Insights into trading system dynamics

Eurex Exchange's T7

January 2016

Agenda

- Achievements
- Topology and system
- Inside a partition
- Eurex Enhanced Order Book Interface
- Trading system dynamics
- Inbound latency spectrum
- What you need to be fast
- Outlook
- Appendix

Eurex Group Technology Roadmap

Eurex Group is pursuing its Technology Roadmap to deliver innovative and superior technology.

This initiative includes:
- Provision of a portfolio of interfaces that meet the needs of different user groups
- High throughput and low latency of the trading system
- Delivery of functionality the market demands with shortened lead time
- Exceptional level of transparency & customer service

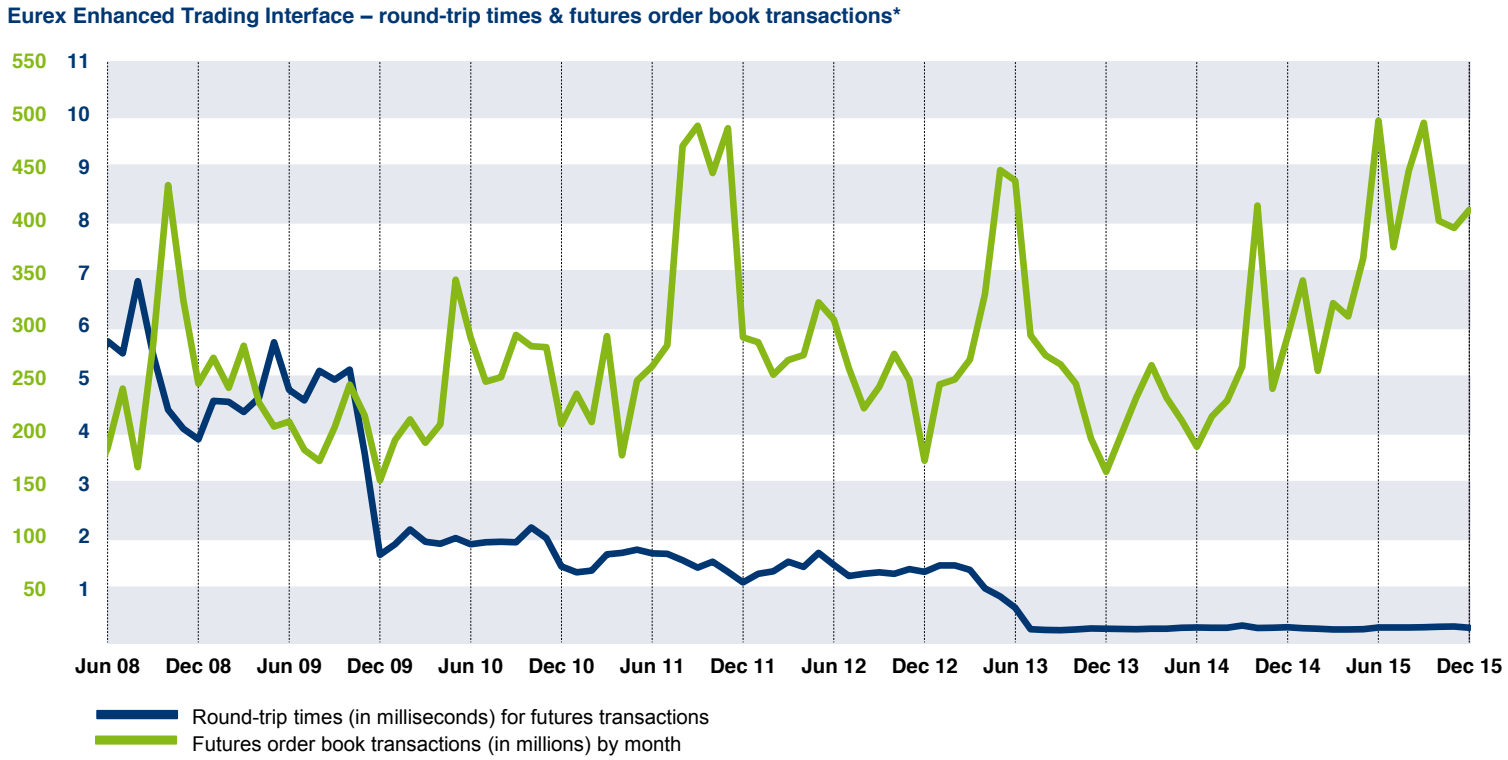
The Eurex Group Technology Roadmap will continue on the trading layer with the launch of T7 release 4.0.

Eurex Exchange's T7 is based on Deutsche Börse Group's proprietary global trading architecture, which is also in use at the International Securities Exchange (ISE) and the Bombay Stock Exchange.

For further details about T7 please have a look at our web page: www.eurexchange.com/t7

This presentation aims at providing information about T7 to latency sensitive users.

Futures order book transactions round-trip times

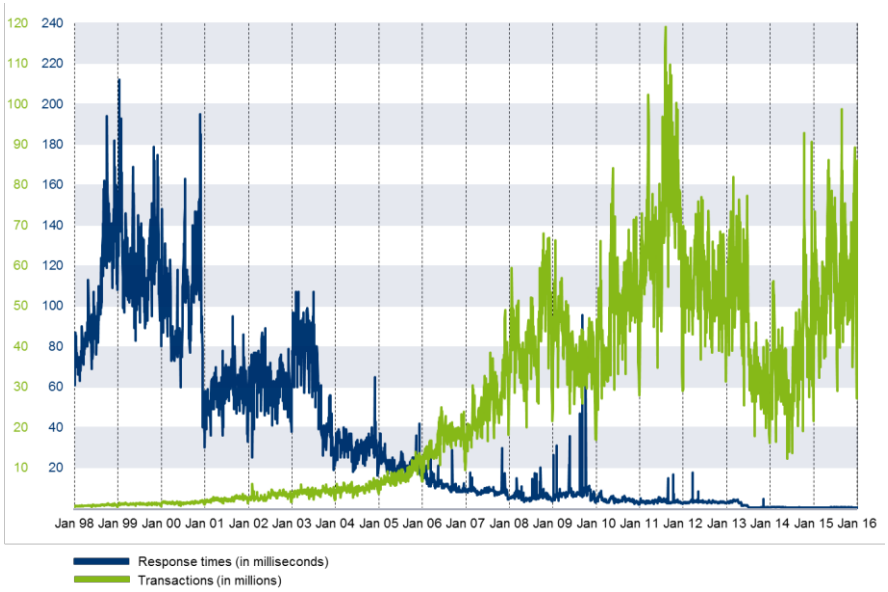


Futures order book transactions show a daily average latency of about 0.18 – 0.35 ms for users of the Eurex Enhanced Trading Interface located in the Equinix data center in Frankfurt. With the software optimizations done with the introduction of the recent Eurex T7 release 3.0, the average latency has improved by about 14 percent.

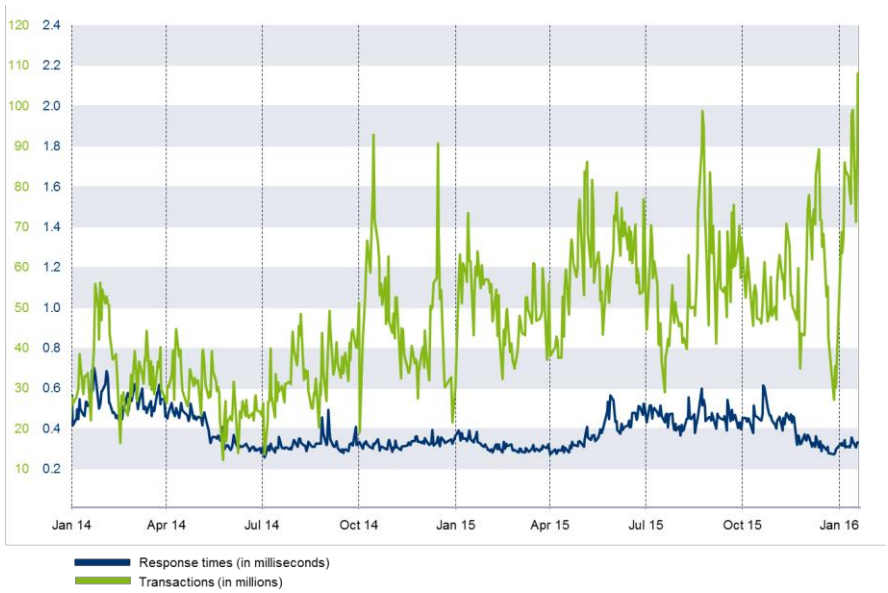
** From 1 July 2013 only T7 transactions have been considered.*

Processed transactions & response times

Number of processed transactions at Eurex Exchange & response times



Eurex on T7



Eurex Group has continuously invested in its trading system and has been able to reduce the processing time of technical transactions significantly although the daily load on the system has grown extremely.

System enhancements since the last version

Since the last update of this presentation, the following enhancements have been carried out:

- More precise time stamping on hardware level with new network cards on the Eurex ETI high-frequency gateways since 9 December 2015. For transactions sent to ETI high-frequency gateways, these new time stamps taken on the gateway network card replaced the former gateway-in time stamps taken on the application level (t_3 = "RequestTime" sent in the Eurex ETI Response, in the Eurex EMDI Depth Incremental message in case of a trade, and in the Eurex EOBI Execution Summary message).

- Software optimization on all core components (ETI gateways, matching engines, EOBI and EMDI market data publishers). Additionally, more efficient mass quote processing on ETI gateways. (slides 25 and 32).

- Introduction of self-match prevention (SMP) functionality: A new field "RestingCxlQty" was added to the Eurex EOBI Execution Summary and to the Eurex EMDI Depth Incremental message to show the deleted quantity due to SMP.

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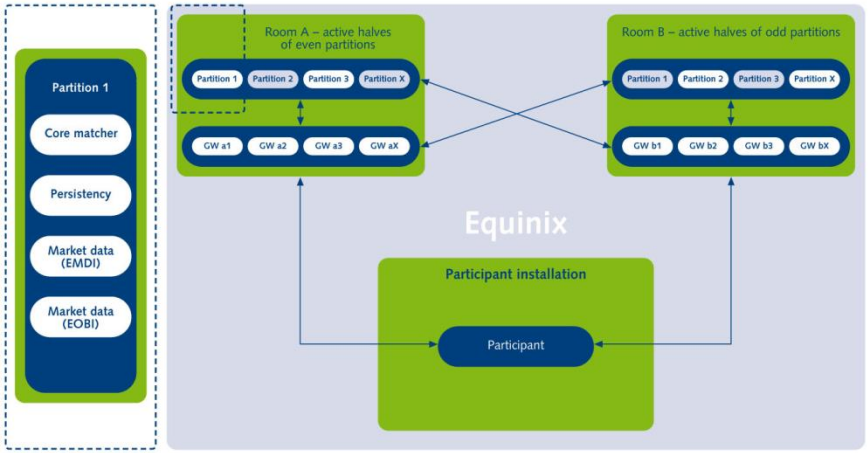
Overview of T7

- T7 consists of partitions. Here, a partition is a failure domain in charge of matching, persisting and producing market data for a subset of products*. Each T7 partition is distributed over two rooms in the Equinix data centre.
- There are 10 T7 partitions in charge of futures and options trading available on Eurex Exchange. A separate additional partition is used for European Energy Exchange (EEX) products.
- There are 16 high-frequency gateways in the Equinix data centre shared by all Trading Participants of Eurex Exchange. Note that it is currently not planned to change the number of high-frequency Eurex Enhanced Trading Interface gateways.
- The reference data contains the mapping of products to partition IDs*. The physical location of the Eurex Enhanced Trading Interface gateways in the Equinix data centre relative to the room where a matching engine resides has no impact on the order latency.
- Note that normally the active half of a partition is either in room A (for even partitions) or in room B (for odd partitions).
- Only in case of the failure of a matching engine or a market data publisher, the active half of the service will shift to the other room.

T7 data center topology



** We are currently finalizing the tests on moving a product to a different partition in case of failure of a partition on start-up in the morning. To allow Participants' application to test this exceptional case, focus days in T7 simulation are planned for February/March.*

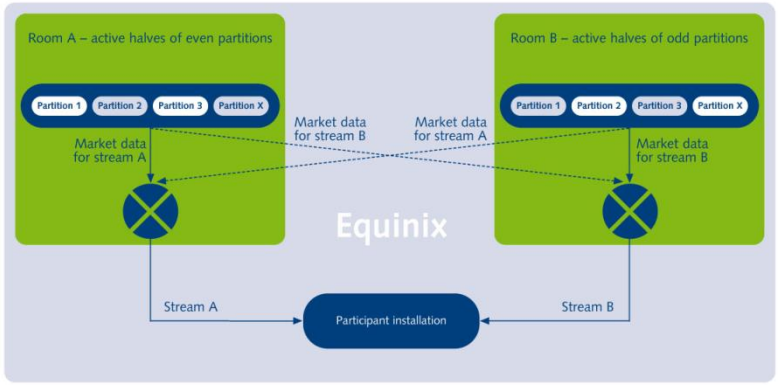
Middleware, network, hardware and OS overview

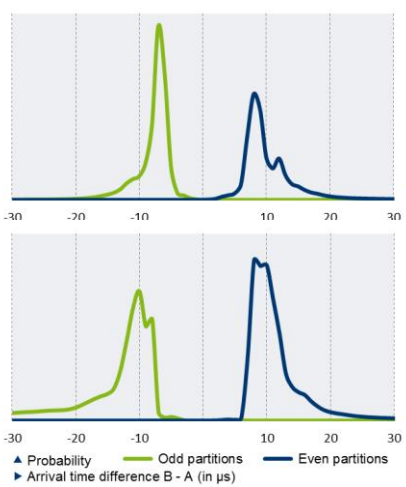
T7 uses state-of-the-art infrastructure components:

- The hardware used for T7 is
  - HP Gen8 DL380 servers for core components (matching engines, EOBI and EMDI market data publishers, gateways,…).
  - Intel Xeon E5-2643 v2 CPUs (Ivy Bridge) on the matching engines and EOBI market data publishers of the partitions 1 to 4 (currently used to match FDAX, FGBL, FESX and FGBM).
  - Intel Xeon E5-2690 CPUs (Sandy Bridge) on all other core components.
- Participant facing interface cards on the gateways and market data publishers use Solarflare EnterpriseOnload technology to bypass the kernel TCP stack.
- The operating system used is Red Hat Linux 6.5 with real-time kernel on all core components.
- On the network layer Eurex Exchange offers Trading Participants to connect via 10 GbE cross connects to its platform in the Equinix data centre.
- Internally, all core components are connected via an Infiniband network in order to provide lowest possible latency.
- T7 internal communication between its core components is based on IBM WebSphere MQ Low Latency Messaging in order to deliver the required speed, capacity and stability requirements.

Market data distribution

Enhanced Market Data Interface/Enhanced Order Book Interface – latency impact for market data

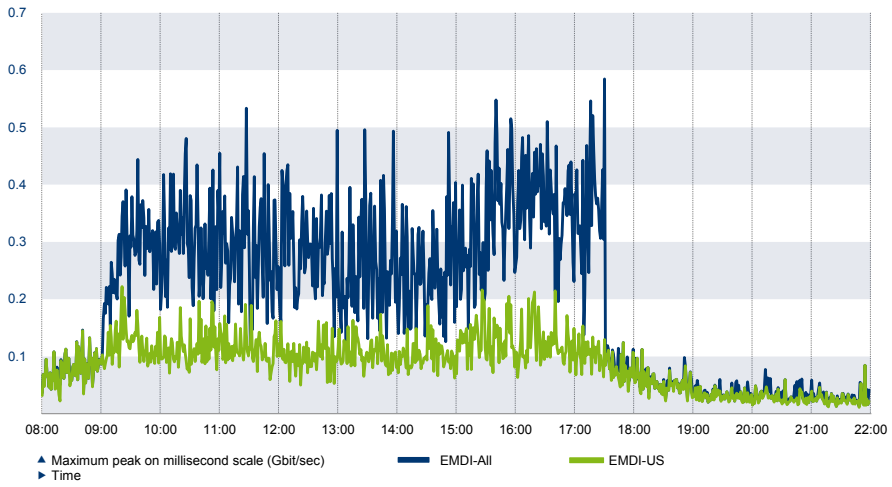




- Please note that for products assigned to an even partition, market data is published first on the A stream and then on the B stream whereas, for products assigned to an odd partition market data is published first on the B stream and then on the A stream.
- The partition ID/product ID is contained in the UDP datagram header of the order book incremental messages and can be used for filtering on UDP datagram level for EMDI/EOBI.
- Furthermore, a UDP datagram on the Eurex EMDI/EOBI order book delta or snapshot channel will only contain data of exactly one product (e.g. EURO STOXX 50® Index Future).
- The median latency difference between the A and the B feed is about 7µs for EOBI (see top diagram to the left) and 15µs for EMDI (see bottom diagram to the left).
- Eurex Exchange provides a csv file on a daily basis with the minute-by-minute network latency (minimum, average, maximum 99 percent) for the A and B streams of the Eurex Enhanced Market Data Interface for non-co-location access points. This information can help you determine whether you or Eurex Exchange had an issue causing a market data delay.

EMDI: Market data volume

Eurex Enhanced Market Data Interface: data volume for 17 December 2015

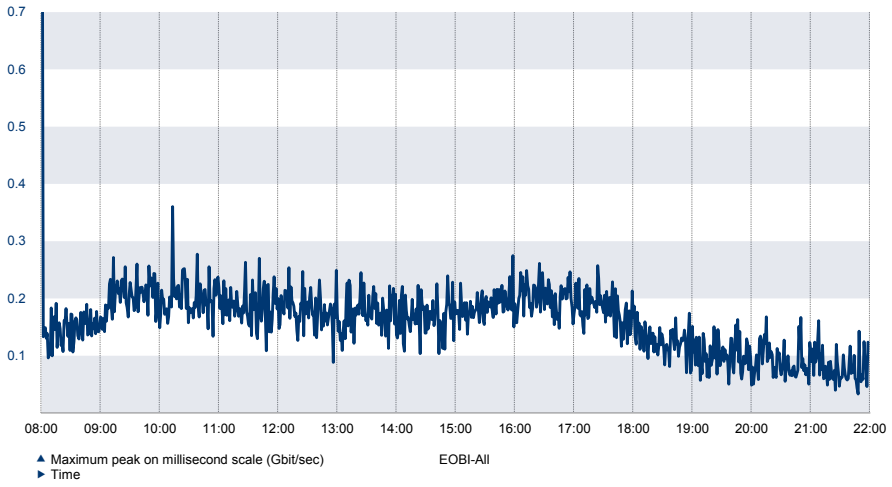


- The provided data shows one data point per minute for 17 December 2015.
- Each data point equals the maximum bandwidth produced on a 1 ms scale by the incremental A stream in Gbit/sec.
- Eurex Enhanced Market Data Interface peak data volume can be a significantly higher on high volume trading days. Hence Participants that want to receive data for all Eurex Exchange's products or U.S. only products with less than 1 ms queuing delays need to use a connection with a bandwidth of more than 700 Mbps (all products) or 250 Mbps (for U.S. only products), respectively.

- Latency sensitive Trading Participants are advised to use two 10 GbE connections (one for each market data stream) in co-location to receive market data.

EOBI: Market data volume

Eurex Enhanced Order Book Interface: data volume for 17 December 2015

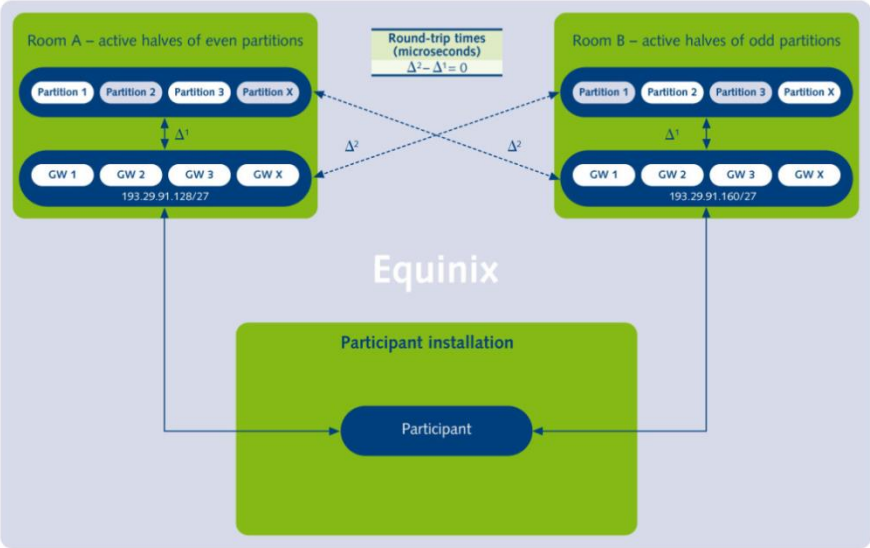


- The provided data shows one data point per minute for 17 December 2015.
- Each data point equals the maximum bandwidth produced on a 1 ms scale by the incremental A stream in Gbit/sec.
- At around 8 a.m. CET the 1 ms peak is about 2.9 Gbit/sec. It corresponds to the first broadcast of the complete order books.
- Eurex Enhanced Order Book Interface peak data volume is expected to be significantly higher on high volume trading days.

- Enhanced Order Book Interface market data is currently only available to Trading Participants using 10 GbE connections. Trading Participant are advised to take two cross connects (one for each market data stream) in co-location to receive market data.

Orders/quotes – optimal access

Eurex Enhanced Trading Interface – latency impact for orders



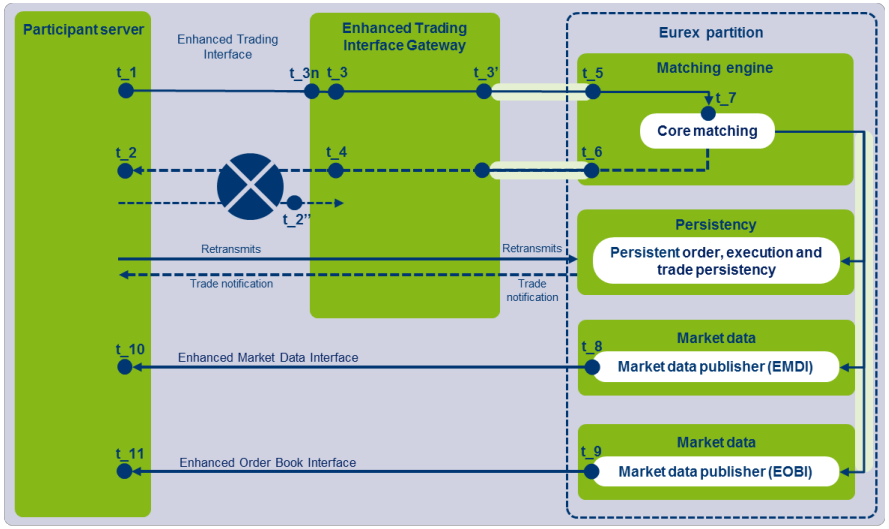
- Using 10 GbE cross connects for the access to the high-frequency Eurex Enhanced Trading Interface gateways in the Equinix facility provides the fastest way for order and quote management to T7.
- Access via the 10 GbE or 1 GbE cross connects to the low-frequency Enhanced Trading Interface gateways is as fast as access to the high-frequency gateways.
- For optimal routing of orders, the room in which the gateways and matching engines are located is not relevant.
- The T7 gateways duties include all validations that do not need the knowledge of the order book or market state.
- To achieve lowest possible latency, it is recommended to use the short order layout if possible - this saves about 8 µs gateway processing time on the way in compared to "normal" lean orders.

- Daily statistics about private "last mile" performance between the high-frequency gateways and Participant servers as well as best in class numbers (per location and system wide) are currently provided for the 10 GbE connections to T7 (this will be extended to cover all Eurex ETI sessions soon). Eurex Exchange expects that a good daily average TCP/IP round-trip will be less than 8 µs for 10 GbE connections.

Note that using 10 MBit connections (built on 1 GbE cross connects) to connect to Eurex low-frequency or high-frequency gateways results in an additional latency of about 50µs (round-trip) compared to the 10 GbE access to high-frequency gateways .

T7 topology

Time stamp overview



- Matching engine:
  - order book maintenance & execution
  - creation of direct responses as well as execution messages all for passive orders/quotes
  - creation of listener broadcast for standard orders
- Persistency:
  - persistent order storage,
  - trade/execution history,
  - transaction history for standard orders
- Market Data (Eurex EMDI):
  - creation of order book delta messages
  - creation of order book snapshot messages
- Market Data (Eurex EOBI):
  - creation of order book messages
  - creation of order book snapshot messages

- PTP based synchronization of clocks using hardware support is used for high-frequency gateways, matching engines and market data servers in production (and also in simulation). Hence time stamps on these servers can be used to analyze one way transport times.

Orders/quotes – detailed performance data for futures

Our transparency

- For the top 12 futures products, daily statistics about the matching engine processing times as well as Eurex Enhanced Transaction Interface gateway processing times are provided via the 'Member Section' on Eurex Exchange's website. The ETI round-trip times are calculated based on t_4 – t_3 (gateway SendingTime – gateway application start).

18 January 2016

Product	Product ID	Matching engine Round-trip times (in µs)			Enhanced Trading Interface Round-trip times (all GWs, t_4 - t_3 in µs)		
		Average	Median	99th percent	Average	Median	99th percent
EURO STOXX 50® Index Futures	FESX	113	43	880	301	155	2260
STOXX® Europe 50 Index Futures	FSTX	55	49	188	204	170	1320
DAX® Futures	FDAX	92	41	860	292	148	2560
Mini-DAX® Futures	FDXM	45	42	135	204	153	1520
MDAX® Futures	F2MX	53	48	147	178	152	880
SMI® Futures	FSMI	73	47	560	275	149	2380
Euro-Bund Futures	FGBL	118	46	820	280	170	1460
Euro-Bobl Futures	FGBM	99	43	820	252	163	1420
Euro-Schatz Futures	FGBS	95	54	840	319	175	2540
Euro-Buxl® Futures	FGBX	136	63	1180	537	187	4160
Long-Term Euro-BTP Futures	FBTP	110	54	1040	397	177	3180
Euro-OAT Futures	FOAT	123	55	1160	498	179	4220

Throttle and session limits

In order to protect its trading system, Eurex Exchange has several measures in place to ensure that its most vital components are not harmed by a malfunctioning client application. In particular Eurex Exchange uses the following transaction limits:

- All Eurex ETI sessions (HF and LF) are available with throttle values of 150 txns/sec or 50 txns/sec.
- Furthermore, Eurex offers LF sessions that cannot enter orders/quotes but can only receive trade and listener broadcasts (at a reduced price).
- All Eurex ETI session types have an assigned disconnect limit of
  - 450 for sessions with a throttle value of 150 txn/sec, i.e. a session will be disconnected in case of more than 450 consecutive rejects due to exceeding the transaction limit (throttle)
  - 150 for sessions with a throttle value of 50 txn/sec, i.e. a session will be disconnected in case of more than 150 consecutive rejects due to exceeding the transaction limit (throttle).
- Please note that in case Eurex needs to use its disaster recover facility, all ETI sessions will have a throttle limit of 30 transactions per second.
- For both limits, all technical transactions are counted using a sliding window.
- The number of ETI sessions which can be ordered is limited. Currently, up to 80 sessions can be ordered. If more than 80 sessions are required please get in touch with your Technical Key Account Manager.

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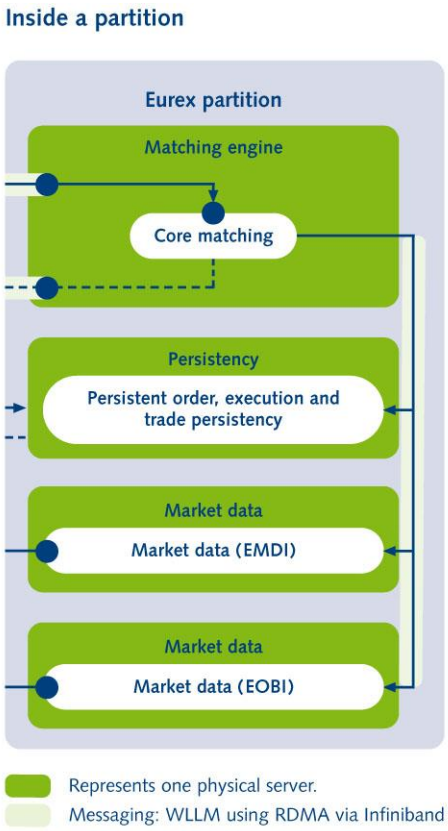
Processing inside a partition



- Orders/quotes entered for a specific product are sent by the gateway server to the respective matching engine (residing in a partition).
- The matching priority is assigned when the orders/quotes are read into the matching engine.
- The core matching component works as follows:
  - when an order/quote arrives, it is functionally processed (e.g. put in the book or matched).
  - handover of all data resulting from the (atomic) processing of the incoming order/quote to the market data and persistency components in the partition.
  - resulting messages for all orders/quotes are sent out in the following order:
    - direct response to the order/quote entered (for persistent as well as for non-persistent orders and quotes)
    - fast execution information for booked orders/quotes (in case of a match)
- In case that during this phase several new orders/quotes transactions arrive at the core matching component the processing remains unchanged, i.e. no batching takes place.
- The generation of market data (by the market data distributers) and trade confirmations (by the persistency server) are done on separate servers. Hence the order of the resulting messages from these servers is not deterministic.

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Enhanced Order Book Interface

Fast trading decision in case of synthetic matching

- In case of synthetic matching (TradeCondition in the Execution Summary set to ‚Implied Trade'), Participants only interested in the front month instrument will also have to read all details that follow the Execution Summary.
- However, we see that not each combination of instruments is equally likely (even during a roll when, on average, more synthetic matches take place). In our benchmark futures, we see that there are three highly liquid, and three less liquid instruments. The front month, the second maturity and the spread between the two are defined as the liquid instruments, the other three instruments are regarded less liquid.
- A possible shortcut which can speed up the decision-making process is available to Participants that base their trading decisions primarily on the Execution Summary. These Participants could potentially save processing time by considering the order books of the three most liquid instruments only.

Enhanced Order Book Interface

Fast trading decision in case of synthetic matching (cont.)

- If the instrument in the Execution Summary belongs to one of the three liquid instruments and the TradeCondition field is set to ‚Implied Trade', Participants can apply the following logic to infer the order books for these liquid instruments:
  - Check price (‚LastPx'), total quantity (‚LastQty') and side (‚AggressorSide') in the Execution Summary.
  - Delete orders in the incoming instrument's order book which have a better price than ‚LastPx'.
  - Check whether a combination of orders in the two other liquid books yields a better price than ‚LastPx'. If true, delete the orders contributing to these combinations from the respective order books.
  - Calculate the remaining quantity (‚LastQty' minus already deleted quantities). If possible, remove this quantity from the incoming instrument's order book at ‚LastPx'. If there is not enough quantity available then try to delete the still remaining quantity from the synthetic order book combination at ‚LastPx'.
  - In case the total deleted quantities from the incoming instrument's order book and the combined synthetic order book do not add up to the ‚LastQty' it can be concluded that the order book is not correct afterwards.
- Our data show that in over 99.7% of the trade cases, it is possible to build a correct order book by using this shortcut.
- Please note that for a consistent order book, Participants should always process all incremental updates following the Execution Summary.

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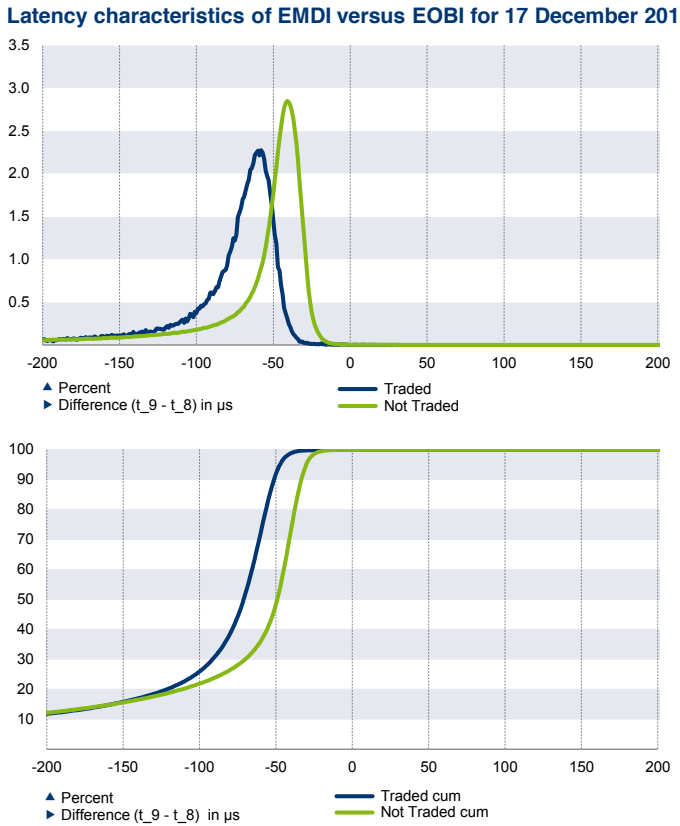
Trading system dynamics

Latency characteristics of EMDI versus EOBI

The market data updates provided via EOBI is almost always faster than EMDI (although the design of the T7 system does not guarantee this):



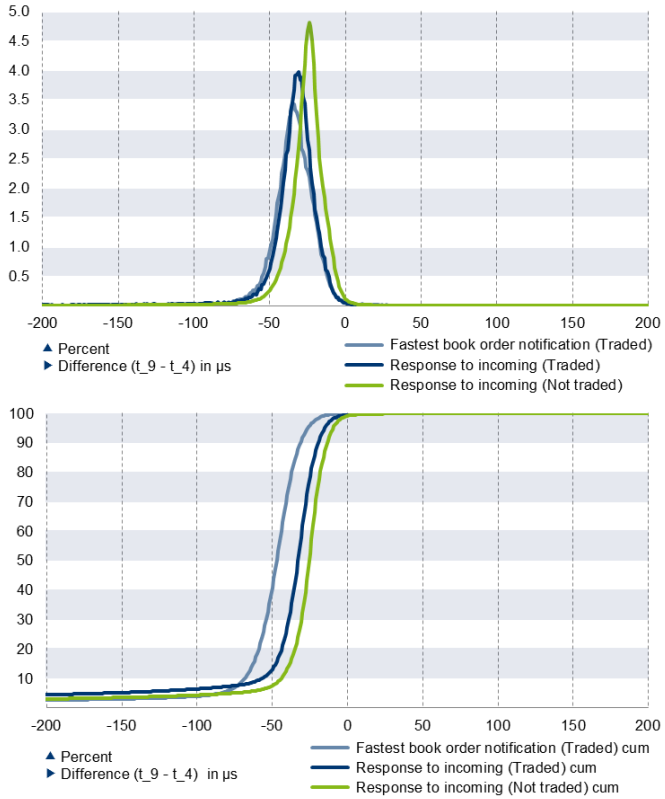
- The top diagram shows the distribution of t_9 minus t_8, i.e. EOBI first datagram versus EMDI sending time, the bottom diagram shows the cumulative distribution.
- The data is a production sample of EURO STOXX 50 ® Index Futures (FESX) taken from 17 December 2015.
- EOBI was faster in more than 99.9 percent of the cases.

Trading system dynamics

Latency characteristics of EOBI versus ETI

Eurex Exchange aims to publish order book updates first on its public data feed. We have met that target for more than 99% of data published via EOBI:

Latency characteristics of ETI response versus EOBI for 17 December 2015

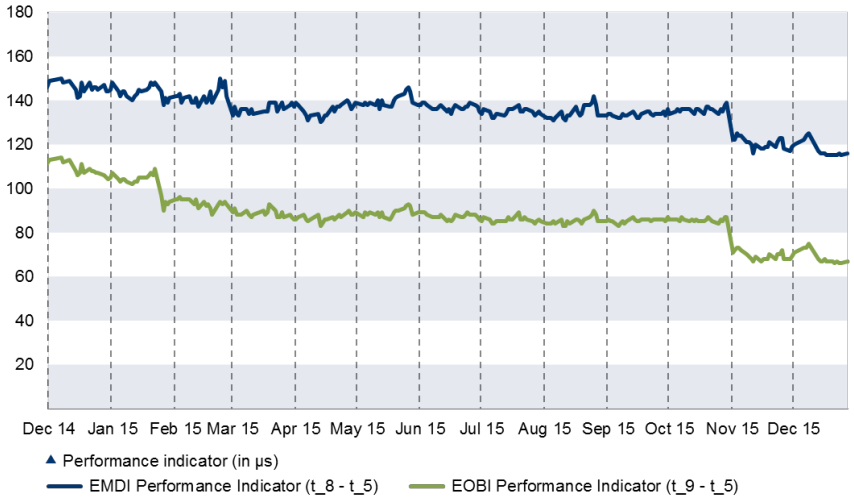


- The top diagram shows the time difference distribution between public and private data (EOBI first datagram vs ETI responses/notification, t_9-t_4), the graph below shows the cumulative distribution.
- We distinguish between the response to incoming orders (traded/not traded) and the fastest private notification for book order matches.
- The data is a production sample of EURO STOXX 50® Index Futures (FESX) from 17 December 2015.
- In cases without trades, the first EOBI datagram was faster in approximately 99.2 percent of the cases compared to the Eurex ETI response.
- In cases with trades, the first EOBI datagram was faster than the matching engine response for the aggressive order in approximately 99.5 percent of the cases. EOBI was faster in approximately 99.9 percent of the cases compared to the fastest ETI book order notification.

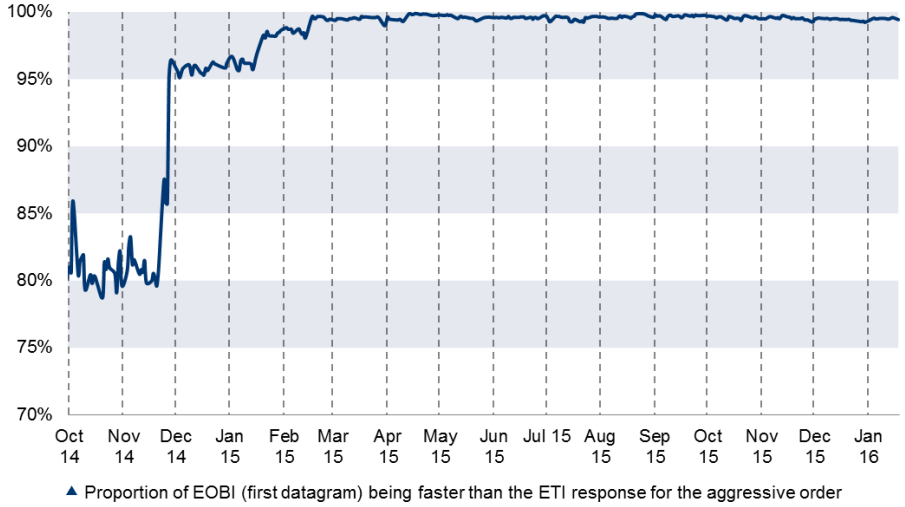
Trading system dynamics

Latency characteristics of EOBI versus EMDI and EOBI versus ETI over time

EMDI versus EOBI performance indicator for FESX



EOBI versus ETI for FESX

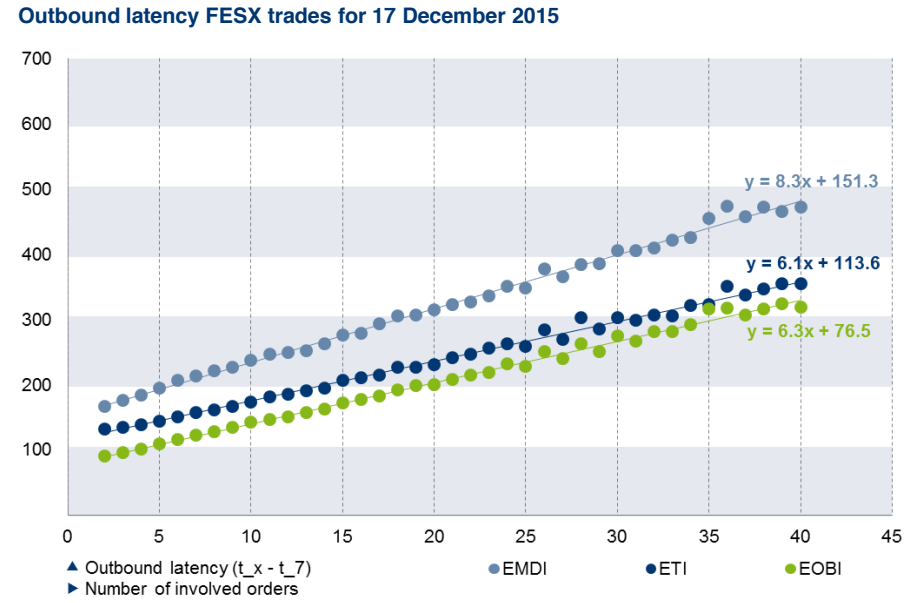


- With the upgrade of the CPUs on the T7 matching engines and EOBI market data publishers of the partitions 1 to 4 (FDAX, FGBL, FESX, FGBM) mid of February 2015, the matching engine processing times as well as the processing times on the EOBI market data publishers have improved significantly.
- Additionally, we have optimized the software on all core components including the matching engines, EOBI and EMDI market data publishers with T7 release 3.0 on 23 November 2015. The positive effects can be observed for example in the median performance indicator for EOBI (t_9 – t_5) and EMDI (t_8 – t_5) on the FESX partition (left graph).
- Furthermore, we have achieved our aim of EOBI being faster than ETI in almost 100 percent of the cases when comparing the first EOBI datagram with the ETI response for the aggressive order (right graph).

Trading system dynamics

Latency characteristics in case of an execution: ETI versus EOBI versus EMDI

The data for the diagram below is taken from EURO STOXX 50® Index Futures (FESX) on 17 December 2015.



- In over 99% of the cases, we have reached the goal of disseminating order book data on the EOBI first (even true for larger trades).
- The advantage for EOBI has increased with the enhancements on the EOBI market data publishers on hardware and application level in the course of last year.

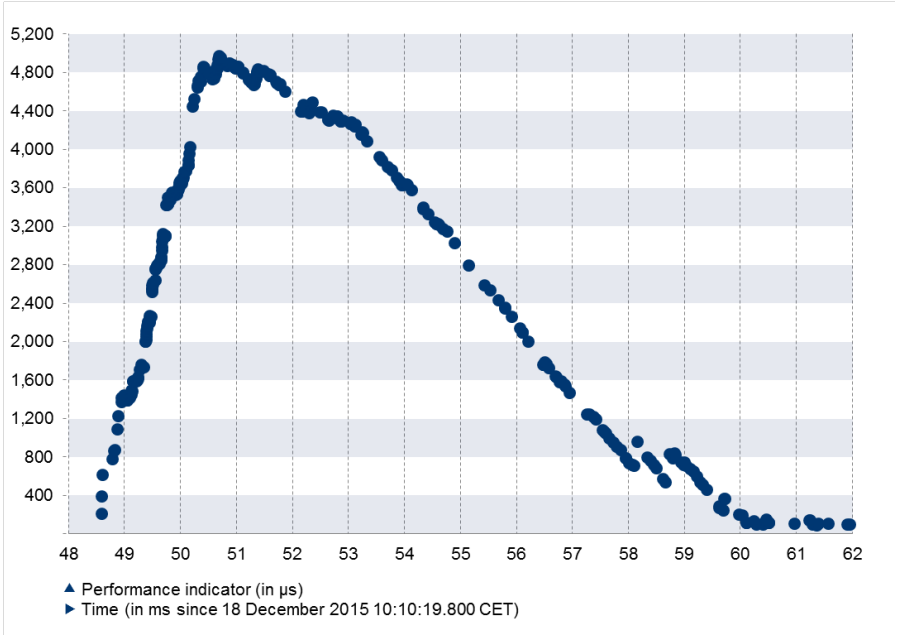
- This diagram displays the dependency of the median latency on the complexity of a trade for Eurex ETI (t_4-t_7), Eurex EMDI (t_8-t_7) and Eurex EOBI (t_9-t_7). Note that for Eurex ETI we display the gateway sending time of the first passive notification and for Eurex EOBI the sending time of the UDP datagram containing the Execution Summary message.

Trading system dynamics

Matching engine and market data performance

- During micro-bursts, our matching engines typically experience a temporary performance degradation.
- Unpredictable latencies cause risk (i.e. it takes longer to pull an order).
- To reduce unpleasant surprises, Eurex Exchange provides real-time insight in the matching engine and market data performance. For EOBI, Eurex Exchange publishes the sending time of a EOBI packet as it leaves the market data publisher (t_9) as well as the matching engine in time (t_5). For EMDI, Eurex publishes the performance indicator (t_8-t_5) explicitly in the EMDI UDP packet header.
- This graph depicts the EOBI performance indicator (t_9-t_5), measured as the time needed by the matching engine to take an order/quote from the wire, process it, forward the resulting data to the EOBI market data server and put the market data incremental message on the wire for an example where a micro-burst caused a latency spike in DAX® Futures (FDAX) on 18 December 2015.

Performance indicator for FDAX, 18 December 2015



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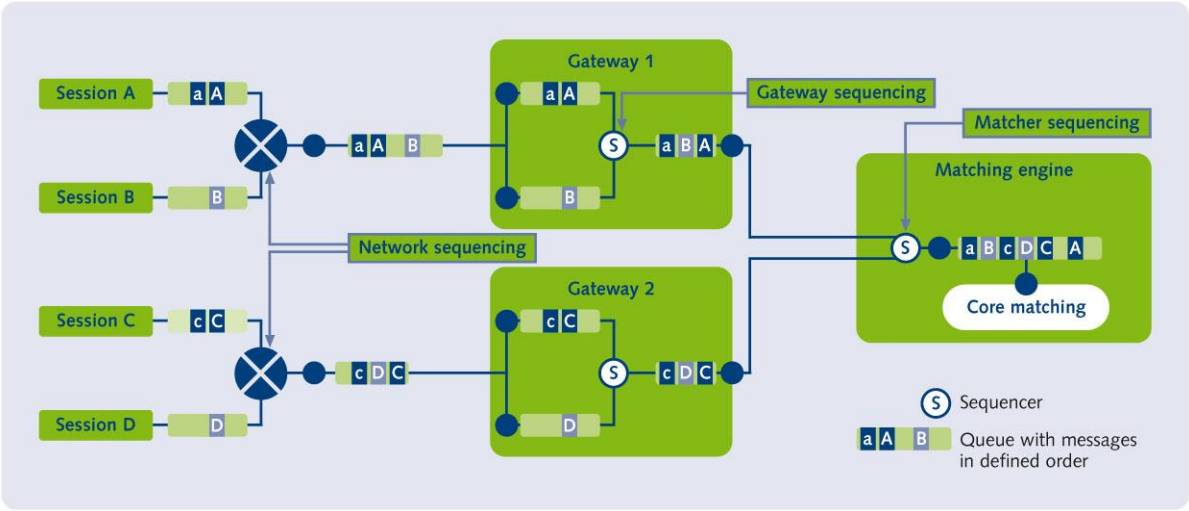
Inbound latency spectrum

Orders/quotes – inbound message sequencing

- For many Participants understanding how inbound messages are forwarded through the T7 infrastructure and between which points the sequencing is preserved is vital. The following diagram shows where inbound sequencing happens.



Inbound sequencing inside the T7 system takes place

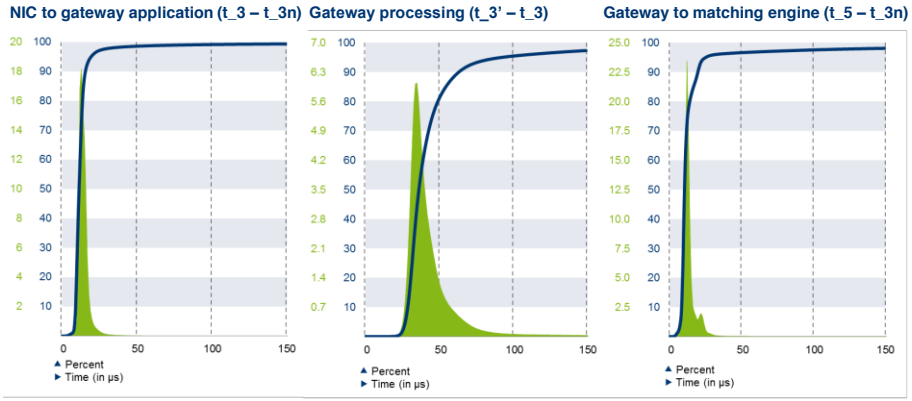
- On the network in front of the trading gateways
- In the gateway for messages of all sessions connected routed to one matching engine (=partition).
- In the matcher for messages of all sessions.

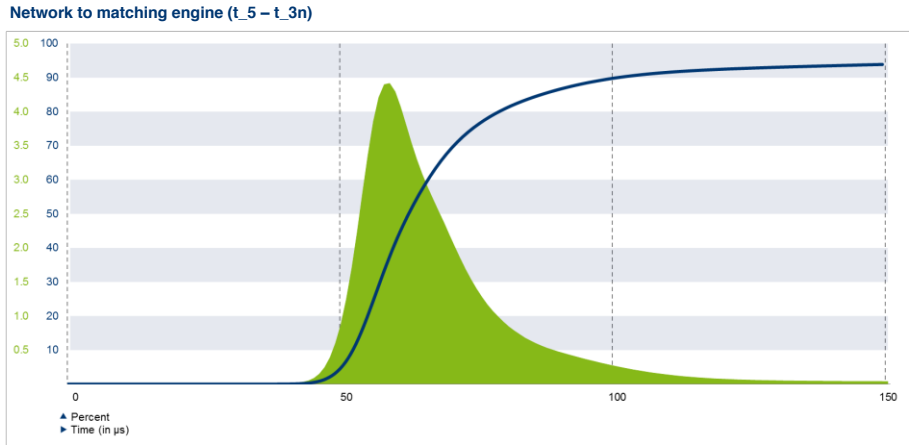
Inbound ordering is preserved

- Within the messages of a session routed to one matching engine (=partition).
- Between the messages sent from one gateway to one matching engine (=partition).

Inbound latency spectrum

Orders/quotes – inbound latency profile





- The top graphs on the left show the latency distribution of the three parts of our trading infrastructure which an order/quote traverses before time-priority is assigned. The three parts are: gateway network interface card (NIC) to gateway application start (t_3n to t_3), gateway application space processing (t_3 to t_3'), gateway-out to matching engine-in (t_3' to t_5).
- We can see that total variance is dominated by the variance of the gateway applications space processing.
- The bottom graph shows the aggregate inbound latency from the gateway NIC to the matching engine in. The gateway processing part is (by far) the most relevant for the total variance on the inbound path of a transaction.
- Graphs show all transactions sent to high-frequency gateways on 18 December 2015.

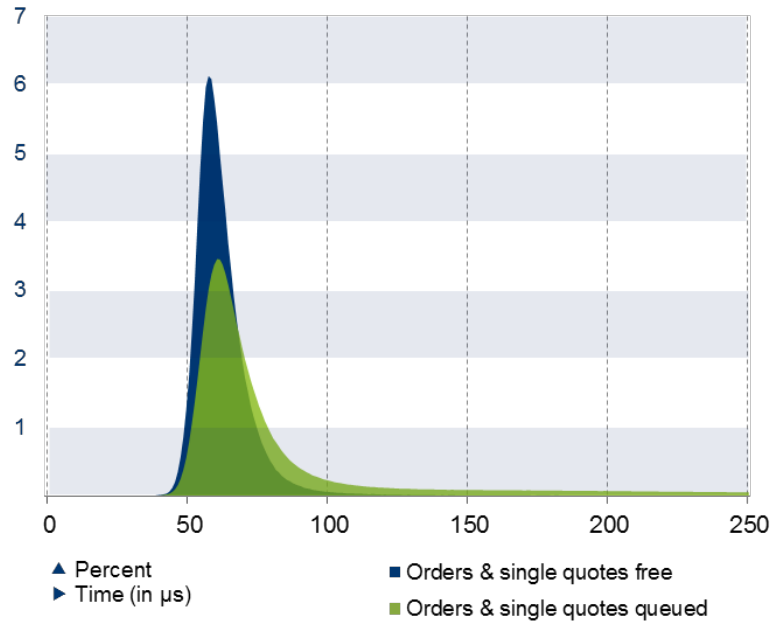
Inbound latency spectrum

Orders/quotes – inbound latency variance

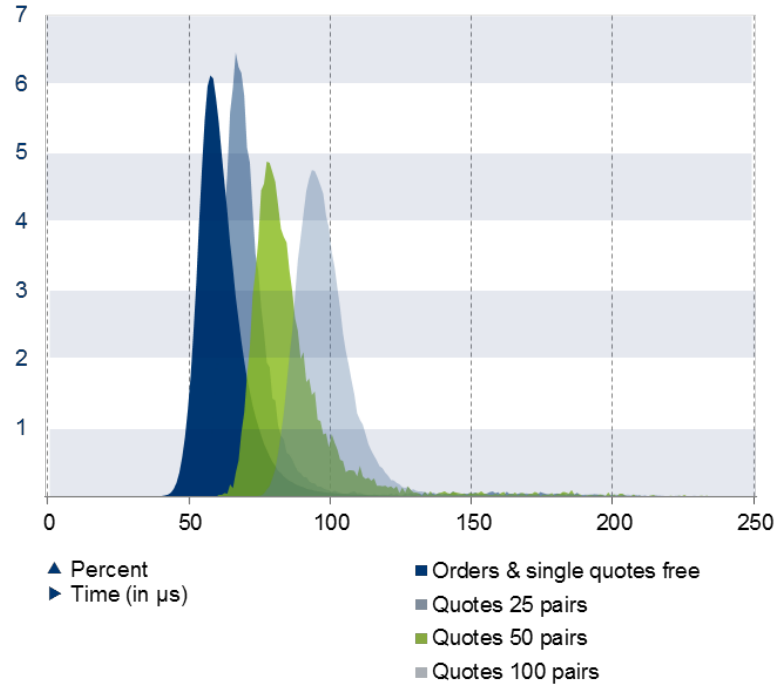
Inbound latency variance has three main sources:

- Statistical effects (always present)
- Queuing/overloading effects (e.g. 'microbursts', input rate > processing rate)
- Data dependent latency differences (e.g. quotes with 100 quote pairs versus single quote)

"Free" vs. potentially queued orders & single quotes (t_5 – t_3n)



"Free" orders vs. "free" quotes (25, 50, 100 quote pairs, t_5 – t_3n)

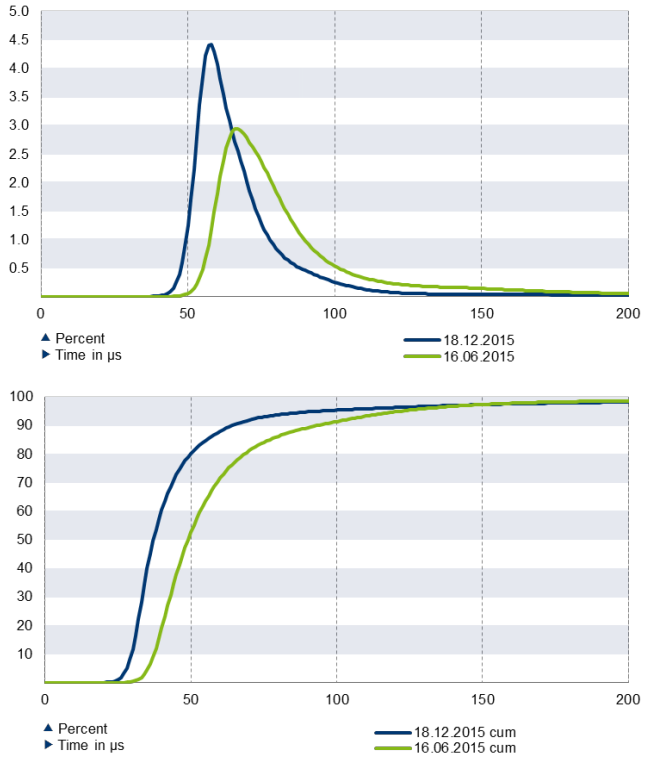


Inbound latency spectrum

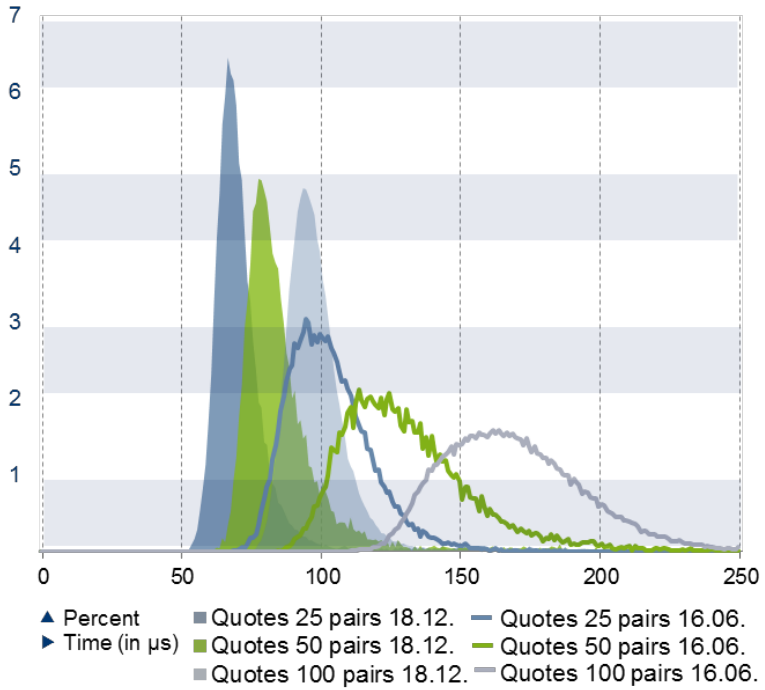
Orders/quotes – Inbound latency comparison

Software optimization on all core components including the ETI gateways and more efficient processing of mass quotes with T7 release 3.0 introduction significantly improved the inbound processing:

Inbound latency* - all transactions on HF gateways



Inbound latency* - free mass quotes on HF gateways



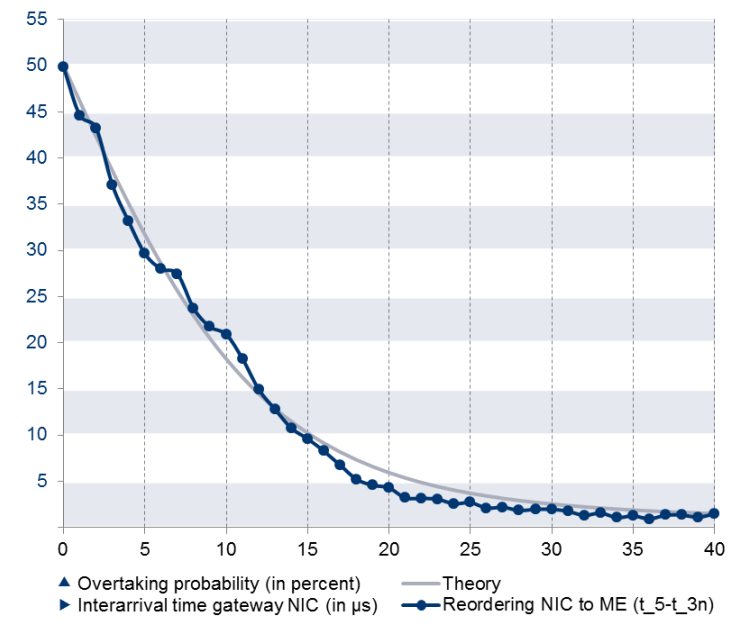
** Inbound latency calculated as (t_5 – t_3n) for 18 December 2015 and (t_5 – network capture time) for 16 June 2015. More details on time stamps can be found in the appendix.*

Inbound latency spectrum

Orders/quotes – inbound latency variance implications

- As outlined, the matching sequence may be different from the incoming sequence because of the statistical distribution of latency figures.
- The graph below shows the 'theoretically expected' probability of reordering of two consecutive transactions compared to the actual observed reordering.
- The expectation matches the data quite well, indicating that the latency of two messages is uncorrelated.

Theoretically expected vs. observed reordering



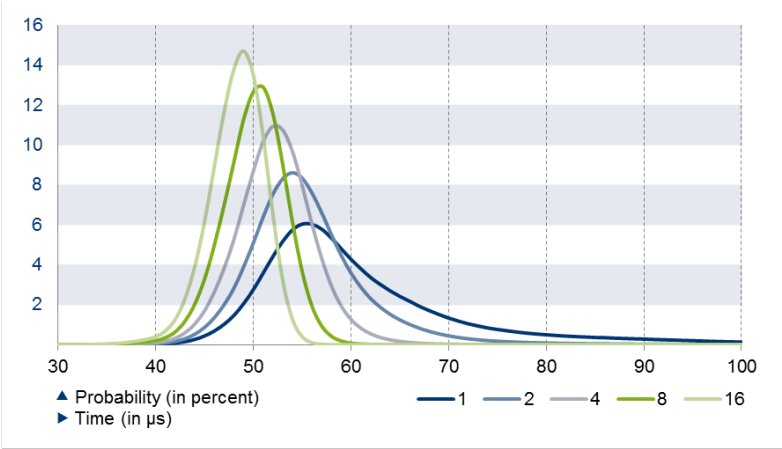
Inbound latency of "free" orders

Percentiles	NIC to ME (t_5 - t_3n)	NIC to GW (t_3 - t_3n)	GW (t_3' - t_3)	GW to ME (t_5 - t_3')
10%	55	11	31	10
25%	59	11	35	11
50%	65	13	38	12
75%	72	14	43	14
90%	80	16	50	21
Confidence intervals				
25-75%	13	3	8	3
10-90%	25	5	19	11

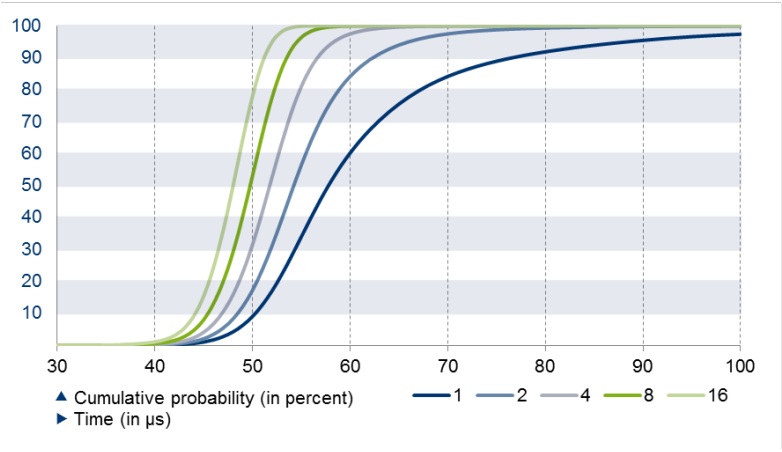
Inbound latency spectrum

Orders/quotes – inbound latency variance for multiple inbound transactions

Inbound latency spectrum for the fastest order transaction



- The graph on the left top shows the "free", i.e. un-queued, inbound latency (t_5 - t_3n) spectrum for the fastest order transaction in case a Participant sends several functionally identical transactions simultaneously (e.g. IOC orders, order delete transactions) to T7 via 1, 2, 4, 8 and 16 different HF gateways.



- The graph on the left bottom shows the respective cumulated probability for the fastest order transaction.

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- Achievements
- Topology and system
- Inside a partition
- Trading system dynamics
- Eurex Enhanced Order Book Interface
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- What you need to be fast
- Outlook
- Appendix

What you need to be fast…

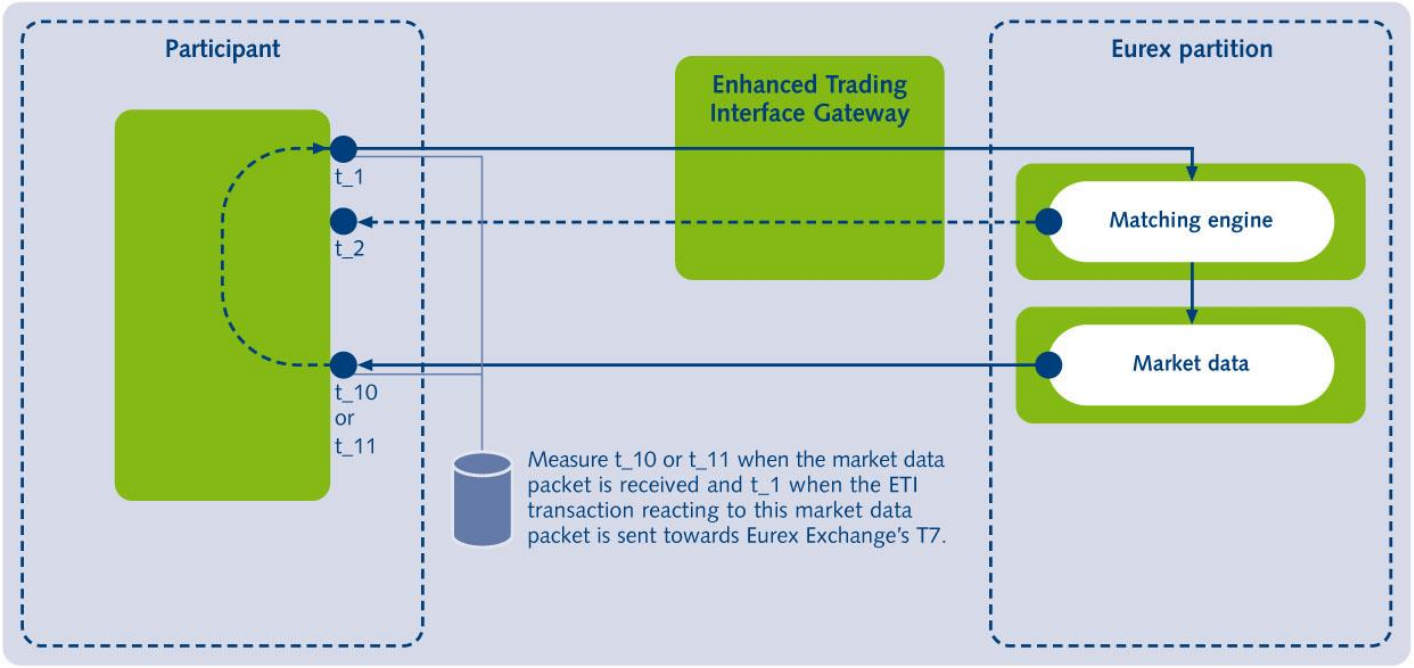
A few recommendations to achieve the lowest possible latency:

- Use the Equinix co-location facility to be close to Eurex Exchange's T7.
- Use state-of-the-art switches and only have at most one hop between the exchange network and your server.
- Use good network interface cards and TCP/IP acceleration, e.g. a Linux kernel-by-pass library.
- Use two 10 GbE (cross-) connections for the Eurex EMDI or Eurex EOBI and two 10 GbE (cross-) connections for the Eurex ETI.
- Try the two different high-frequency gateways assigned to each Eurex ETI session to see which delivers the better performance for your strategy (try it out and compare your time stamps as well as P&L for different days).
- Measure and analyze your own time stamps (e.g. the reaction time as recommended on the next slide).
- Use state of the art time synchronization, e.g. by the exchange provided time service to synch your clocks with ours via PTP.
- Trade notifications need to be processed to create safety (only the trade notifications contain legally binding information about a trade!). Therefore, we recommend to use either a low-frequency Eurex ETI session or a FIX trade capture drop copy to confirm the fast execution information provided by the execution reports via high-frequency sessions*.
- Try to use the Eurex EOBI Execution Summary for fast trading decisions and position keeping (passive executions).

** Please see the Eurex ETI manual for more details and best practices in handling of the "optimistic" Eurex Enhanced Trading Interface execution reports.*

What you need to be fast…

Participant reaction time measurement



- Include the sequence number of the Eurex Enhanced Market Data Interface or Eurex Enhanced Order Book Interface packet in the header of your ETI request (NetworkMsgID) to measure your reaction time to a certain market data event (calculate difference between t_10 (for EMDI) or t_11 (for EOBI) and t_1). The best way is to record both messages using a passive tap in the connection to Eurex.

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Outlook

The next scheduled updates to the T7 system are planned already with T7 release 4.0:

- Enhancement of the Order Mass Delete request to include the functional scope filters 'Price' and 'Side' for a specific instrument.
- Merging of matching engine and EOBI market data publisher into a single process to save transportation time (with this change, we expect to reduce t_9 – t_7 significantly).
- Migration of Trade Entry Services from the Eurex legacy system to T7.

For further information in the context of trading system dynamics and high-frequency trading, please have a look at: www.eurexchange.com > **High-frequency trading**

In case you are an Exchange Participant and want to be notified (via e-mail) about a new version of this presentation, let us know by sending an e-mail to hft@eurexchange.com.

Eurex Exchange will continue to investigate possibilities of extending the transparency with respect to latency figures. In case you have any suggestion please get in touch with us!

Thank you for your attention!

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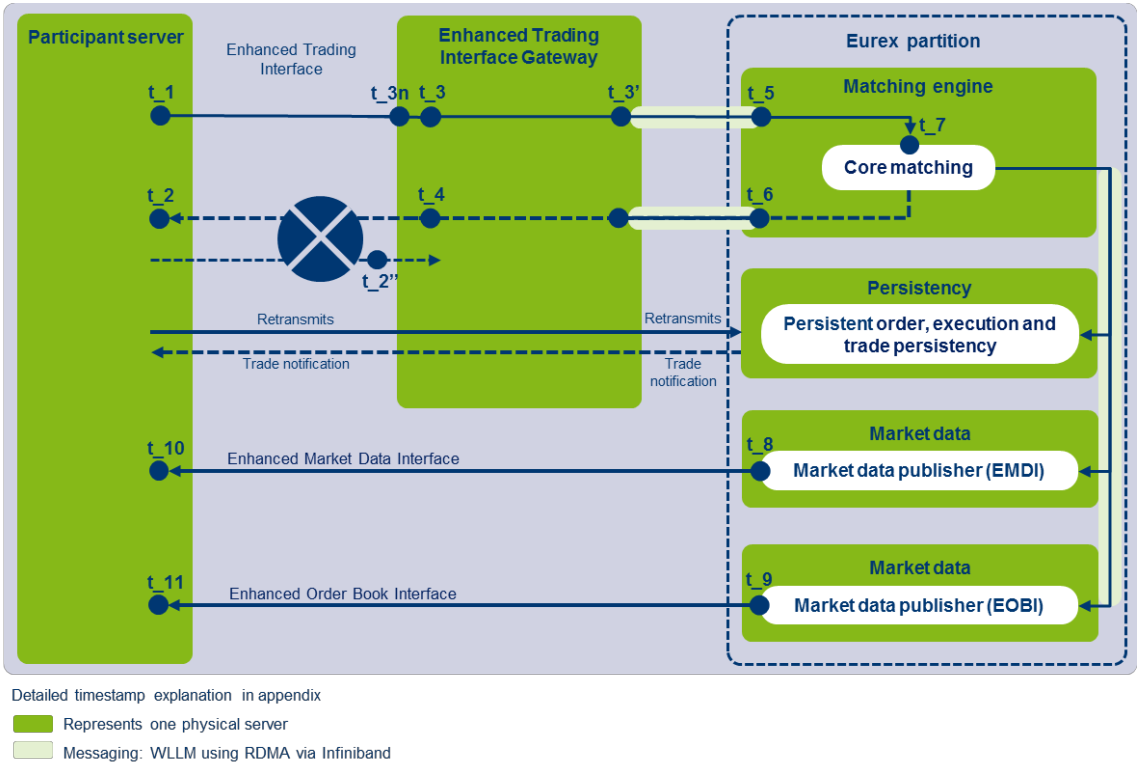
T7 topology & time stamps

Time stamp overview



- PTP based synchronization of clocks using hardware support is used for high-frequency gateways, matching engines and market data servers in production (and also in simulation). Hence time stamps on these servers can be used to analyze one way transport times.

Description of time stamps

Definition

- t_1,t_2: can be taken by a Participant (e.g. via a network capture) when a request/ response is read from/written to the socket.
- t_2'': time when the TCP acknowledge from a Participant server of a TCP packet sent by the Eurex ETI gateway to the Participant server passes a tap just in front of the Eurex ETI gateway.
- t_4: taken by the Eurex ETI gateway when a response/ notification is written to the socket on the Participant´s side of the gateway; contained in (private) Eurex ETI response/ notification.
- t_3n: taken by the Eurex ETI gateway when the first bit of a request arrives on the HF gateway NIC; contained in (private) Eurex ETI response for transactions sent via HF gateways.
- t_3: taken by the Eurex ETI gateway application when a request is read from the socket on the Participant´s side of the gateway; contained in (private) Eurex ETI response for transactions sent via LF gateways.
- t_3': taken by the Eurex ETI gateway right before a request is sent towards the matching engine; contained in (private) Eurex ETI response.
- t_4': taken by the Eurex ETI gateway when a response/ notification is received by the Eurex ETI gateway from the matching engine; contained in (private) Eurex ETI response/ notification.
- t_5, t_6: taken by the matching engine when a request/response is read/written; contained in (private) Eurex ETI response.
- t_7: time at which the matching engine maintains the order book
- t_8: time taken by EMDI publisher just before the first respective UDP datagram is written to the UDP socket.
- t_9: time taken by EOBI publisher just before the first respective UDP datagram is written to the UDP socket.
- t_10, t_11: can be taken by a Participant (e.g. via a network capture) when a UDP datagram is read from the UDP socket.

T7 time stamp reference

The time stamps t_3,…,t_8 are available via the following fields:

• t_3, t_3n:	Tag	5979	("RequestTime")	in the Eurex ETI Response in the Eurex EMDI Depth Incremental message, in case a trade is reported in the Eurex EOBI Execution Summary message
• t_3':	Tag	7764	("RequestOut")	in the Eurex ETI Response (from the matching engine)
• t_4':	Tag	7765	("ResponseIn")	in the Eurex ETI Response (from the matching engine)
	Tag	25043	("NotificationIn")	in the Eurex ETI Notification (from the matching engine)
• t_4:	Tag	52	("SendingTime")	in the Eurex ETI Response and Notification
• t_5:	Tag	21002	("TrdRegTSTimeIn")	in the Eurex ETI Response (from the matching engine)
	Tag	21002	("TrdRegTSTimeIn")	in the Eurex EOBI Order Add, Order Modify, Order Modify Same Priority and Order Delete messages
	Tag	28820	("AggressorTimestamp")	in the Eurex EMDI Depth Incremental message, in case a trade is reported
	Tag	28820	("AggressorTimestamp")	in the Eurex EOBI Execution Summary message
• t_6:	Tag	21003	("TrdRegTSTimeOut")	in the Eurex ETI Response and Notification (from the matching engine)
• t_7:	Tag	17	("ExecID")	in the Eurex ETI Response (from the matching engine) in the Eurex EOBI Execution Summary message
	Tag	273	("MDEntryTime")	in the Eurex EMDI Depth Incremental message
	Tag	21008	("TrdRegTSTimePriority")	in the Eurex EOBI Order Add and Order Modify messages
	Tag	60	("TransactTime")	in the Eurex EOBI Order Modify Same Priority and Order Delete messages
• t_8:	no Tag		("SendingTime")	in the Eurex EMDI UDP packet header
• t_9:	Tag	60	("TransactTime")	in the Eurex EOBI packet header
• (t_8-t_5):	no Tag		("PerformanceIndicator")	in the Eurex EMDI UDP packet header of the Eurex EMDI Depth Incremental stream.

Notes on time stamps:

- All time stamps provided are 8 byte integers (in nanoseconds after Unix epoch).
- The PerformanceIndicator is a 4 byte integer (in nanoseconds as well).