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SECURITIES TECHNOLOGY ANALYSIS CENTER

STAC-T1™:
A Tick-to-Trade Test Harness

In most cases, STAC provides products and services to help firms analyze the performance of specific segments of the trading workload (e.g., market data feed handling, messaging, etc.). STAC-T1 builds on some of these offerings to help firms improve <u>end-to-end</u> (or "tick-to-trade") testing of their trading systems. This document provides an overview of the STAC-T1 test harness approach.

> *This overview does not discuss delivery dates or pricing.*
> *Contact STAC to for details.*

STAC-T1 Test Harness Software

STAC-T1 responds to requests from members of the STAC Benchmark™ Council for both high-quality market data replay and high-performance simulation of trade-execution venues for the purpose of testing complete trading systems. The test harness enables latency measurement from wire to wire or between points within software. The "stack under test" (SUT) may be a distributed system consisting of ticker plants, trading apps, and execution gateway servers, or a tightly contained system handling all market data, algorithmic, and execution functions for a given set of instruments in a single box.

There is currently no STAC-T1 working group or STAC-T1 standard benchmark. Instead, our plan is first to deliver STAC-T1 test harnesses to a number of customers and let a dialog around standard benchmarks emerge later, using the STAC-T1 parameters as vocabulary.

Architecture

STAC-T1 can work with any SUT that accepts Ethernet for market data and execution (Infiniband may be available in the future; if you wish to emulate a dark pool or other venue that provides Infiniband connectivity, please contact STAC). As illustrated in Figures 1 and 2, the STAC-T1 Test Harness draws from the STAC-M1™ (market data feed handling) and STAC-E1™ (execution gateway) Test Harnesses. STAC-T1 will consist of four fundamental components:

- STAC Hi-Fi™ (market data feed replay)
- STAC Responders™ (venue gateway emulators)
- STAC analysis & reporting tools
- STAC orchestration scripts and the STAC-T1 Controller

STAC Hi-Fi is software that leverages hardware such as Endace DAG cards to record and play back any UDP-based feed at multiples of market rates. Compared to software-based replay, this approach provides far better fidelity to the original data stream (sub-microsecond fidelity, in fact), which preserves the natural pattern of the market data traffic, micro-bursts and all. STAC Hi-Fi is also integrated with the STAC Controller (see below) for automated test execution.

> Note: STAC Hi-Fi does not emulate a retransmission line or other TCP link for market data. We assume that the SUT is capable of functioning without a TCP link (for example, that it can build its symbol list by listening to a data replay before the performance tests start). Contact STAC if this assumption is not valid for any of your use cases.

STAC Responders are software processes that accept orders and provide ACKs, fills, rejects, etc. according to a given wire protocol and the scenario they are configured to run. They operate by applying rules such as fill ratios rather than by maintaining an order book and performing matching. Thus, the probability of a fill has no relationship to the marketability of the order. Note that STAC Responders will not emulate an exchange 100% and are meant for performance testing rather than extensive protocol-conformance validation.

The combination of STAC Hi-Fi and STAC Responders enables the tester to vary several aspects of the workload imposed by the harness, such as:

- Number of market data sources
- Redundancy of market data sources (A & B channels)
- Rate multipliers applied to market data streams
- Number of Responders
- Fill and reject ratios for different order types, including partial fill ratios
- Timing of partial fills
- Responder delays (ACKs, initial fills)

STAC analysis and reporting tools. These STAC tools automatically output the following:

- A customizable PDF report. Reports follow the STAC standard, including a detailed description of the SUT and extensive statistical analysis of latency.

- Tabular CSV output suitable for import into Excel or another analysis tool to enable easy comparison of each benchmark from SUT to SUT. This output is an ideal basis for a centralized benchmark repository and "performance audit trail" for system changes.

- Detailed results in CSV format that enable deep-dive analysis of performance for troubleshooting or other purposes.

Orchestration scripts and the STAC-T1 Controller application (which communicates with STAC Hi-Fi and STAC Responders via UDP multicast channels on a network that is out of band from the SUT network) control the entire test process from end to end. They iterate through the configured test sequences, run tests, collect the low-level data, and launch the analysis and reporting tools. Along the way, the scripts periodically call out to SUT-specific scripts (supplied by the customer) to start up and shut down SUT processes, etc. This automation enables tests to run as unattended background tasks, such as Linux cron jobs.

Monitoring. The STAC-T1 Test Harness design allows for two different measurement paradigms: internal monitoring and external monitoring.

- **Internal monitoring** (illustrated in Figure 1) means that the trading application (the "top" layer of the SUT) timestamps messages and computes pair-wise latency observations, which it provides to the STAC analysis and reporting tools via a standard file format (files can be written after testing, to minimize performance impact). The application deter-mines which latencies to measure. The advantage of internal monitoring is that it leverages latency calculations already present in many applications. (For example, most trading applications routinely track round-trip order-to-ACK latencies.) This approach does not require specialized wire-capture equipment and therefore costs the least to acquire and implement.

STAC-T1 Test Harness
(Internal Monitoring)
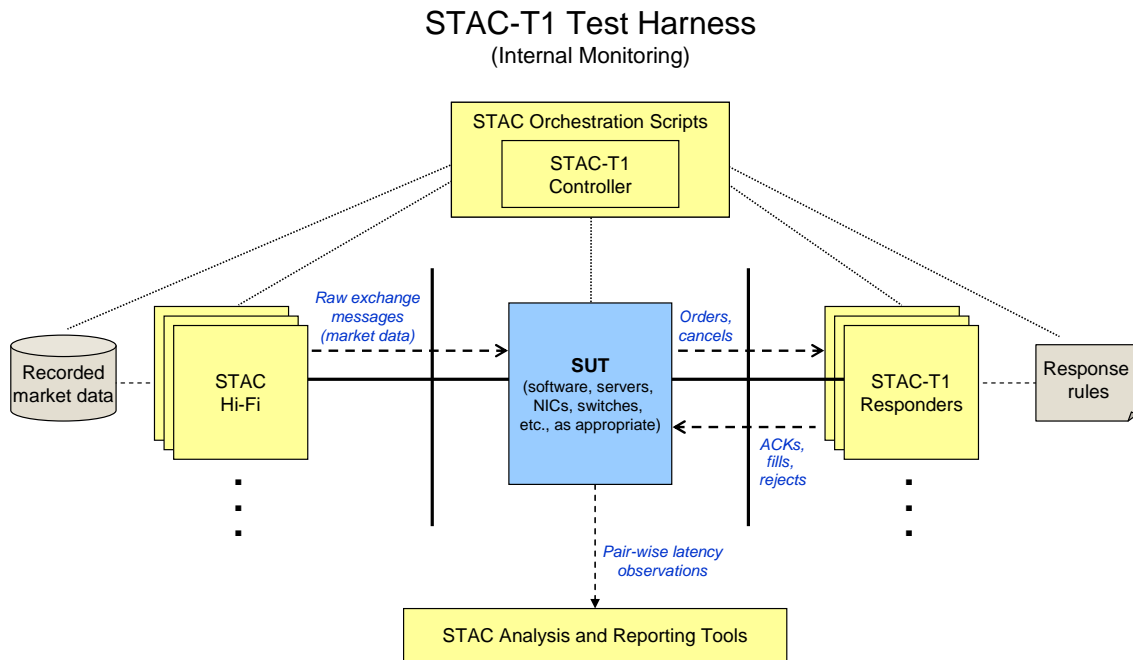
Figure 1

- **External monitoring** (illustrated in Figure 2) means that a latency monitoring system captures messages on the wire into and out of the SUT and correlates them to make pair-wise latency observations, which it provides to the STAC analysis and reporting tools. The latency monitor can be a third-party vendor product or something developed by the customer. The advantage of external monitoring is that it provides a complete view of end-to-end latency including latencies due to networking equipment and the network stack on the SUT node(s). These are not captured via internal monitoring.

STAC-T1 Test Harness
(External Monitoring)
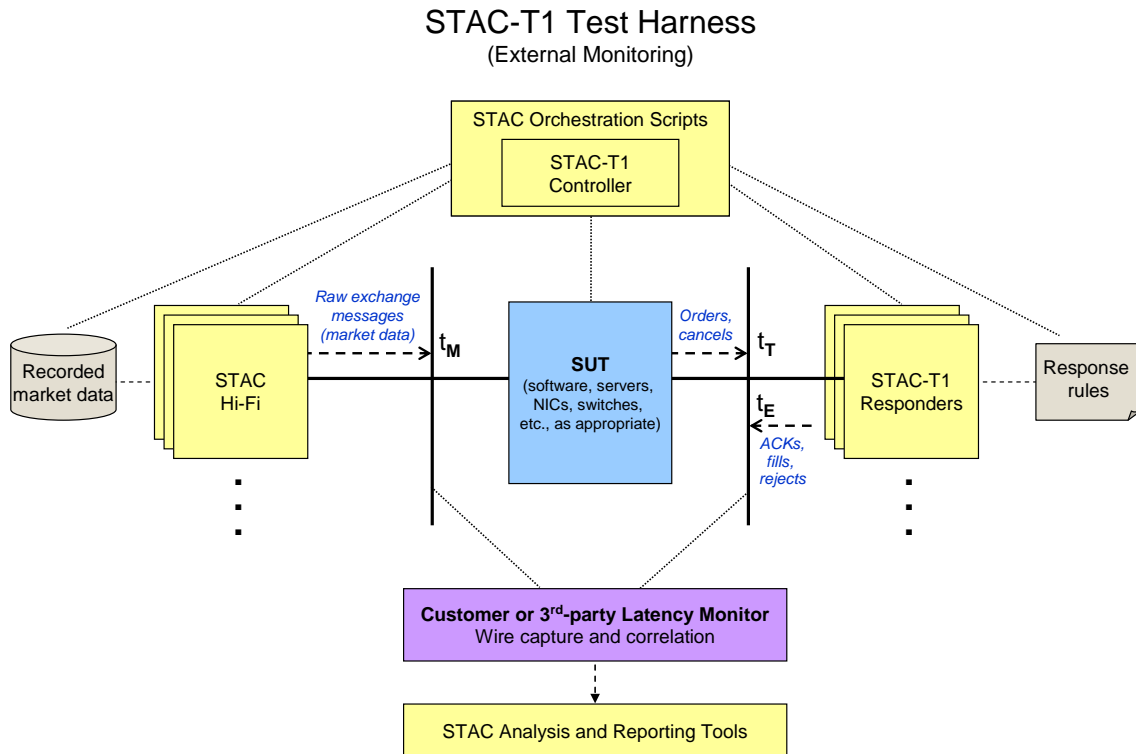
Figure 2

Various measurements are possible with an external monitor, but the ultimate objective for most customers is measuring "tick-to-trade" latency for trades that are triggered by market data messages, execution reports, or a combination thereof ("Trigger Events"). The latency for such a trade is the egress time of the trade message minus the ingress time of the Trigger Event. If multiple events trigger a given trade, the Trigger Event timestamp is considered to be the last timestamp of any Trigger Event for that trade. Timestamps in the diagram are defined as follows:

- t_M is the time that a triggering market data message is available on the wire attached to STAC Hi-Fi;

- t_E is the time that a triggering execution report is available on the wire attached to the STAC-T1 Responder. Note that t_E for a given trade is the time of an execution report for a <u>previous</u> trade, not the trade in question;

- t_T is the time that the trade message is available on the wire attached to the STAC-T1 Responder.

(Note: Wire-time definitions may be changed depending on your choice of wire capture, whether you wish to include switches in the measurement, etc.)

Thus, the latency for a given trade is always $(t_T - t_M)$ or $(t_T - t_E)$. Correlation of trade messages with their Trigger Events requires information from the trading application, as described in the Implementation section, below.

Implementation

Implementating a STAC-T1 Test Harness consists of four or five steps:

1. Get the hardware in place
2. Prepare the trading application
3. Obtain the desired market data for playback (if necessary)
4. Optional: Integrate a latency monitoring solution
5. Integrate the test harness

Hardware requirements are as follows:

- SUT: Whatever hardware the SUT requires, including servers, switches, etc.
- STAC Hi-Fi: One or more high-performance servers (2 x quad core, very fast disks and controllers) with Endace cards, depending on requirements (note that multiple feeds can be played from a single box). Details available on request. This box can also be used to host the STAC-T1 Controller and orchestration scripts.
- STAC Responders: One or more servers, depending on requirements.
- Optional: Separate box to accelerate data analysis. This box can also be used to host the STAC-T1 Controller and orchestration scripts.

Note that no time-synchronization hardware or software is required, irrespective of the monitoring mode chosen (internal or external). Internal monitoring assumes that the trading application is able to timestamp on a consistent clock. External monitoring assumes that the Latency Monitor captures all messages for a given instrument on a single capture card, using a single clock.

Preparing the trading app. Different modifications to the trading application(s) are necessary for internal monitoring and external monitoring:

- If using internal monitoring, customers need to ensure that the trading application timestamps the desired events, correlates events to generate pair-wise latencies, and generates latency files in the STAC format, during or after a test run.

- If using external monitoring, customers need to make one modification to the trading application: externalizing information required to correlate events. Latency measurement requires an understanding of which market data updates or execution reports triggered a given order or cancelation (e.g., the line and sequence number of the triggering market data message, together with the corresponding order ID). Since only the trading application knows this, it must externalize the knowledge. There are a few ways to do this, and determining the best way for a given application may require discussion. For example, the application might send information about triggering events in a field in the order. Or it could store the information in memory during the test run and dump it to a file in a STAC-specified format after the test run. Note that if a third-party application is being tested, the third party will need to make this modification, unless the customer has access to its source code.

Market data. As explained above, the STAC-T1 Test Harness is designed to use recorded raw market data messages that can be played repeatably at various rates. It is also possible to use live market data; however, this does not provide repeatability. STAC Hi-Fi comes with utilities for capturing and cleaning recordings. STAC's intent is to provide recordings for specific trading venues; however, there will likely be cases where STAC does not have redistribution rights. In such cases, the customer must make its own recordings. Contact STAC to discuss your specific requirements.

Optional: Integrate a latency-monitoring solution. The STAC-T1 Test Harness is designed to be integrated with any latency monitoring system that captures and parses market data and execution messages. If you use such a system in production, it can be integrated with STAC-T1. If not, contact STAC for a list of leading latency-monitoring vendors integrating their products with STAC test harnesses. In terms of hardware, a latency monitor for STAC-T1 is typically a single appliance. Several methods are available for getting network traffic to the appliance (taps, span ports, aggregation taps). These have varying degrees of accuracy, and the state of the art continues to advance. Contact STAC if you're not sure how you want to capture traffic.

Integration. Integrating the STAC-T1 Test Harness involves writing some SUT-specific scripts (e.g., startup, shutdown) as required by the STAC-T1 orchestration scripts, performing configuration steps, and validating proper operation. STAC Test Harnesses are well documented, so the educated user may be able to integrate his or her harness without assistance. However, STAC recommends a simple support contract which includes a tutorial and 8 hours of pre-paid support, available over the course of a year. STAC can also provide on-site integration assistance.

Optional customization. The STAC-T1 Test Harness will enable the tester to customize many aspects of the tests through configuration. However, if the customer wants customizations that require code changes, STAC can do so as a chargeable service.