVMe's parallel queue architecture.

To break down the NVMe-oF architecture consists of:

- **Host**: The initiator that submits NVMe commands.
- **Fabric (Transport Layer)**: The medium that encapsulates NVMe commands (e.g., TCP, and RDMA).
- **Target**: The NVMe storage device that processes commands as if they originated from a local PCIe bus, including the NVMe controller and NVMe Namespace.

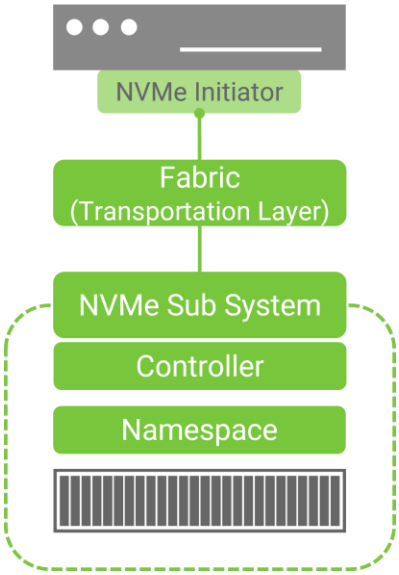


Figure 2-1 Data I/O Task under NVMe-oF

©2025 QSAN Technology, Inc. All rights reserved.

This design ensures that applications interacting with NVMe-oF targets experience performance comparable to locally attached NVMe SSDs, while retaining the scalability and flexibility of a networked solution.

2.2. Transport Options

NVMe-oF is designed to be transport-agnostic, offering multiple options to meet different infrastructure requirements. Each transport has unique trade-offs in terms of performance, deployment complexity, and hardware needs.

2.2.1. NVMe/TCP

NVMe/TCP encapsulates NVMe commands within standard TCP/IP packets, allowing organizations to deploy NVMe-oF on their existing Ethernet infrastructure without requiring specialized hardware. This broad compatibility and ease of deployment make it an attractive choice for enterprises seeking cost-effective NVMe adoption. Compared with iSCSI, NVMe/TCP reduces protocol overhead and delivers significantly higher performance while maintaining simple scalability.

2.2.2. NVMe/RoCE

RoCE (RDMA over Converged Ethernet) is designed to achieve the lowest possible latency by bypassing the traditional TCP/IP stack. By enabling direct memory access between nodes, it reduces CPU utilization and improves throughput, making it ideal for latency-sensitive applications such as AI/ML training, real-time financial trading, HPC clusters, and high-performance databases.

©2025 QSAN Technology, Inc. All rights reserved.

3. NVMe-oF Configuration

The following are tutorials for configuring NVMe-oF environments. Follow the steps and you can learn them quickly.

Setup Tutorial

- How to Setup NVMe/TCP
-

©2025 QSAN Technology, Inc. All rights reserved.

4. TEST RESULTS – NVME/TCP

This test verifies the dramatic performance improvement offered by NVMe-oF. We test the the NVMe-oF in TCP and RoCE environment. Please check the following test result for a clear vision of the benefit from NVMe-oF.

Test Equipment and Configurations

- Server
  - Model: GIGABYTE R181-342
    Memory: 64 GB
    iSCSI HBA: Mellanox ConnectX-4 Lx
    OS: Ubuntu 22.02Equipment
- Storage
  - Model: XN4226D-8C
    Memory: 32 GB per controller
    Host Connection: iSCSI: HCQ25GS3-40
    Firmware: QSM 4.1.6
    SSD: QSAN SD43T840-00 3.84 TB * 26

©2025 QSAN Technology, Inc. All rights reserved.

4.1. NVMe/TCP Test Configuration

The first test item is the widely adopted TCP environment data transfer. The NVMe/TCP test showed a maximum 95% performance gain, with a notable improvement in read-intensive workloads.

Table 4-1 XN4226D NVMe/TCP Test Matrix

Test Item	NVMe/TCP	iSCSI	Improvement
4K Random Read (IOPS)	916,059	551,722	66%
4K Random Write (IOPS)	485,000	401,957	21%
128K Sequential Read (MB/s)	12,626	6,481	95%
128K Sequential Write (MB/s)	5,817	4,821	21%

©2025 QSAN Technology, Inc. All rights reserved.

5. TEST RESULTS – NVME/ROCE

5.1. NVMe/RoCE Test Configuration

The next test evaluates the NVMe/RoCE data transfer method for the all-flash model in RDMA environment. The most significant improvement was observed in 128K sequential read throughput, which increased by 82% with in NVMe-oF protocol, demonstrating its advantage in accelerating large block sequential transfers.

Table 5-1 XN4226D NVMe/RoCE Protocol Test Matrix

Test Item	NVMe/RoCE	iSCSI over RDMA	Improvement
4K Random Read (IOPS)	967,357	591,306	64%
4K Random Write (IOPS)	521,900	445,308	17%
128K Sequential Read (MB/s)	14,094	7,764	82%
128K Sequential Write (MB/s)	9,049	7,721	17%

©2025 QSAN Technology, Inc. All rights reserved.

6. CONCLUSION

substantial performance improvements compared to traditional block storage protocols, with clear benefits across random and sequential workloads. NVMe/RoCE excels in environments requiring ultra-low latency and maximum throughput, showing up to 82% gain in sequential read performance. On the other hand, NVMe/TCP offers remarkable scalability and ease of deployment while still delivering up to 95% performance improvement in sequential reads over legacy approaches.

By supporting both transports, QSAN enables users to select the optimal balance between performance, deployment simplicity, and infrastructure investment. This flexibility ensures enterprises are well-prepared to meet the demands of next-generation workloads, from virtualization and media production to AI-driven analytics and beyond.

©2025 QSAN Technology, Inc. All rights reserved.

7. APPENDIX

7.1. Apply To

- QSM firmware 4.1.5 and later (Not available in XN8100 / XN5100 / XN1 series)
- XEVO firmware 3.0.0 and later

7.2. Reference

Document

- QSM 4 Software Manual
- XEVO 3 Software Manual

©2025 QSAN Technology, Inc. All rights reserved.