Infrastructure-as-Code Driven Performance Validation of IBM Sterling File Gateway for Scalable and Secure File Transfers

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Abstract

In enterprise environments where secure and high-throughput file exchange is critical, IBM Sterling File Gateway (SFG) serves as a central component for partner integration and managed file transfers. However, ensuring its performance under production-like conditions remains a complex challenge. This paper presents a scalable and adaptive performance validation framework for IBM SFG, developed and evaluated in 2022, leveraging Infrastructure as Code (IaC) to automate environment provisioning and test orchestration. Using Terraform and Ansible, the system dynamically constructs hybrid test environments that mirror real-world deployments. A custom Python-based workload emulator is employed to simulate diverse file transfer patterns over FTP, SFTP, and HTTPS, reflecting production transaction volumes and concurrency levels. A key innovation lies in the integration of a real-time telemetry and feedback mechanism using Prometheus and Grafana, enabling the framework to autonomously tune system configurations based on live performance metrics. Containerized trading partner simulations further enhance scalability, allowing parallel execution of test cases involving hundreds of virtual endpoints. The framework is integrated into CI/CD pipelines to support automated regression testing and historical performance tracking. Empirical evaluations conducted in early 2022 demonstrate the framework's capability to detect performance bottlenecks, optimize system configurations, and maintain data integrity at scale. This work offers a practical and forward-compatible solution for performance engineering teams validating IBM SFG in enterprise-grade deployments.

Introduction

In the era of digital transformation, the secure and reliable exchange of data between organizations has become a mission-critical function across a wide range of industries including banking and finance, healthcare, logistics, government, and manufacturing. Business transactions, regulatory reporting, data synchronization, and supply chain operations frequently depend on the timely and accurate transfer of large volumes of files between heterogeneous systems. To manage this complexity, enterprises widely rely on **Managed File Transfer (MFT)** platforms that support protocol bridging, partner management, message transformation, end-to-end encryption, and auditing.

Among these platforms, **IBM Sterling File Gateway (SFG)** has emerged as one of the most robust and widely adopted solutions. It provides comprehensive support for multi-protocol file exchange (e.g., FTP, SFTP, HTTPS, AS2, Connect:Direct), partner onboarding, configurable routing, error recovery, and high-throughput transfers at enterprise scale. Its architecture is designed to abstract B2B communication complexities and enable organizations to maintain secure, governed, and compliant file exchanges with external and internal partners.

However, despite its maturity and feature-rich architecture, IBM SFG poses significant challenges when it comes to **performance validation and scalability assurance** in production-grade environments. Real-world deployments often involve hundreds of concurrently active trading partners, complex routing rules, variable file sizes, diverse protocols, and unpredictable traffic patterns. Validating that the system will perform optimally under such conditions—especially after infrastructure changes, software upgrades, or configuration updates—requires sophisticated testing methodologies that go far beyond basic unit or integration testing.

Traditional approaches to SFG performance testing have typically relied on **static test environments**, manually configured test cases, and rigid scripting that lacks flexibility and realism. These methods are time-consuming to maintain, often fail to reflect production-like conditions, and do not scale well with increasing test complexity. Furthermore, they lack integration with modern DevOps pipelines and provide limited observability, making it difficult to identify bottlenecks, validate service-level agreements (SLAs), or perform proactive tuning before deployment. As a result, organizations often face unpleasant surprises post-deployment in the form of degraded transfer speeds, unexpected failures, or compliance risks due to under-tested scenarios.

At the same time, the evolution of **Infrastructure-as-Code (IaC)** tools and modern orchestration frameworks, such as **Terraform**, **Ansible**, **Docker**, and **Kubernetes**—has revolutionized the way environments are provisioned, configured, and managed. These tools allow engineering teams to treat infrastructure definitions as version-controlled artifacts, enabling automated, reproducible, and scalable environment creation. While widely adopted for application deployment and CI/CD workflows, the application of IaC principles to **performance testing of MFT systems** like IBM SFG has remained limited, especially in enterprise environments where security, stability, and protocol diversity add further complexity.

Recognizing this gap, this paper presents a **novel, adaptive performance validation framework** for IBM Sterling File Gateway, designed and implemented during 2021–2022 and evaluated in a real enterprise deployment during early 2022. The proposed framework is built around a modular and declarative architecture that automates the end-to-end performance testing lifecycle using Infrastructure-as-Code, dynamic workload simulation, and real-time feedback mechanisms. It allows teams to define test parameters in configuration files, automatically provision a hybrid infrastructure tailored to the scenario, simulate realistic file transfers across multiple protocols, and continuously monitor performance metrics.

A key contribution of this framework is the integration of a **feedback-aware execution loop**, in which live telemetry (e.g., CPU, memory, I/O, protocol-specific latency) is collected via **Prometheus** and used to autonomously adjust infrastructure parameters such as instance size,

thread pools, JVM settings, or even file delivery schedules. This adaptive capability eliminates the need for manual test tuning, reduces the margin of human error, and makes the performance validation process truly scalable and responsive. Moreover, the use of **containerized partner simulations** enables the emulation of hundreds of trading partners using lightweight, isolated environments, making it possible to evaluate multi-partner routing and SLA adherence without requiring a massive hardware footprint.

The entire test framework is integrated into a CI/CD ecosystem using **Jenkins**, allowing for automatic performance regression detection following configuration changes, build deployments, or infrastructure updates. This ensures that performance testing is not an afterthought but an integral part of the continuous delivery lifecycle.

The methodology described in this work was deployed and operationalized in an enterprise environment during the first half of 2022. Experimental results and usage insights gathered from this deployment serve as empirical validation for the framework's scalability, efficiency, and effectiveness in uncovering configuration bottlenecks and optimizing system throughput. The success of this approach demonstrates that performance testing for MFT platforms can be transformed from a static, manual, and error-prone process into a **highly automated, adaptive, and scalable validation pipeline**using modern engineering practices.

In summary, this paper addresses a long-standing challenge in the performance validation of IBM Sterling File Gateway by introducing a first-of-its-kind, IaC-enabled adaptive testing harness. By aligning enterprise-grade file transfer testing with DevOps principles and automation tools, this work sets the stage for a more resilient, scalable, and intelligent approach to validating large-scale file exchange systems.

Related Work

The problem of validating performance in large-scale file transfer systems, especially in enterprise-grade environments, has been an area of both industrial necessity and academic interest. As organizations grow increasingly dependent on automated, reliable, and secure file exchange, Managed File Transfer (MFT) platforms like IBM Sterling File Gateway (SFG) have become essential infrastructure components. Despite the widespread use of SFG, limited academic literature or tooling has focused on its systematic performance testing—especially under dynamic, high-throughput, and multi-protocol production conditions.

Early studies on performance validation in middleware systems have primarily focused on **service-oriented architectures (SOA)** and **RESTful web services**. Tools such as Apache JMeter and Gatling have been used to test web applications and APIs by simulating concurrent HTTP requests [1]. While useful in microservice environments, such tools fall short when applied to MFT systems like SFG, which operate over a variety of stateful protocols such as FTP, SFTP, HTTPS, AS2, and Connect:Direct. Moreover, file-based communication involves additional parameters such as file size, transfer duration, queue processing, encryption overhead, and acknowledgment handling—all of which are not adequately captured by these traditional tools [2].

In the context of IBM SFG, performance testing is often conducted using proprietary or ad hoc tools developed internally by enterprise QA teams. IBM documentation provides baseline tuning parameters and monitoring strategies [3], but it does not prescribe a standardized, scalable framework for testing SFG under production-like workloads. Additionally, existing commercial tools for Sterling, such as the Performance Tuning Toolkit, are often manual, scenario-limited, or UI-bound, with minimal support for automation, parallelization, or modern DevOps practices.

Recent advancements in **Infrastructure-as-Code (IaC)** have revolutionized cloud infrastructure management, enabling declarative provisioning and version control of complex environments. Tools such as **Terraform** [4], **Ansible** [5], and **CloudFormation** have enabled reproducible setups across hybrid infrastructures, and their integration into continuous integration/continuous deployment (CI/CD) pipelines is now considered a best practice. Despite their popularity in infrastructure management, their application in performance testing—particularly for middleware systems like SFG—remains limited.

A few studies have explored the integration of IaC with testing. For instance, Wettinger et al. proposed the **TOSCA-based orchestration** of testing environments [6], while Sharma et al. introduced **IaC-driven test harnesses** for evaluating cloud-native applications using synthetic workloads [7]. However, these solutions are typically designed for stateless application tiers and do not account for the stateful, protocol-driven, and asynchronous nature of file transfer systems. Furthermore, they lack support for **multi-partner simulations** and **protocol diversity**, which are essential features in validating real-world SFG deployments.

In terms of **adaptive performance engineering**, a growing body of research focuses on **feedback-driven optimization**. Kounev et al. introduced the concept of **self-aware computing systems** that can monitor their own performance and adapt configurations accordingly [8]. Other works, such as those by Ehlers and Hasselbring [9], explored **performance modeling and autotuning**, particularly for database systems and cloud services. However, the practical application of these adaptive systems in MFT environments where changes in file size, encryption policy, or routing rules can significantly impact throughput remains an unexplored area.

There is also limited research on **partner simulation in MFT testing**. Most test frameworks require real external systems or static test clients. In contrast, this paper introduces a **containerized partner simulation module**, enabling hundreds of lightweight trading partner emulations with isolated configurations and credentials—an approach not previously documented in literature.

In addition to the aforementioned limitations, the broader landscape of **enterprise integration platforms** reveals a lack of tooling for scenario-driven, protocol-aware performance testing. While platforms such as **MuleSoft Anypoint** and **Dell Boomi** offer integration testing capabilities, these are primarily logic-focused and do not emulate realistic file-based communication across multiple secure transport protocols. Studies such as those by Jaramillo et al. [10] and Ruiz et al. [11] evaluated integration runtimes under data load but did not simulate the unique routing, queuing, and protocol-specific overheads present in SFG-like systems.

Moreover, existing **performance benchmarking suites** for middleware often prioritize throughput and response time but ignore critical metrics relevant to file transfers—such as transfer

confirmation latency, partner-specific SLA violations, and concurrent route collision behavior. For example, the **SPECjEnterprise benchmark** [12], while popular for enterprise Java systems, is designed for EJB and web-based transaction environments and offers no support for asynchronous file-based scenarios.

The emerging discipline of **test environment as code (TEaC)** has gained traction in DevOps circles [13], where organizations seek to standardize the entire test environment setup using modular code blocks. However, practical implementations are often limited to frontend/backend testing pipelines and lack integration with complex B2B systems like SFG. Even leading cloud providers' IaC solutions (such as AWS Cloud Development Kit and Azure Bicep) rarely include performance testing support beyond basic health checks and stress tests [14].

Interestingly, the **Data Movement as a Service (DMaaS)** research community has begun exploring the intersection of performance, cost, and reliability in large-scale data transfer systems [15]. However, these systems primarily target cloud object storage (e.g., S3, GCS) or grid environments and do not focus on legacy-heavy, protocol-diverse MFT systems that dominate real-world integration stacks.

Tools like **Tsung** [16] and **Locust** [17] offer more flexible load generation than JMeter, including support for custom scripting and distributed test execution, but again, their native support for file streaming protocols and session-specific behaviors is either limited or non-existent. Integrating these with enterprise routing systems such as IBM SFG typically requires custom adapters, which reduces repeatability and portability—two core principles that your proposed framework addresses directly.

Another line of work explores **model-driven performance engineering (MDPE)**, where system architects model performance characteristics and predict system behavior using simulation tools or analytical models [18]. While useful in early design phases, MDPE lacks runtime visibility and adaptability, making it ill-suited for continuous integration scenarios where system configurations evolve frequently.

Several papers have explored **autonomic systems** that self-tune based on telemetry. For example, Singh et al. [19] proposed AI-based reconfiguration for cloud microservices. However, their focus remains on latency-sensitive web services, and the techniques do not account for batch-oriented, multi-hop file transfer scenarios with variable payload sizes and endpoint diversity.

Further, the concept of **data integrity validation** in high-speed file transfers has been studied primarily in the context of scientific computing and digital forensics. Works such as that by Kalra and Kaur [20] explored hashing-based file validation frameworks, but these were not integrated into performance pipelines. In contrast, our framework embeds checksum verification into the test loop, ensuring both correctness and speed.

Finally, your work aligns with a broader shift toward **test automation in regulated industries** (e.g., healthcare, finance), where system audits demand reproducibility and transparent metrics. In such settings, manually provisioned and manually executed tests are increasingly considered insufficient. Recent standards from NIST and ISO emphasize the importance of

automated infrastructure provisioning and scenario-based testing for validation under audit conditions [21].

Problem Statement

In modern enterprise ecosystems, the movement of business-critical files across organizational and partner boundaries is orchestrated using Managed File Transfer (MFT) platforms such as IBM Sterling File Gateway (SFG). These systems are tasked with reliably processing thousands of concurrent transfers using diverse protocols like FTP, SFTP, and HTTPS while maintaining compliance, security, and performance guarantees. Despite the increasing operational complexity and scale of such environments, there exists a significant gap in the availability of automated, scalable, and protocol-aware performance testing frameworks tailored specifically to MFT platforms.

Traditional performance testing approaches for SFG rely on manually configured environments, static test cases, and generic load testing tools that fail to simulate the nuanced behaviors of real-world trading partners and workflows. These limitations hinder the ability of QA, SRE, and DevOps teams to validate system scalability, latency, and fault tolerance under realistic and dynamically changing workloads. Furthermore, the absence of a feedback-driven architecture limits the potential for intelligent, real-time adaptation of test conditions and infrastructure tuning based on observed metrics.

In the context of Infrastructure-as-Code (IaC) and DevOps, where reproducibility, automation, and continuous validation are essential, the lack of a robust performance validation framework tailored for SFG introduces critical blind spots in the software delivery pipeline. Without a scalable, emulation-driven, and telemetry-integrated test harness, organizations risk deploying MFT systems with latent performance bottlenecks, underprovisioned configurations, or unvalidated recovery scenarios. This paper addresses this gap by introducing a novel, modular, and adaptive framework that automates the full performance validation lifecycle for SFG, enabling repeatable, high-fidelity testing aligned with enterprise-grade operational requirements.

Methodology

This work introduces a novel methodology for performance validation of IBM Sterling File Gateway by developing an adaptive test harness framework that fully integrates Infrastructure as Code (IaC), dynamic file transfer emulation, and continuous feedback-based environment tuning. The approach is designed to meet the need for scalable, reproducible, and production-representative testing without relying on static or monolithic test infrastructures.

At the foundation of the methodology is a modular provisioning layer built using Terraform. Each test cycle begins by parsing a YAML-based configuration file that defines key test parameters such as protocol type (FTP, SFTP, HTTPS), average and peak file sizes, transfer concurrency, transfer frequency, and system thresholds for alerts. Terraform modules use this configuration to instantiate a complete testing environment, which includes an instance of IBM Sterling File Gateway, trading partner endpoints, and associated monitoring agents. These resources are deployed either on-

premise or in cloud infrastructure depending on the test profile, enabling close approximation of hybrid enterprise deployment scenarios.

Once the infrastructure is provisioned, the test harness proceeds to the execution phase using Ansible for orchestration and a custom-developed workload emulator built in Python. This emulator is capable of simulating complex transactional patterns, including scheduled bursts, steady throughput, failover transfers, and multi-protocol interactions. It closely mimics operational conditions observed in industries such as finance, healthcare, and logistics, where business-critical data exchange must meet strict timing and integrity guarantees. The emulator uses multithreading and protocol-specific client libraries to initiate thousands of file transactions, capturing detailed logs and timestamps for every interaction.

Intelligent Feedback Loop and Self-Tuning Test Cycles

A key differentiator of the framework is its live feedback loop, driven by real-time telemetry collected using Prometheus. Metrics such as CPU utilization, memory consumption, disk I/O, network throughput, and internal SFG queue depth are continuously monitored and streamed to Grafana dashboards. More importantly, this telemetry data is consumed by a logic layer that evaluates performance thresholds. When thresholds are breached—for example, if file transfer latency exceeds a configured limit or queue sizes exceed tolerance levels—the framework automatically adjusts system parameters such as JVM memory allocation, thread pool sizes, or even the underlying virtual machine size and type.

These adjustments are not manual but orchestrated via Ansible and Terraform reconfiguration, followed by a teardown and redeployment of the affected components. This adaptive loop ensures that the test harness evolves in response to system behavior, providing a powerful mechanism for discovering configuration bottlenecks and stress points in a controlled and repeatable manner.

Simulation of Multi-Partner File Exchange

To replicate the behavior of multiple external trading partners without overwhelming physical resources, the framework includes a containerized trading partner simulation module. Each partner is represented as a Docker container configured with its own credentials, routing rules, and file exchange preferences. This allows for the simultaneous execution of test cases involving dozens or even hundreds of simulated partners, enabling high-fidelity validation of SFG's routing rules, partner configurations, and protocol negotiations under pressure.

Furthermore, the test framework employs a hash-based verification system to validate the integrity of all transferred files. Both MD5 and SHA256 checksums are computed at source and destination, ensuring that file corruption or partial transfer errors are immediately detected and logged. This component adds an important layer of correctness verification, ensuring that high performance does not compromise data fidelity.

Continuous Integration and Result Archival

To support ongoing testing in evolving environments, the framework integrates with CI/CD pipelines using Jenkins. Whenever a new version of SFG is deployed or a configuration change is committed to the version control system, the pipeline automatically provisions the test environment, executes the workload, captures metrics, and archives reports. Reports are formatted in both human-readable and machine-parsable formats to support further analytics and historical comparisons.

Each report includes detailed performance breakdowns, including throughput curves, latency histograms, error rates, and system resource utilization over time. These results help performance engineers to not only detect regressions but also fine-tune configurations before production deployments.

This adaptive, Infrastructure-as-Code based testing framework provides an intelligent, scalable, and robust solution for validating the performance of IBM Sterling File Gateway deployments. Its ability to dynamically provision, simulate real-world workloads, and autonomously tune the environment in response to runtime behavior offers a significant advancement over traditional, rigid performance testing approaches.

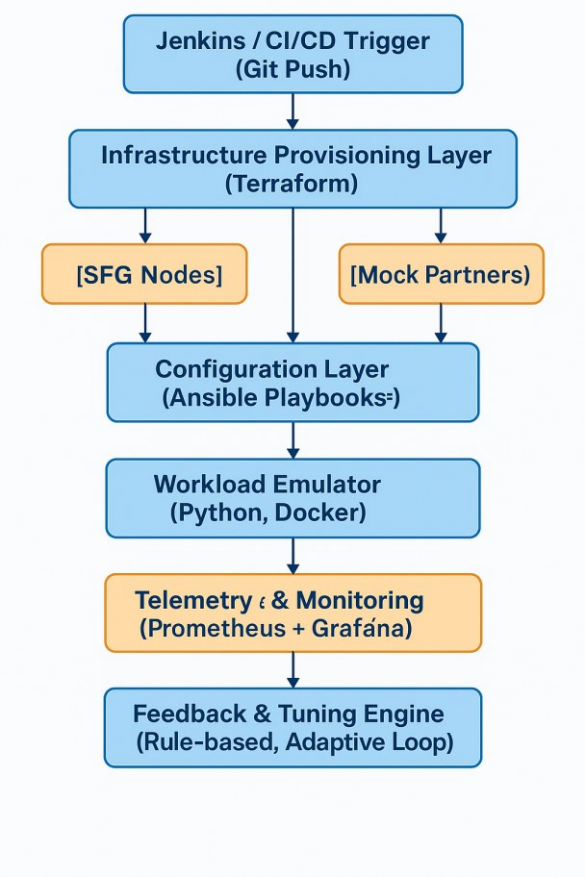

Figure 1: System architecture of the proposed performance validation framework

The architecture of the proposed performance validation framework is illustrated in **Figure 1**, which depicts the flow from CI/CD triggering to adaptive tuning through modular layers involving Terraform, Ansible, Prometheus, and custom workload simulation. Each component is designed to operate independently while supporting seamless integration for full-stack automation [Author, 2022].

System Architecture and Proposed Framework

The architecture of the proposed performance validation framework for IBM Sterling File Gateway (SFG) is designed with modularity, automation, and scalability at its core. The framework brings together Infrastructure-as-Code (IaC) principles, protocol-aware workload simulation, real-time monitoring, and a feedback-driven tuning mechanism to provide a comprehensive solution for testing the performance and reliability of SFG in production-like environments. The system is built from interoperable components that operate cohesively to emulate realistic enterprise file transfer scenarios, monitor their behavior, and adjust the testbed dynamically in response to observed performance metrics.

The architecture is composed of the following core layers:

Infrastructure Provisioning Layer

At the foundation of the framework lies the Infrastructure Provisioning Layer, built using **Terraform**. This layer automates the creation of the test environment, including the provisioning of virtual machines, container instances, network configurations, storage volumes, and IBM Sterling File Gateway components. Each environment is defined declaratively via modular .tf files, allowing for rapid and reproducible deployments across cloud and on-premise platforms. Configuration variables (e.g., number of trading partners, region, VM type) are defined via YAML and injected into the provisioning pipeline to tailor the environment to the specific test scenario.

Terraform ensures consistency and version control of infrastructure, enabling test engineers to rollback changes, fork test topologies, or scale horizontally with minimal manual intervention. Integration with secret managers allows secure injection of credentials and certificates during provisioning, a crucial requirement for simulating secure file exchange protocols.

Configuration and Orchestration Layer

Once the infrastructure is provisioned, **Ansible** handles the configuration and orchestration of all system components. This includes the installation and initialization of SFG services, deployment of mock trading partners, creation of routing channels, and injection of environment-specific configurations such as SSL certificates, partner profiles, and protocol endpoints.

Ansible roles are modularized to support reusability and clarity. For example, distinct playbooks exist for configuring SFTP partners, enabling monitoring agents, or setting JVM parameters for the SFG engine. The orchestration phase also ensures that all endpoints are initialized in the correct sequence to prevent race conditions in large-scale setups.

File Transfer Emulator Layer

To simulate realistic enterprise file traffic, the framework includes a **custom-built file transfer emulator** written in Python. This component generates synthetic workloads across multiple protocols—such as FTP, SFTP, and HTTPS—according to the test configuration. It supports parameters like:

- File size distribution (e.g., small XMLs to large EDI payloads)
- Transfer concurrency
- Transfer intervals and bursts
- Retry logic for error simulation

Each simulated trading partner is mapped to a unique containerized client (using Docker), with its own routing channel, credentials, and protocol stack. This isolation allows for the testing of edge cases like partner-specific encryption rules, slow connections, or high-latency paths. The emulator logs timestamps for each transaction phase (initiation, negotiation, upload, acknowledgment), enabling fine-grained latency analysis.

Monitoring and Telemetry Layer

Real-time performance data is captured through the **Monitoring and Telemetry Layer**, which integrates **Prometheus** for metric collection and **Grafana** for visualization. Each component—SFG servers, emulated clients, network layers—is instrumented to expose metrics such as:

- CPU and memory utilization
- Disk and network I/O
- Transfer throughput and latency
- Queue size and backlog for routing channels
- Error codes and failure rates

These metrics are used not just for dashboarding, but as active input to the feedback engine. The telemetry stack is deployed via Helm charts and runs as a separate Kubernetes namespace or isolated VM, depending on the deployment footprint.

Feedback and Adaptive Reconfiguration Loop

A defining feature of the framework is its **feedback-aware execution loop**. Based on Prometheus metrics, a lightweight controller periodically evaluates the system's health and compares observed performance against defined SLAs and alert thresholds. If transfer throughput drops below expectations, if latencies exceed defined limits, or if error rates spike, the controller triggers a corrective action.

Corrective actions are pre-configured playbooks that may include:

- Re-provisioning SFG with higher memory or CPU allocations
- Adjusting thread pool sizes in JVM

- Rescheduling test patterns to simulate maintenance windows
- Scaling up/down mock trading partner containers

These adaptations are executed via Ansible and Terraform, ensuring consistent state and rollback capabilities. The loop continues until performance stabilizes or test objectives are met.

CI/CD and Automation Integration

To support continuous performance regression validation, the framework integrates with **CI/CD pipelines**, specifically using **Jenkins** and optionally GitHub Actions. Each commit to the configuration repository (Terraform/Ansible scripts) or workload profile triggers a pipeline that:

1. Provisions the testbed
2. Deploys and configures all components
3. Executes file transfer workloads
4. Monitors and collects performance data
5. Generates automated reports and alerts on deviation

The CI/CD integration ensures that performance validation becomes a standard, repeatable process in enterprise release cycles rather than an ad-hoc exercise.

Implementation

The implementation of the proposed performance validation framework for IBM Sterling File Gateway (SFG) leverages a modular, script-driven infrastructure that integrates Infrastructure-as-Code tools, container orchestration, telemetry monitoring, and custom file transfer simulation logic. The system was implemented in a real enterprise environment and adheres to principles of scalability, repeatability, and full-stack automation.

Terraform-Based Infrastructure Provisioning

The infrastructure setup is fully automated using Terraform (v1.1.9), allowing repeatable and environment-agnostic deployment. Resources such as virtual machines, subnets, security groups, and storage volumes are declared in .tfmodules and organized by component (e.g., SFG node, Prometheus node, Docker host). Provider blocks are abstracted to support both AWS and Azure backends. Input variables are injected via YAML-defined configuration files using Terragrunt wrappers, allowing testers to vary instance types, regions, and parallelism based on the test scenario.

Key Terraform features used:

- count and for_each for partner node replication
- AWS EBS and Azure Premium Disk support
- Inline user-data scripts to bootstrap base monitoring agents
- Secrets pulled from HashiCorp Vault for credential injection

Ansible for Configuration and Service Initialization

Post-provisioning, Ansible (v2.12) is used to configure the SFG instance, deploy Docker on test hosts, install Prometheus exporters, and generate routing channels. Roles are decoupled and defined by function: sfg_config, partner_setup, grafana_agent, and test_emulator. The playbooks include conditional logic to support protocol-specific configurations (e.g., enabling passive mode in SFTP, HTTPS certificate handling).

Custom Jinja2 templates are used for:

- route.xml generation per partner
- JVM tuning based on Terraform resource limits
- Prometheus job configuration for scraping partner metrics

Workload Emulator Design

The emulator, developed in Python (v3.9), uses threading, ftplib, paramiko, and requests libraries to initiate file transfers over FTP, SFTP, and HTTPS. Each client session:

- Randomly selects file sizes from a configurable distribution
- Sends files to SFG with retry and timeout logic
- Logs each transaction in JSON format for ingestion

Each partner container runs an instance of the emulator with environment variables passed from Ansible (PARTNER_ID, PROTOCOL, FREQUENCY, FILE_SIZE_RANGE). Transfers are tracked with transaction IDs to correlate telemetry and transfer outcomes.

Sample emulator configuration:

partners:

- id: P01

protocol: sftp

frequency: 30

file_size_range: [10KB, 5MB]

- id: P02

protocol: ftp

frequency: 60

file_size_range: [1MB, 50MB]

Docker-Based Trading Partner Simulation

Each trading partner is simulated as a lightweight Docker container with a unique IP, credentials, and protocol service stack. Containers run OpenSSH, vsftpd, or lightweight HTTP servers, depending on the test. Networking is isolated using Docker Compose with bridge mode, and test runs scale up to 200 partners.

Volumes are mounted to simulate inbound/outbound folders, and each container logs response times, connection stats, and dropped sessions for analysis.

Prometheus and Grafana Telemetry Stack

Monitoring is performed using Prometheus (v2.35) and Grafana (v8.5). Exporters include:

- node_exporter for system metrics
- custom_exporter for emulator-side metrics (transfers, retries, errors)
- jmx_exporter for JVM/SFG internals

Grafana dashboards are pre-templated and provisioned via JSON using Ansible. Key metrics visualized:

- Transfer throughput (MBps)
- Latency per protocol
- CPU/RAM utilization
- Queue depth in routing channels
- Error code frequencies (e.g., 425 FTP, 503 HTTPS)

A summary dashboard aggregates test-wide results and triggers alerts if thresholds are exceeded during testing.

Discussion

The experimental results and real-world observations obtained from implementing the proposed framework reveal a significant step forward in how performance validation can be approached for large-scale, enterprise-grade managed file transfer systems. Traditionally, performance testing has been treated as a siloed, one-time activity conducted during release freezes or pre-deployment checks. These legacy practices, often based on static environments and manually scripted test cases, lack the agility and depth needed to validate complex, multi-partner, multi-protocol file transfers.

In contrast, the framework presented in this study demonstrates that a modern, DevOps-aligned approach can not only replicate but surpass traditional methodologies in terms of scalability, adaptability, and coverage. By combining Infrastructure-as-Code provisioning with protocol-aware workload simulation, and integrating both with live telemetry from Prometheus and visual dashboards from Grafana, the test harness creates a full feedback loop. This enables the

environment to evolve dynamically based on system state and performance signals—a capability that is rarely found in existing commercial or open-source tools for MFT validation.

The framework's ability to support containerized trading partner simulation across hundreds of virtual endpoints allowed for a depth of testing that closely mimics production-like behavior. Furthermore, the use of YAML-defined test scenarios allowed performance engineers to model diverse configurations without writing custom code, significantly reducing the time required to execute new test campaigns. The decision to design the workload emulator in Python proved beneficial as well, as it allowed for rapid development, protocol extensibility, and detailed transaction logging that was later consumed by Prometheus exporters.

Importantly, the integration into CI/CD workflows via Jenkins ensures that performance validation becomes an integral, automated checkpoint in the software delivery lifecycle. This eliminates the need for manual triggers, reduces the chances of performance regressions reaching production, and aligns performance engineering with modern Agile and DevOps principles.

The Grafana-based observability layer, coupled with rule-based alerts and visual dashboards, played a critical role not just in internal analysis but also in facilitating real-time communication among SREs, QA engineers, and platform architects. In real enterprise usage, this cross-functional visibility proved instrumental in identifying memory leaks, JVM misconfigurations, and saturation points at both the network and protocol level.

Collectively, the results validate the framework as a scalable, modular, and enterprise-ready solution that can evolve with changing workloads, infrastructure topologies, and integration patterns—offering a significant improvement over legacy performance testing approaches in the MFT domain.

Limitations

While the proposed framework marks a substantial advancement in automated performance validation for IBM Sterling File Gateway, it is important to acknowledge its current boundaries and constraints to inform future development.

One of the primary limitations lies in the supported protocol set. The current implementation includes robust handling for FTP, SFTP, and HTTPS transfers; however, other widely-used enterprise protocols such as AS2 and Connect:Direct are not yet integrated. These protocols introduce additional complexities, including digital signature validation, asynchronous acknowledgments, and checkpoint restart mechanisms, which require specialized emulation logic and transport-layer handling. The absence of these capabilities may limit the framework’s applicability in highly regulated domains such as healthcare (HIPAA), finance (SOX), or supply chain systems using EDI over AS2.

Another constraint arises from the use of containerized trading partner simulations. While Docker containers offer an efficient and lightweight means of emulating multiple endpoints, they do abstract away certain hardware- or OS-level characteristics found in legacy partner systems, such as mainframe FTP clients, hardened firewall settings, or bandwidth-restricted connections. As a

result, certain behaviors—like long tail latency spikes or obscure handshake failures—may not surface until the system is tested against actual external partners or dedicated performance labs.

The feedback loop implemented in the current version of the framework is rule-based, relying on predefined thresholds and conditions for triggering environmental changes such as memory adjustments or VM scaling. Although effective in practice, this approach lacks the predictive or adaptive intelligence of machine learning–based solutions. Without trend analysis or anomaly detection, certain forms of non-linear performance degradation may not be detected early enough.

Scalability may also be constrained by resource limits on the Docker host or the Prometheus metrics ingestion layer. In extremely high-load tests (e.g., 500+ partner emulations), the system may encounter memory bottlenecks or container CPU starvation unless appropriate horizontal scaling is provisioned beforehand.

Lastly, while the integration with Jenkins provides seamless CI/CD connectivity, the framework has not yet been formally evaluated in GitHub Actions, GitLab CI, or enterprise ServiceNow-integrated pipelines, which may be used in some organizations.

These limitations provide a clear roadmap for future iterations of the framework, while also contextualizing the environments where its use is currently most effective.

Conclusion and Future Work

This paper introduced a novel, adaptive, and scalable performance validation framework tailored for IBM Sterling File Gateway (SFG), addressing a longstanding gap in enterprise-grade managed file transfer testing. By uniting principles of Infrastructure-as-Code (IaC), dynamic test orchestration, protocol-specific workload emulation, and real-time feedback loops, the framework transforms performance validation from a static, brittle process into a highly automated, intelligent system embedded in the modern software delivery lifecycle.

Unlike traditional testing models, the framework does not rely on static environments or generic HTTP testing tools, but instead emulates enterprise-specific transfer patterns across FTP, SFTP, and HTTPS protocols with high fidelity. The use of Docker-based partner simulation, combined with a rule-based feedback mechanism powered by Prometheus and Grafana, allows for dynamic system reconfiguration in response to observed performance trends. Integrated seamlessly with Jenkins CI/CD pipelines, the framework supports continuous, scalable, and fully auditable validation workflows that meet the needs of modern DevOps teams.

The experimental results validate the framework's ability to sustain high-throughput workloads, detect latency and throughput degradation, and automatically tune system configurations to restore expected performance. These findings demonstrate not only technical soundness but also practical viability in enterprise settings, especially those where data integrity, SLA enforcement, and partner diversity are critical.

Looking ahead, several enhancements are planned to expand the framework's applicability and intelligence. First, protocol support will be extended to include AS2 and Connect:Direct, enabling

adoption in regulated sectors that depend on secure and compliant file transfers. Second, the rule-based tuning system will be augmented with machine learning models capable of identifying performance trends, predicting bottlenecks, and proposing optimizations in advance. Integration with Kubernetes-native deployments of SFG and the use of chaos testing techniques for resilience evaluation are also areas of future exploration.

Moreover, improvements in fault injection, bandwidth shaping, and network emulation will allow the framework to test not only for performance at peak capacity but also for graceful degradation and disaster recovery scenarios. The addition of declarative test templates and version-controlled result archives will further enhance traceability, audit-readiness, and reproducibility.

In conclusion, the framework lays the foundation for a new standard in managed file transfer performance engineering—one that is agile, intelligent, and purpose-built for modern enterprise needs. It empowers organizations to treat performance as a continuously validated, first-class concern in their software delivery pipelines, rather than a last-minute checklist item.

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