

Appendix H
Test Report for 100 Test Runs
for the End-to-End Prototype

Appendix for Master Thesis:
*Different Paths to High Availability
by Introducing Redundancy
in a Distributed SCADA System*

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1 Comments to the Graphs

This appendix contains the detailed test graphs for all 100 test runs for the end-to-end based prototype. The unprocessed data that these graphs are created from, are included in the source archive for the thesis in the `test-runs/end2end-timings` folder.

Figure 1 below is a summary of all 100 tests in one graph, showing the *maximum* observed client data age for each of the 100 test runs as the solid line, and the *mean value over the max values* as the dashed line. It is seen that test run number 27 is a single outlier that just reaches the 5 second deadline (QAS1). For all other tests the maximum age is in the range 3.5 to 4.0 seconds. With respect to the mean values, these are slightly below the 1 second deadline (QAS3).



Figure 1: Aggregated max and mean of the max values for all 100 test runs.

2 Network Measurements

The two figures on the following page shows the network measurements of the nodes in the test system before and after the 100 test runs.

It is seen that the network layout as reported by the hop length between the nodes are stable during the test. This verifies that no live migration of running systems happens in the Amazon EC2 data center.

With respect to the network round trip times (rtt) 6 notable outliers are seen in the test before the tests was performed. These are the 6 white spots in figure 2, with rtt crossing 100 ms. This is somewhat surprising and shows that one must expect a certain degree of variation in network latency in the test system. This would have been a problem if the deadlines in the wind farm SCADA system has been in the millisecond range, instead of in the seconds range.

Network Hops – 2011-06-04 18:11:59

Network Round Trip Time – 2011-06-04 18:11:59

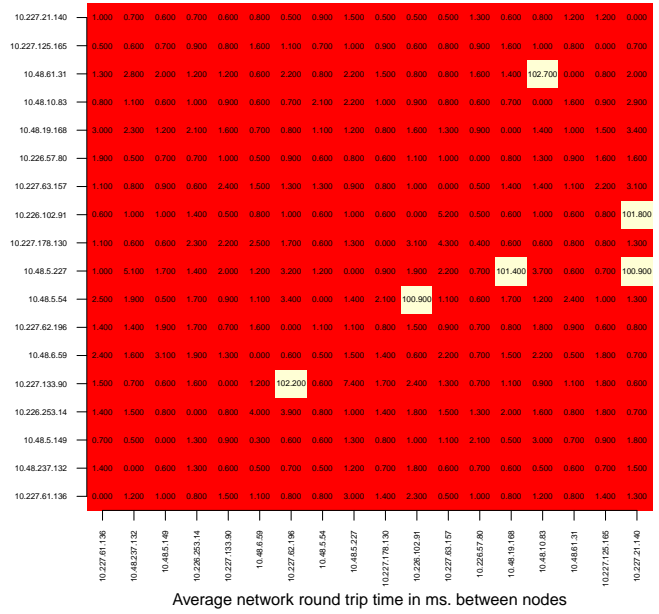
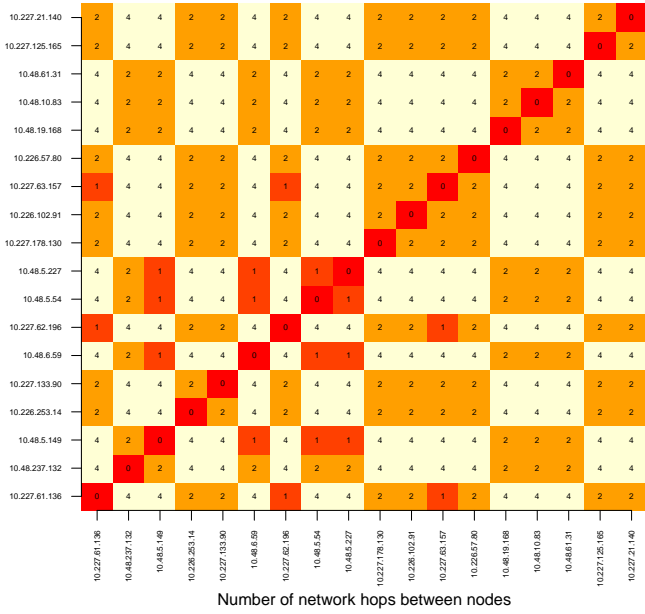


Figure 2: Network measurements *before* the test runs.

Network Hops – 2011-06-05 13:32:59

Network Round Trip Time – 2011-06-05 13:33:00

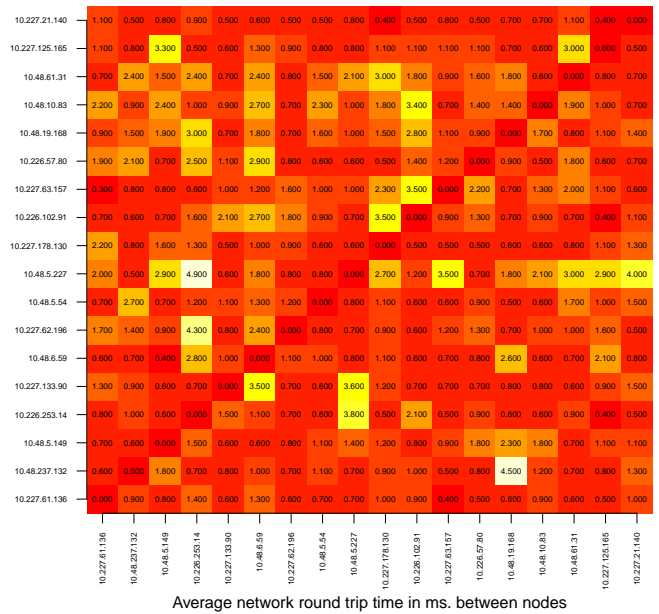
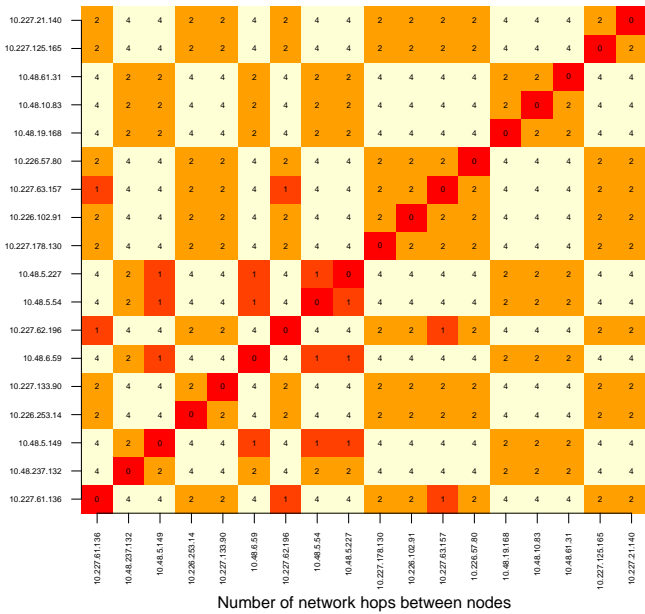
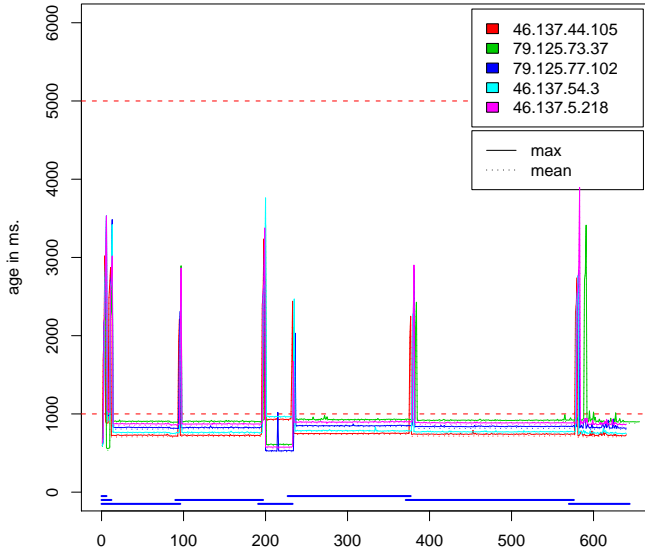


Figure 3: Network measurements *after* the test runs.

3 Measurements for the 100 Prototype Test Runs

The following 100 images each depict the measured timings during *one* prototype test run. Except for test run 27 on page 12 there are no real surprises. When the system is running in normal operation the measured max and mean values are in a narrow band around the 1 second deadline (QAS3), and at failover situations as indicated by the 3 blue server lines depicted at the bottom of each graph, the max values are well below the 5 second deadline (QAS1).

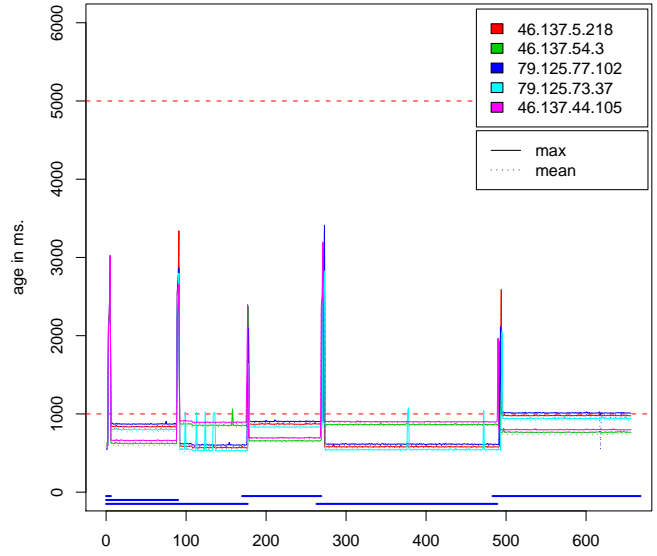
Client Data Age – 2011-06-04 18:23:24



Age in ms. of data on one client – sampling every second

(Test run 1)

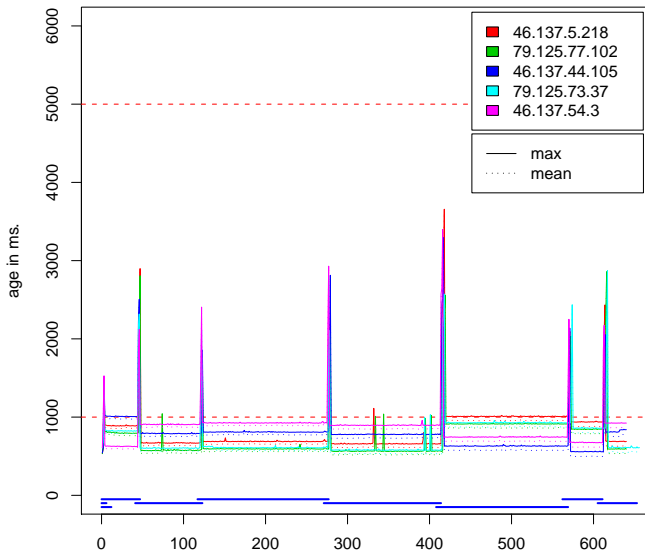
Client Data Age – 2011-06-04 18:35:08



Age in ms. of data on one client – sampling every second

(Test run 2)

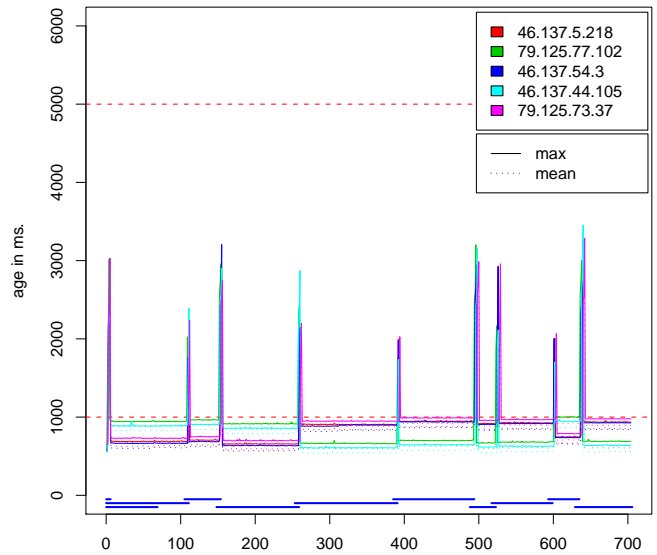
Client Data Age – 2011-06-04 18:46:34



Age in ms. of data on one client – sampling every second

(Test run 3)

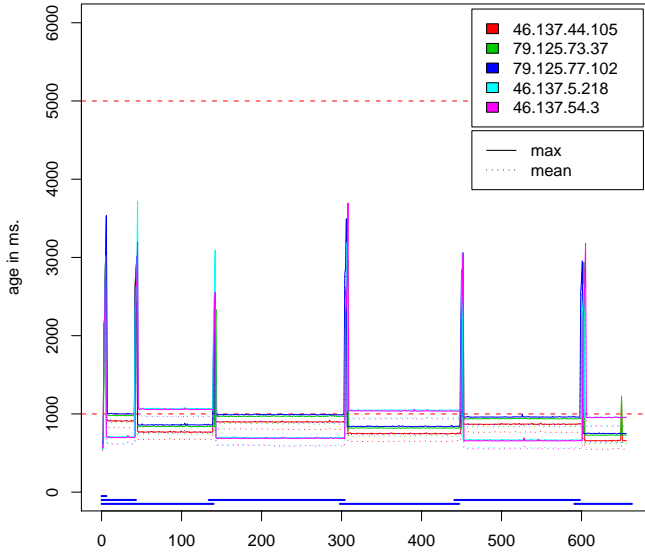
Client Data Age – 2011-06-04 18:58:55



Age in ms. of data on one client – sampling every second

(Test run 4)

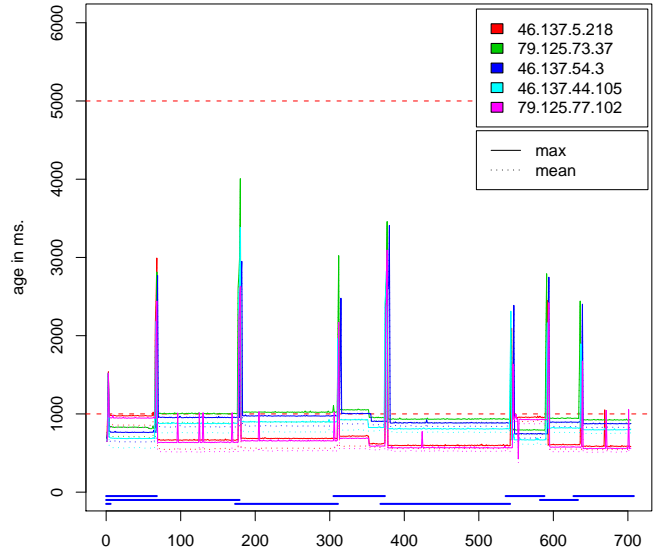
Client Data Age – 2011-06-04 19:10:34



Age in ms. of data on one client – sampling every second

(Test run 5)

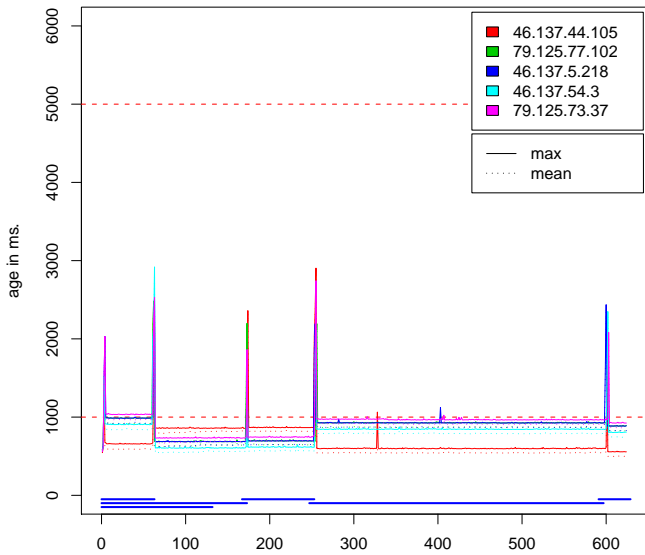
Client Data Age – 2011-06-04 19:22:57



Age in ms. of data on one client – sampling every second

(Test run 6)

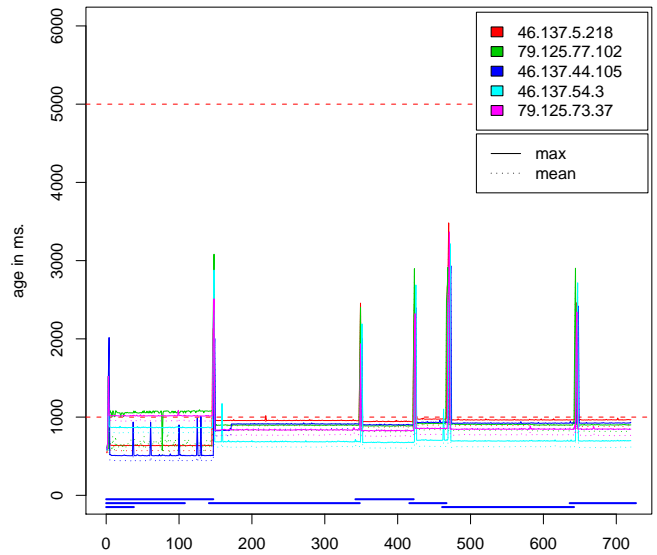
Client Data Age – 2011-06-04 19:34:00



Age in ms. of data on one client – sampling every second

(Test run 7)

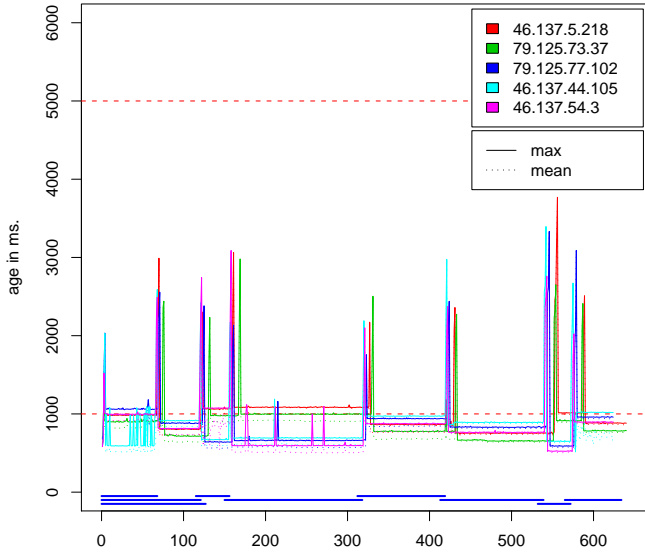
Client Data Age – 2011-06-04 19:46:42



Age in ms. of data on one client – sampling every second

(Test run 8)

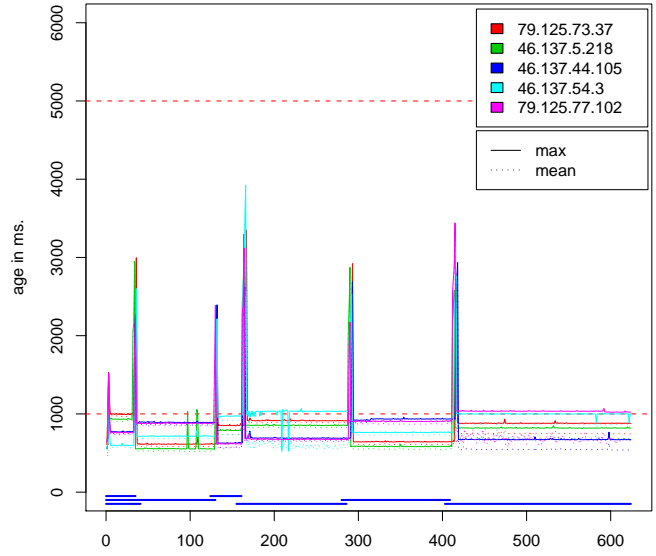
Client Data Age – 2011-06-04 19:57:52



Age in ms. of data on one client – sampling every second

(Test run 9)

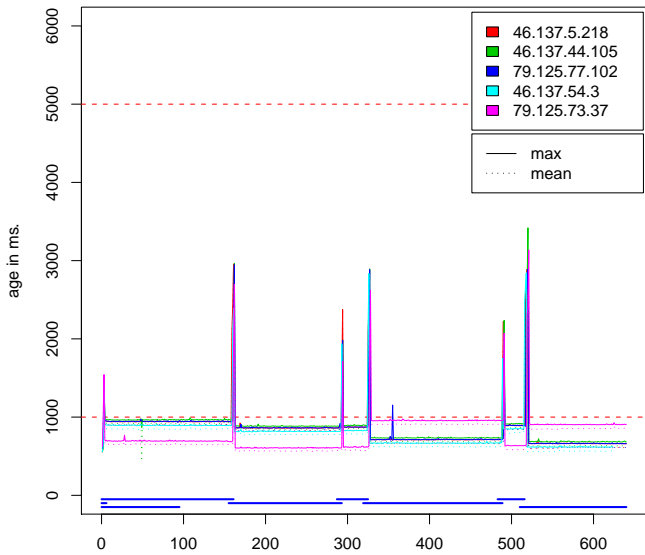
Client Data Age – 2011-06-04 20:08:49



Age in ms. of data on one client – sampling every second

(Test run 10)

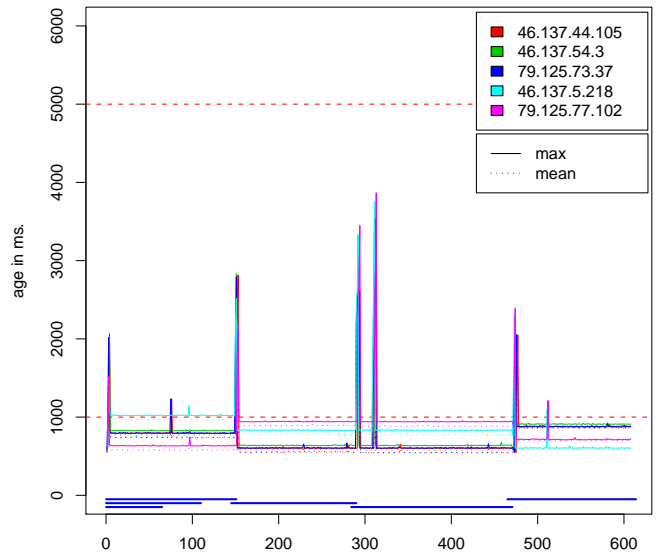
Client Data Age – 2011-06-04 20:20:02



Age in ms. of data on one client – sampling every second

(Test run 11)

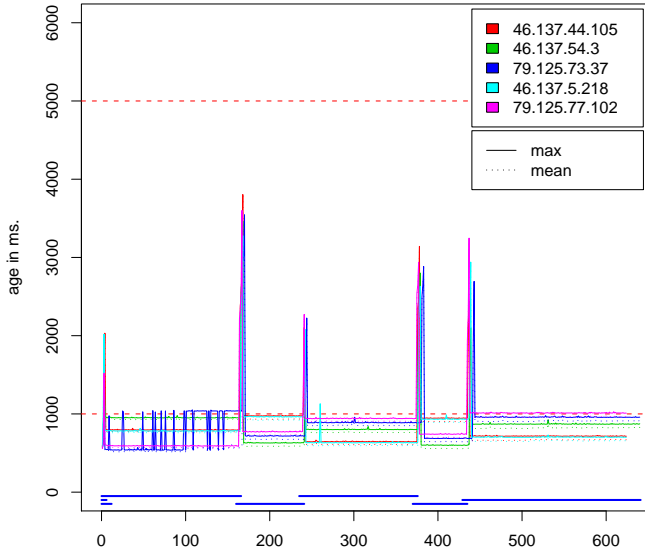
Client Data Age – 2011-06-04 20:30:49



Age in ms. of data on one client – sampling every second

(Test run 12)

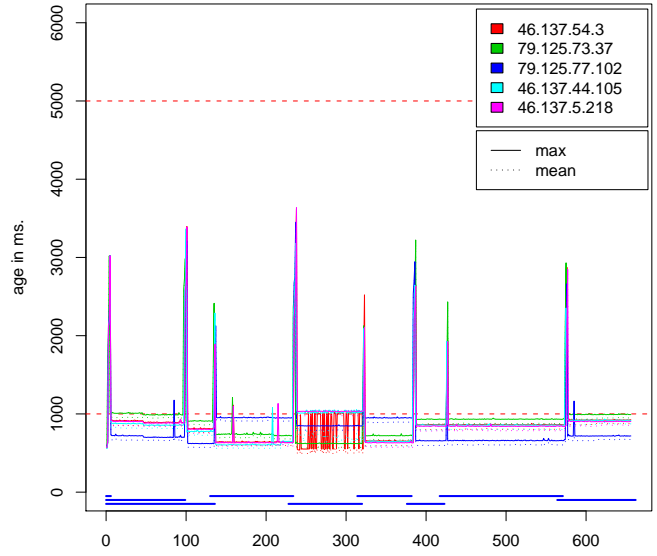
Client Data Age – 2011-06-04 20:42:06



Age in ms. of data on one client – sampling every second

(Test run 13)

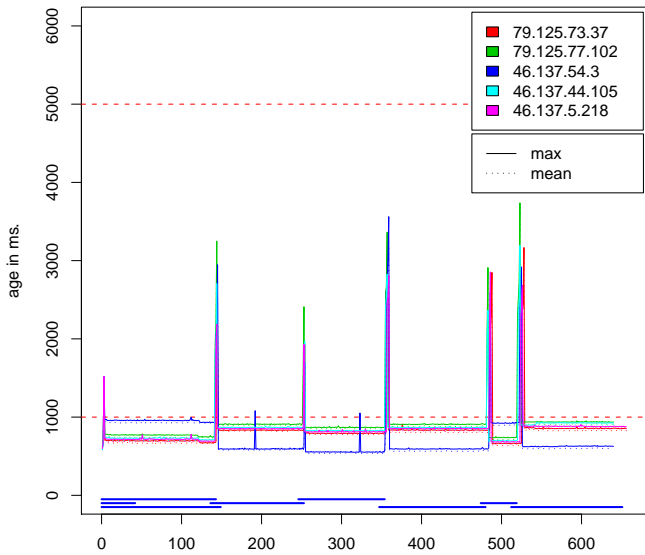
Client Data Age – 2011-06-04 20:53:44



Age in ms. of data on one client – sampling every second

(Test run 14)

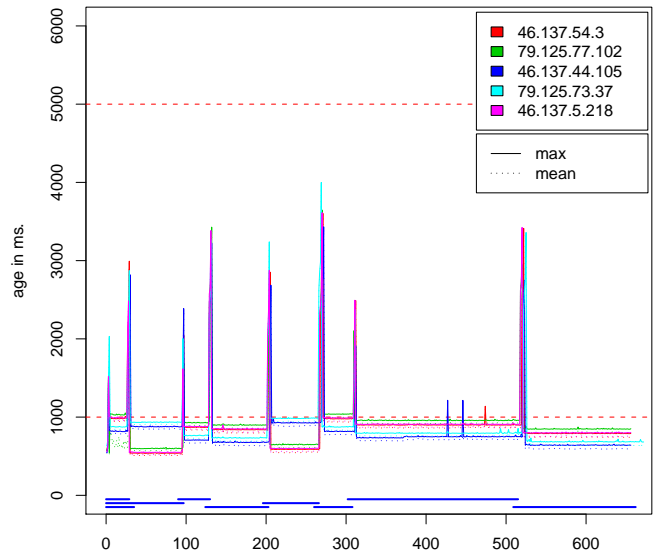
Client Data Age – 2011-06-04 21:05:13



Age in ms. of data on one client – sampling every second

(Test run 15)

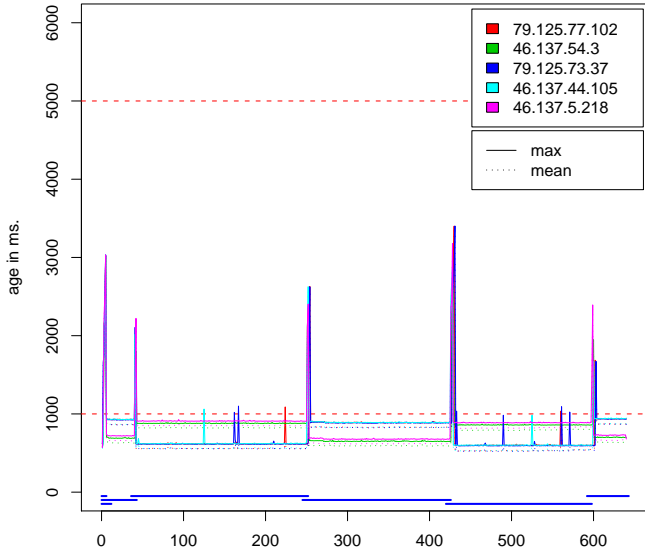
Client Data Age – 2011-06-04 21:16:54



Age in ms. of data on one client – sampling every second

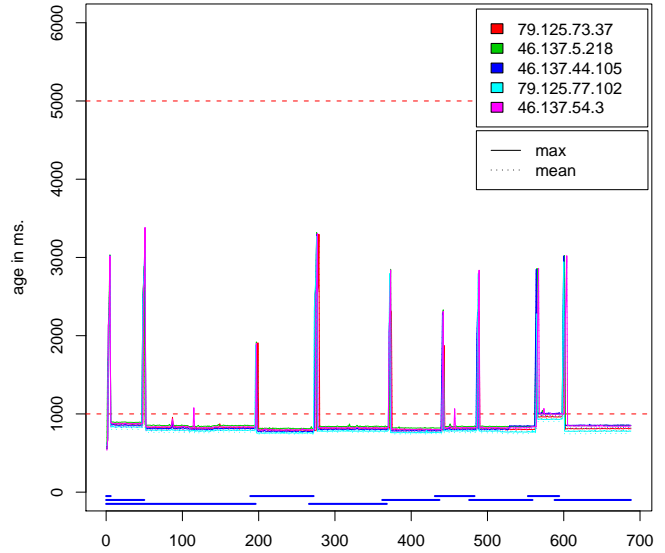
(Test run 16)

Client Data Age – 2011-06-04 21:28:13



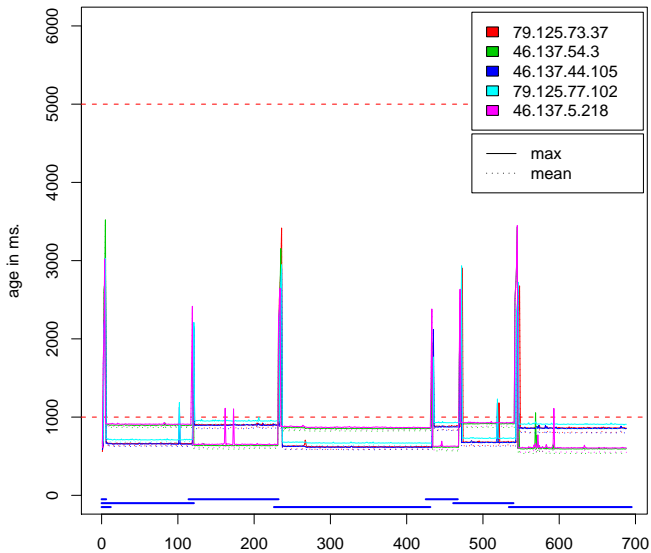
Age in ms. of data on one client – sampling every second
(Test run 17)

Client Data Age – 2011-06-04 21:40:15



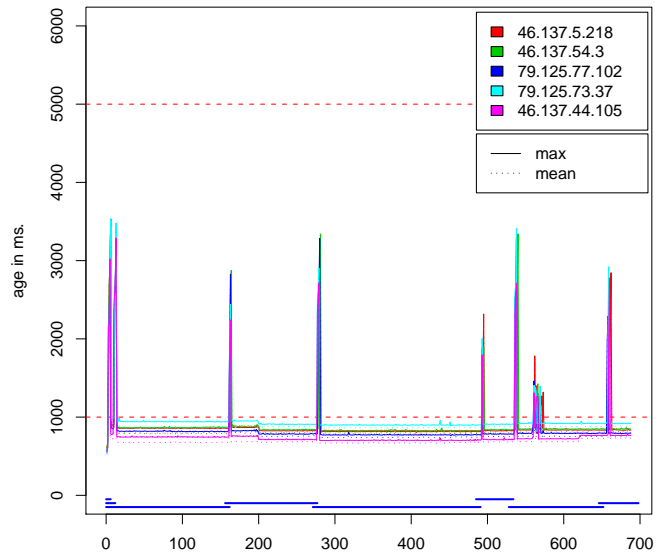
Age in ms. of data on one client – sampling every second
(Test run 18)

Client Data Age – 2011-06-04 21:52:23



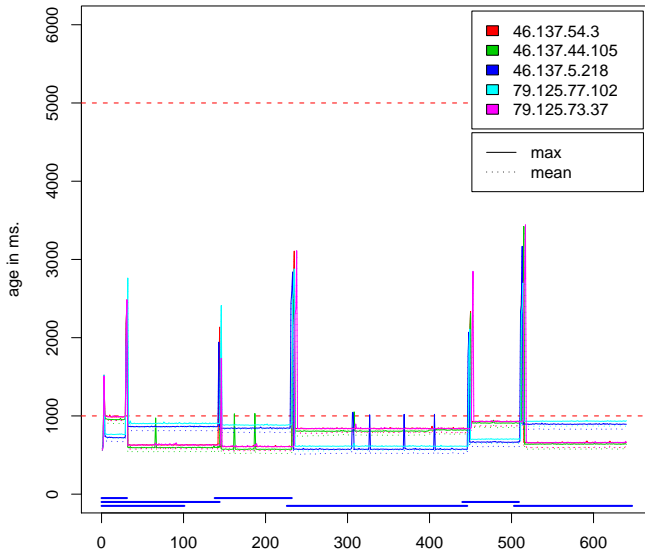
Age in ms. of data on one client – sampling every second
(Test run 19)

Client Data Age – 2011-06-04 22:04:34



Age in ms. of data on one client – sampling every second
(Test run 20)

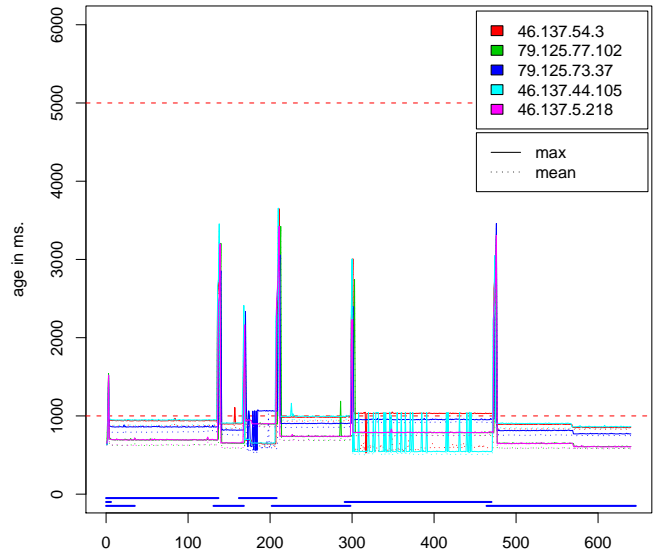
Client Data Age – 2011-06-04 22:15:54



Age in ms. of data on one client – sampling every second

(Test run 21)

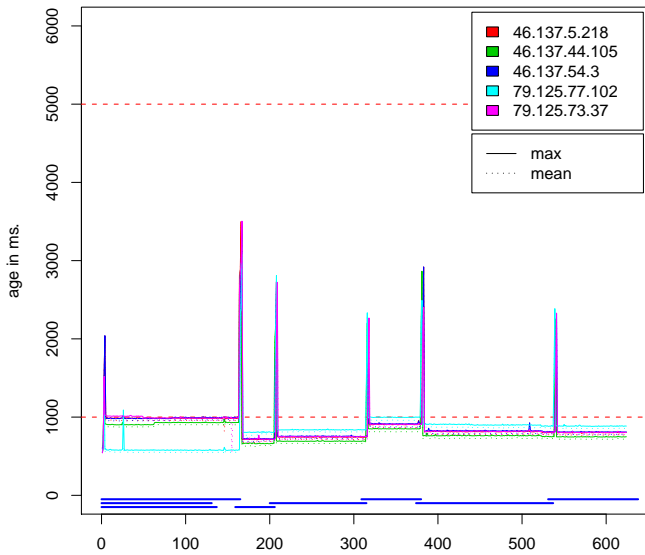
Client Data Age – 2011-06-04 22:27:13



Age in ms. of data on one client – sampling every second

(Test run 22)

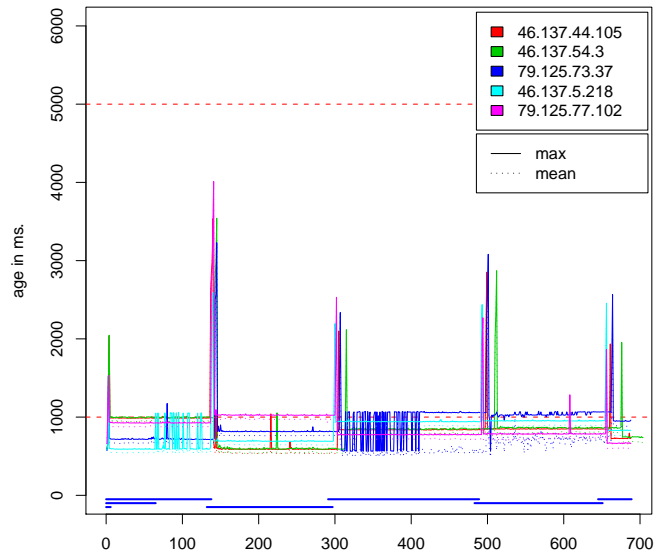
Client Data Age – 2011-06-04 22:38:24



Age in ms. of data on one client – sampling every second

(Test run 23)

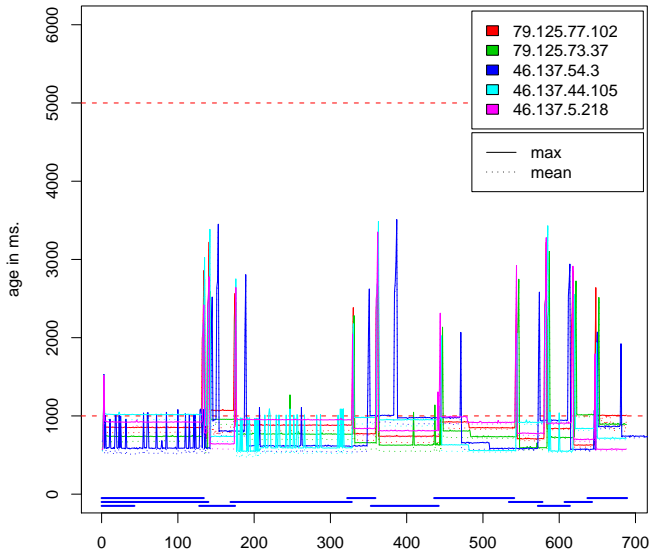
Client Data Age – 2011-06-04 22:50:26



Age in ms. of data on one client – sampling every second

(Test run 24)

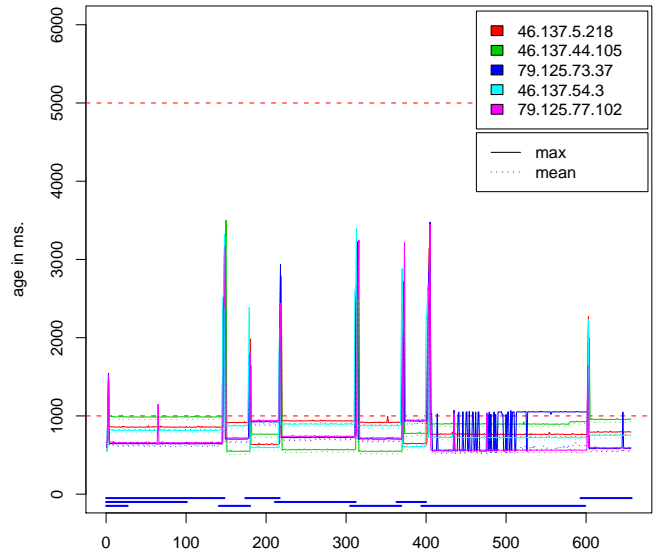
Client Data Age – 2011-06-04 23:02:28



Age in ms. of data on one client – sampling every second

(Test run 25)

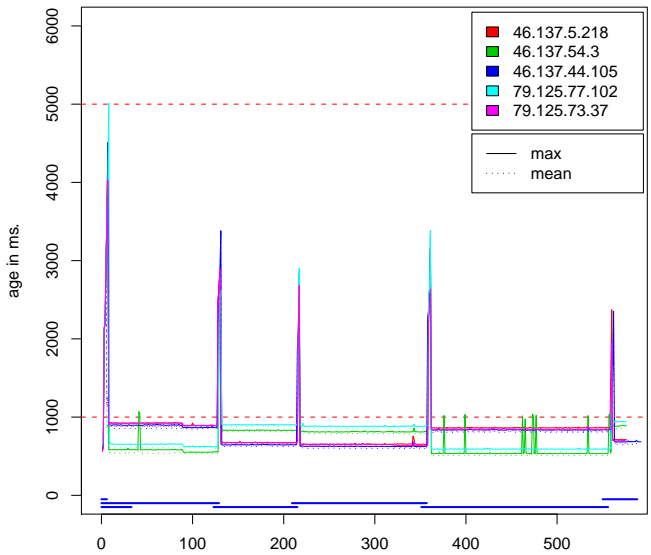
Client Data Age – 2011-06-04 23:13:58



Age in ms. of data on one client – sampling every second

(Test run 26)

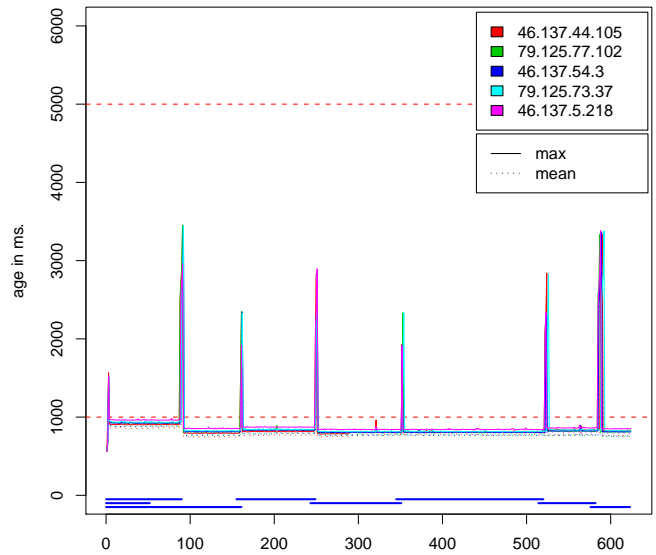
Client Data Age – 2011-06-04 23:24:19



Age in ms. of data on one client – sampling every second

(Test run 27)

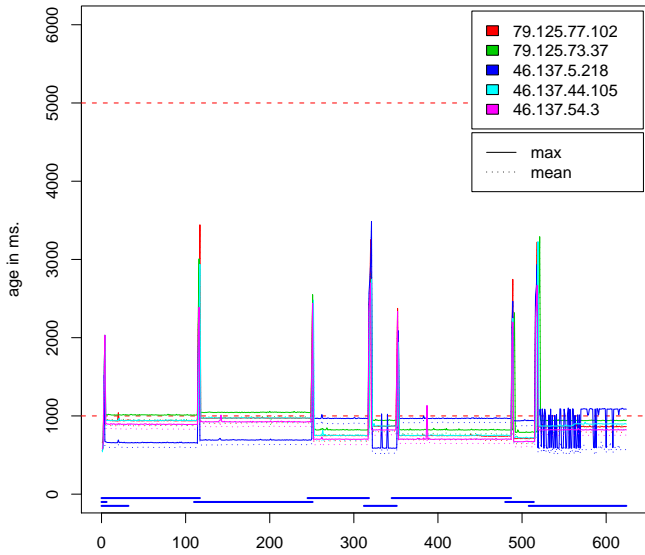
Client Data Age – 2011-06-04 23:35:17



Age in ms. of data on one client – sampling every second

(Test run 28)

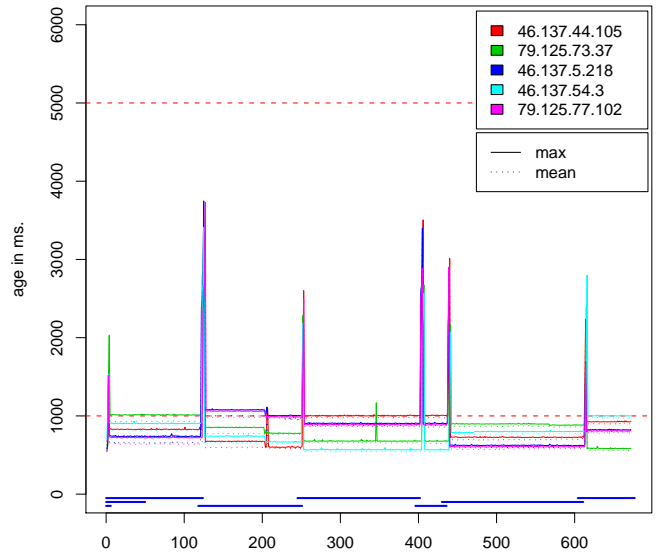
Client Data Age – 2011-06-04 23:46:14



Age in ms. of data on one client – sampling every second

(Test run 29)

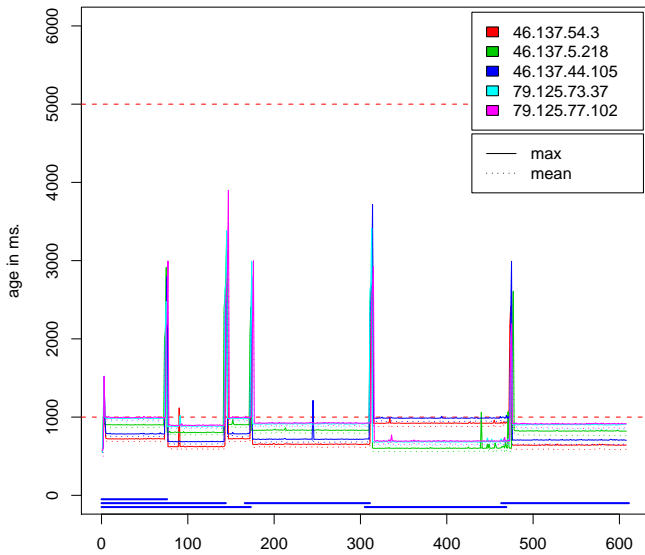
Client Data Age – 2011-06-04 23:58:07



Age in ms. of data on one client – sampling every second

(Test run 30)

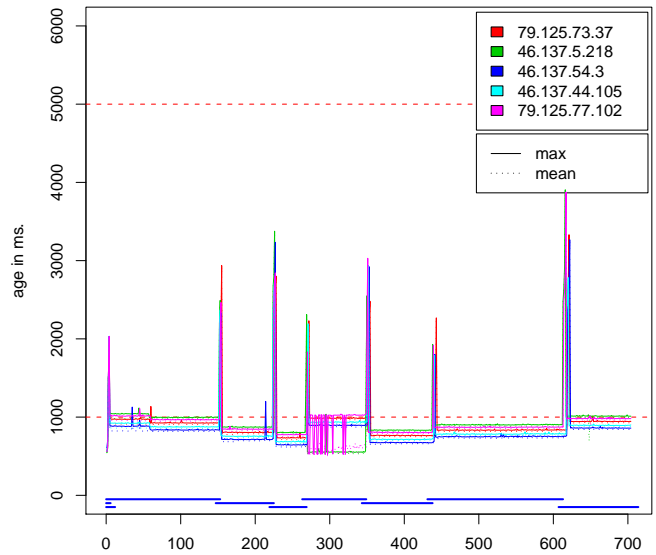
Client Data Age – 2011-06-05 00:08:54



Age in ms. of data on one client – sampling every second

(Test run 31)

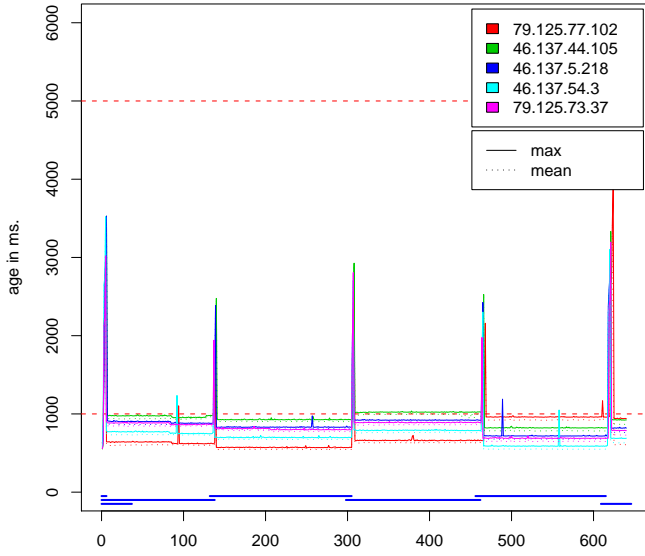
Client Data Age – 2011-06-05 00:21:23



Age in ms. of data on one client – sampling every second

(Test run 32)

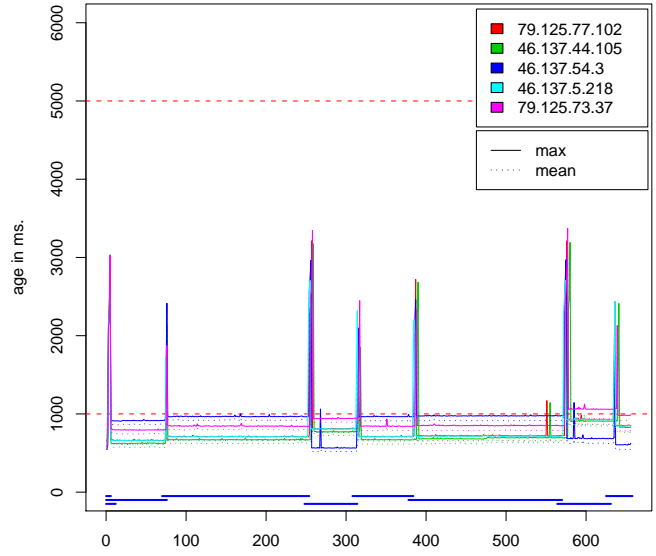
Client Data Age – 2011-06-05 00:32:48



Age in ms. of data on one client – sampling every second

(Test run 33)

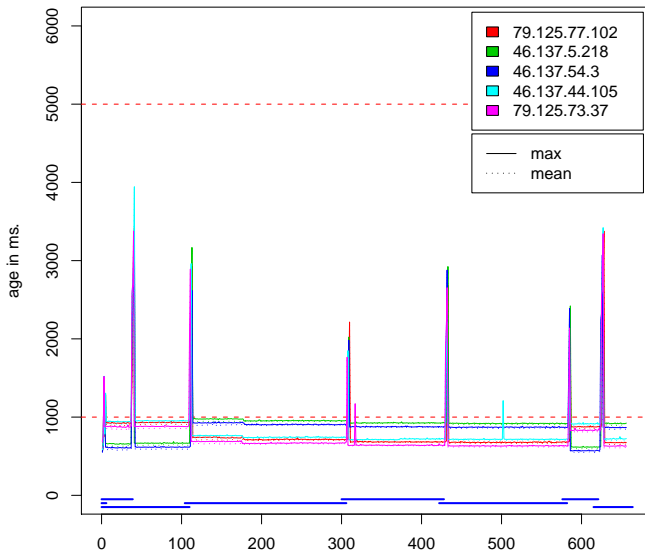
Client Data Age – 2011-06-05 00:44:23



Age in ms. of data on one client – sampling every second

(Test run 34)

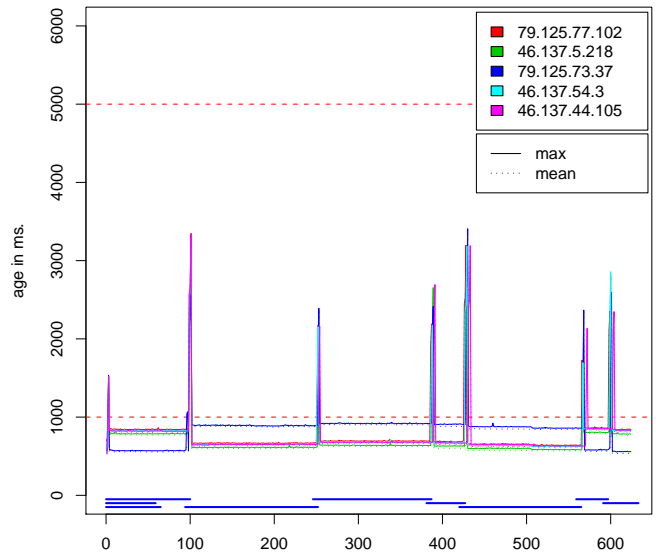
Client Data Age – 2011-06-05 00:56:02



Age in ms. of data on one client – sampling every second

(Test run 35)

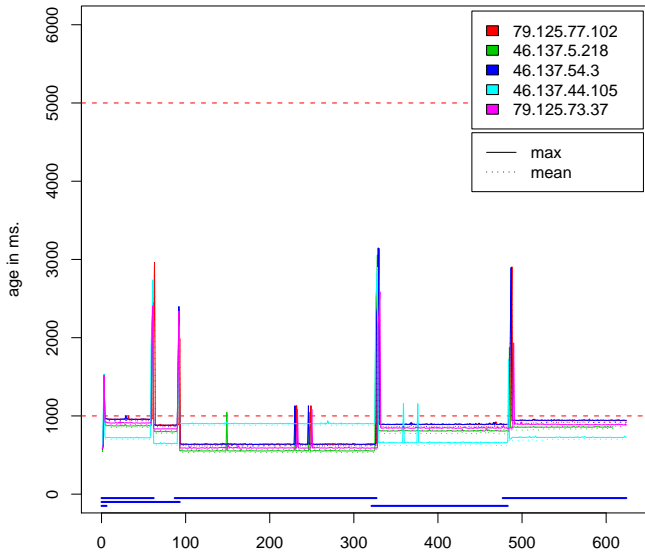
Client Data Age – 2011-06-05 01:07:09



Age in ms. of data on one client – sampling every second

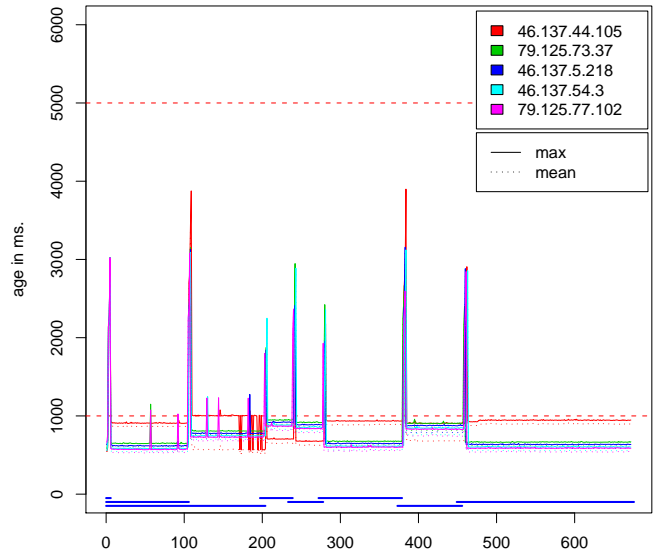
(Test run 36)

Client Data Age – 2011-06-05 01:18:07



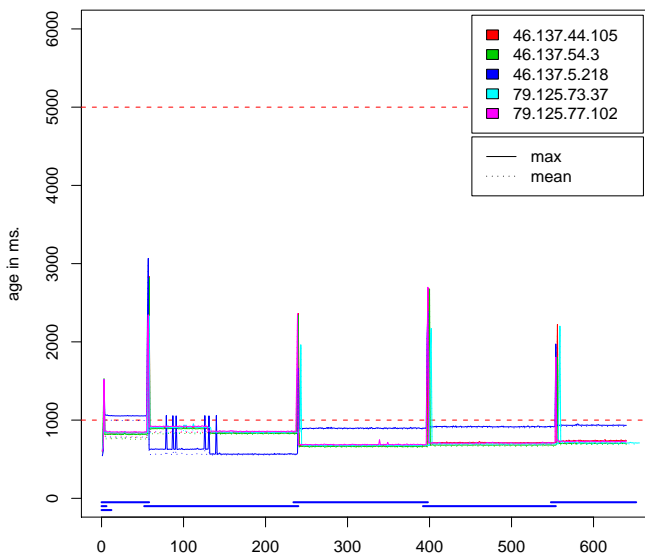
Age in ms. of data on one client – sampling every second
(Test run 37)

Client Data Age – 2011-06-05 01:29:56



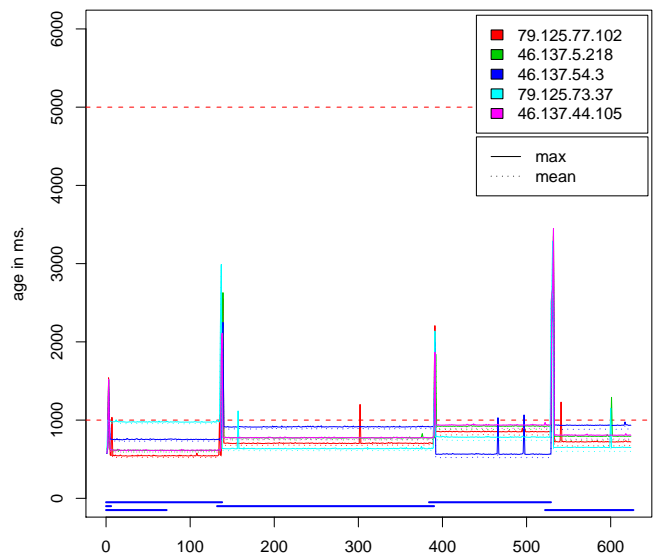
Age in ms. of data on one client – sampling every second
(Test run 38)

Client Data Age – 2011-06-05 01:41:24



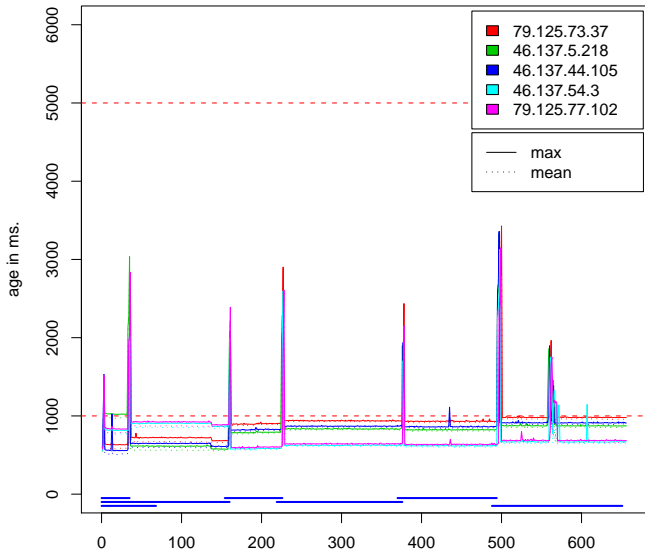
Age in ms. of data on one client – sampling every second
(Test run 39)

Client Data Age – 2011-06-05 01:52:25



Age in ms. of data on one client – sampling every second
(Test run 40)

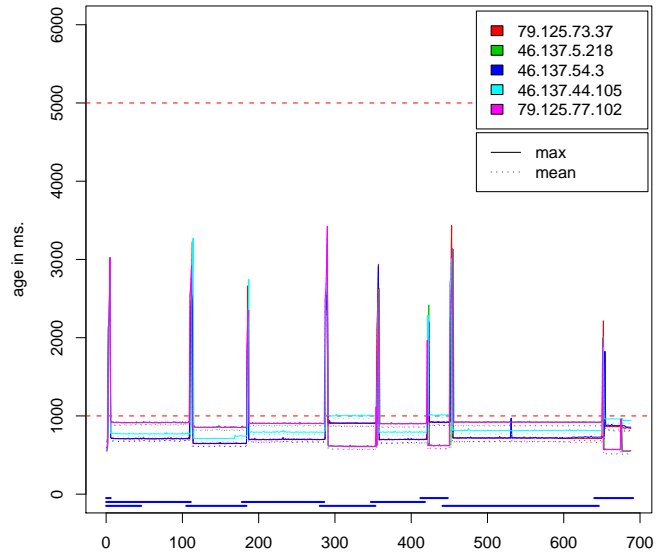
Client Data Age – 2011-06-05 02:03:50



Age in ms. of data on one client – sampling every second

(Test run 41)

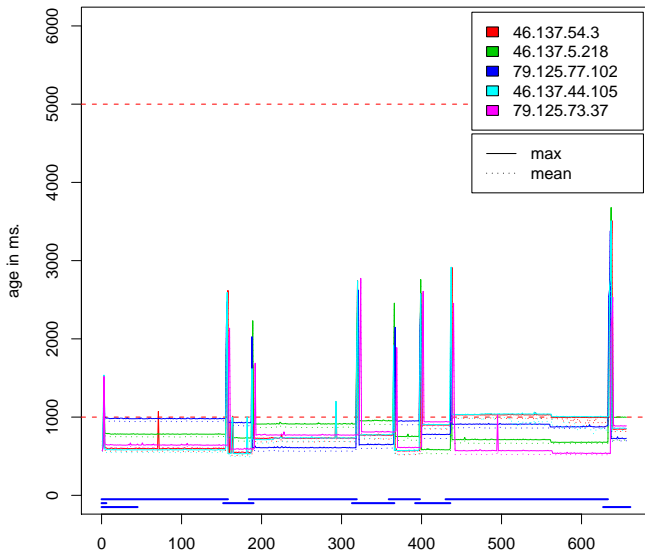
Client Data Age – 2011-06-05 02:15:54



Age in ms. of data on one client – sampling every second

(Test run 42)

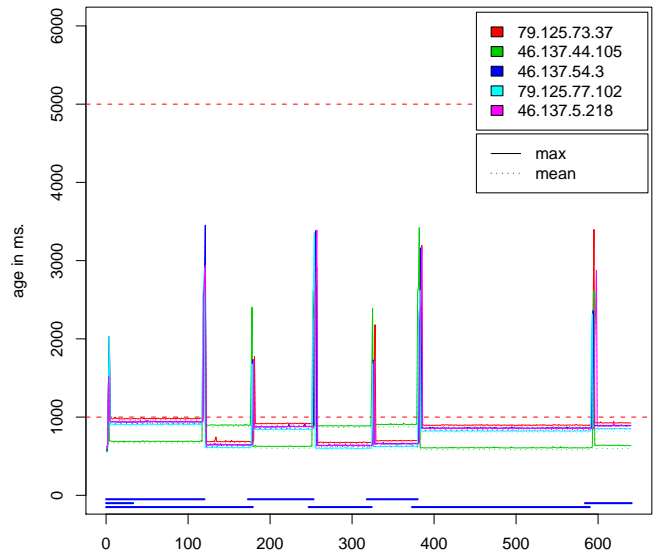
Client Data Age – 2011-06-05 02:27:27



Age in ms. of data on one client – sampling every second

(Test run 43)

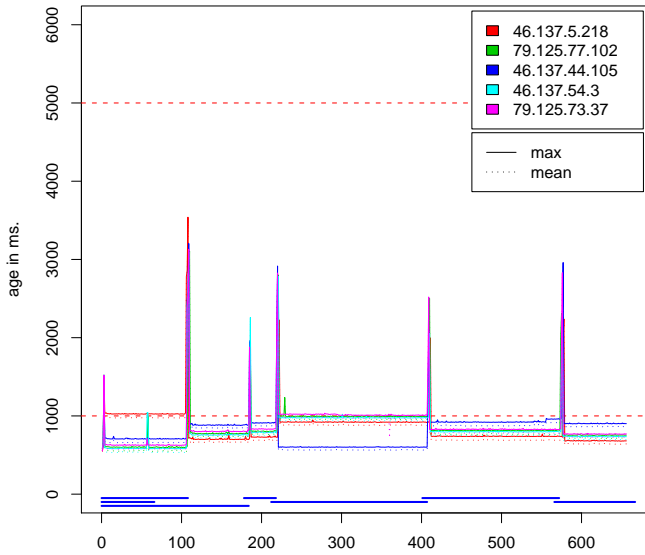
Client Data Age – 2011-06-05 02:38:41



Age in ms. of data on one client – sampling every second

(Test run 44)

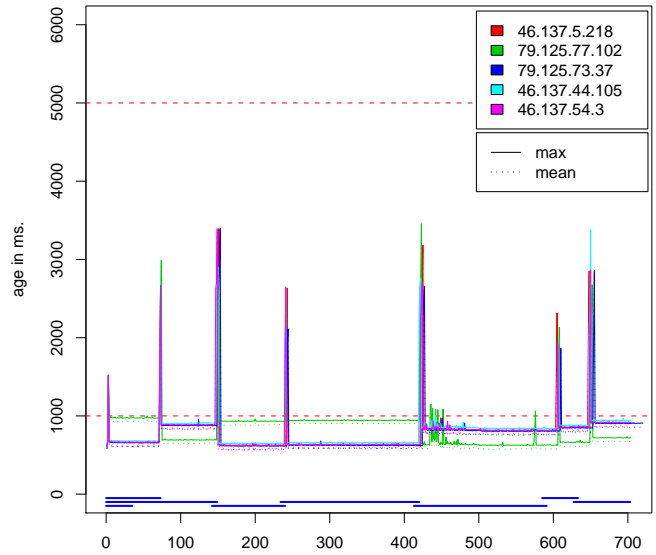
Client Data Age – 2011-06-05 02:50:21



Age in ms. of data on one client – sampling every second

(Test run 45)

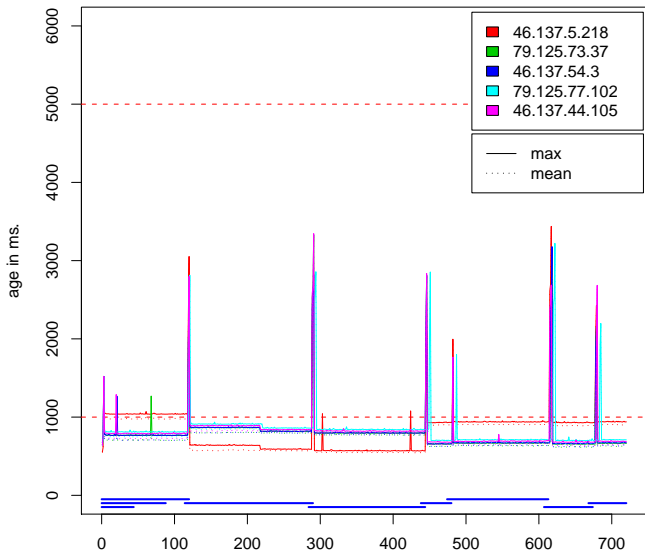
Client Data Age – 2011-06-05 03:02:38



Age in ms. of data on one client – sampling every second

(Test run 46)

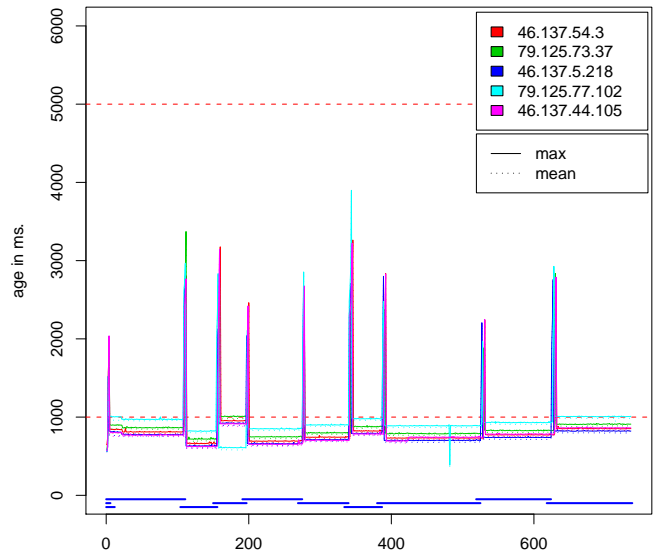
Client Data Age – 2011-06-05 03:15:10



Age in ms. of data on one client – sampling every second

(Test run 47)

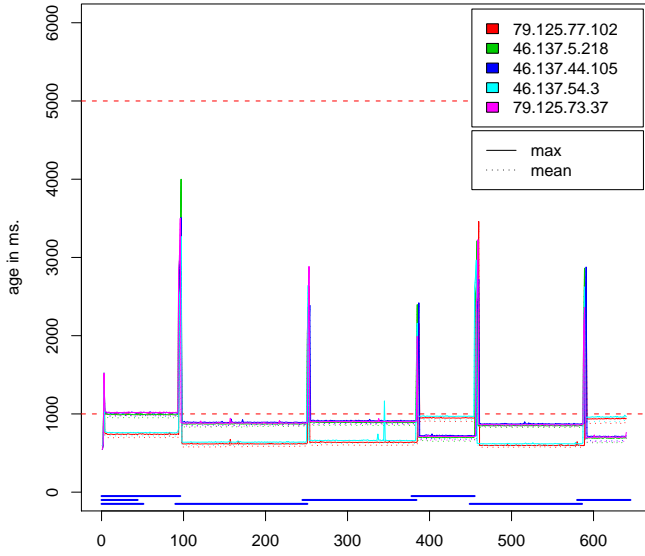
Client Data Age – 2011-06-05 03:28:03



Age in ms. of data on one client – sampling every second

(Test run 48)

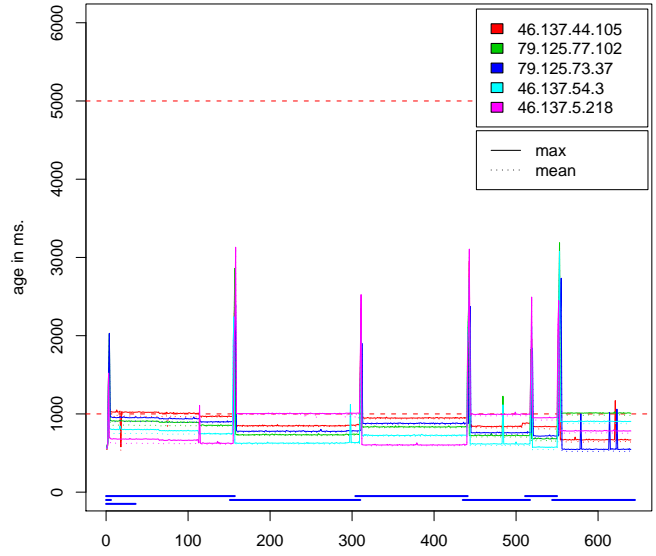
Client Data Age – 2011-06-05 03:39:21



Age in ms. of data on one client – sampling every second

(Test run 49)

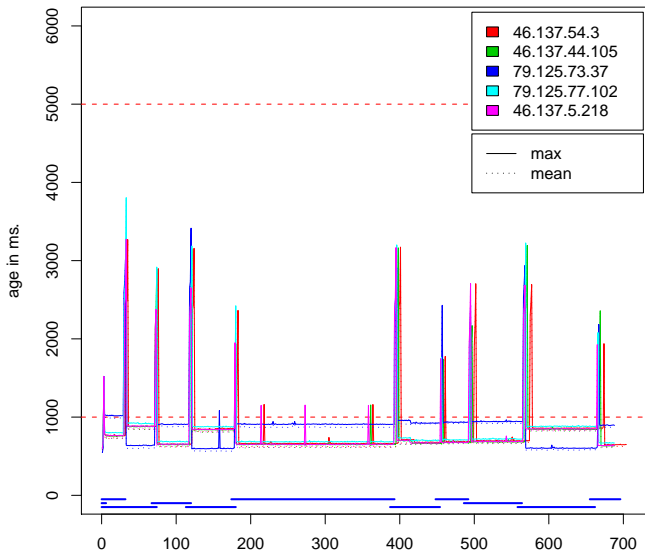
Client Data Age – 2011-06-05 03:50:39



Age in ms. of data on one client – sampling every second

(Test run 50)

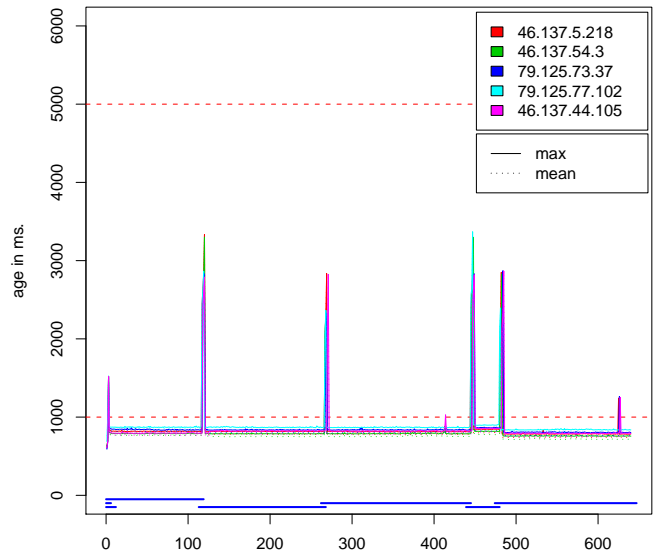
Client Data Age – 2011-06-05 04:02:48



Age in ms. of data on one client – sampling every second

(Test run 51)

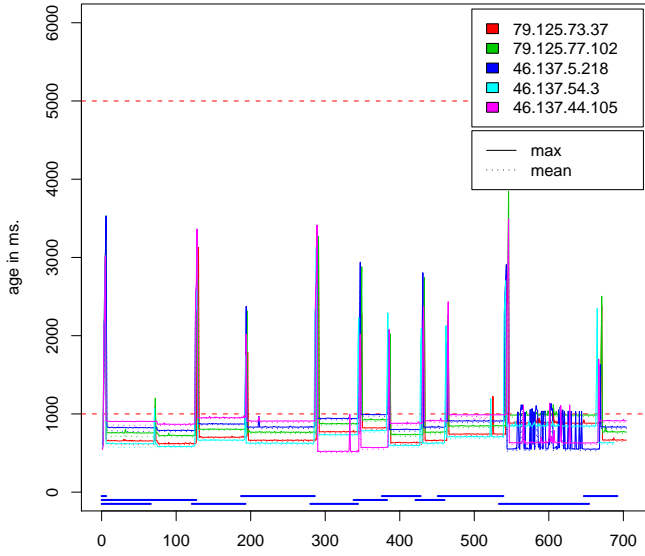
Client Data Age – 2011-06-05 04:14:09



Age in ms. of data on one client – sampling every second

(Test run 52)

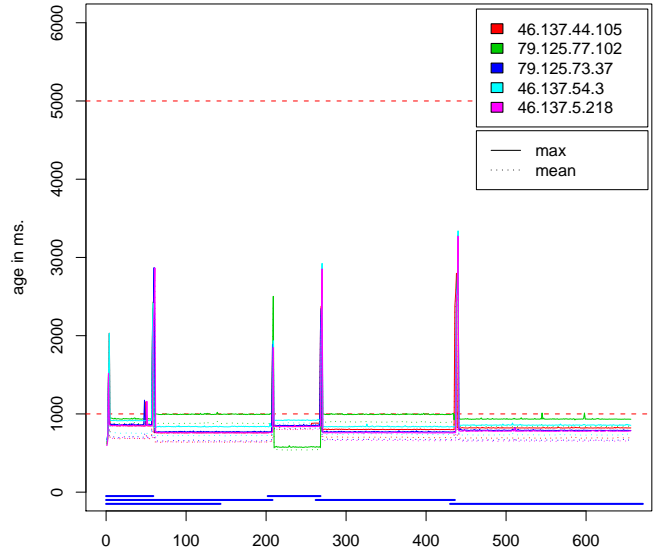
Client Data Age – 2011-06-05 04:26:15



Age in ms. of data on one client – sampling every second

(Test run 53)

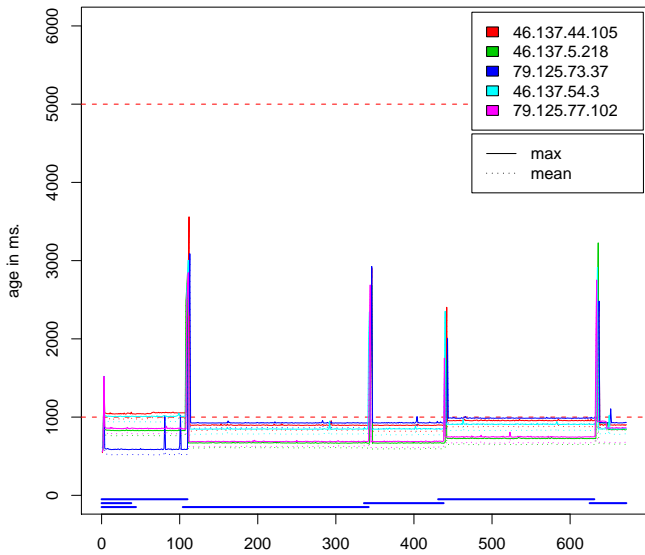
Client Data Age – 2011-06-05 04:37:59



Age in ms. of data on one client – sampling every second

(Test run 54)

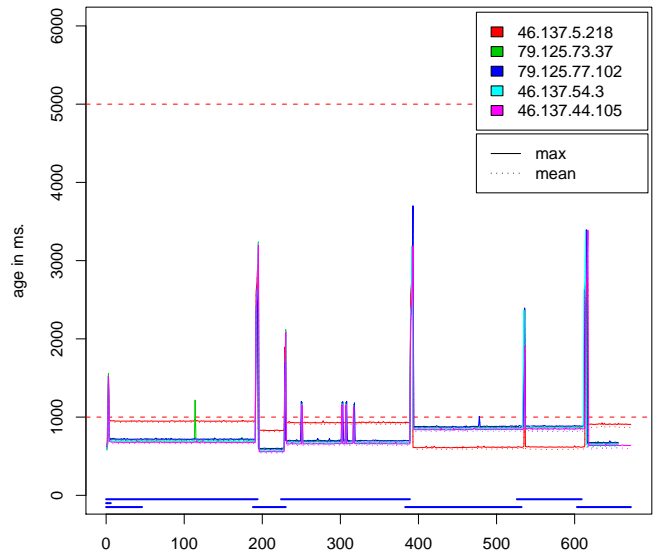
Client Data Age – 2011-06-05 04:49:45



Age in ms. of data on one client – sampling every second

(Test run 55)

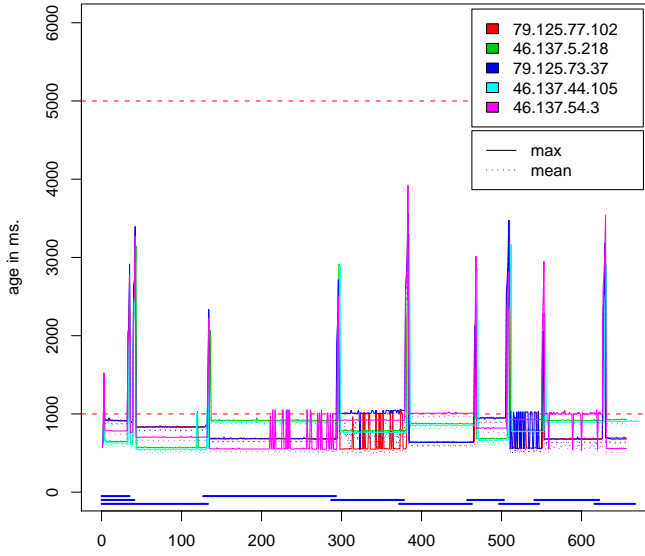
Client Data Age – 2011-06-05 05:01:29



Age in ms. of data on one client – sampling every second

(Test run 56)

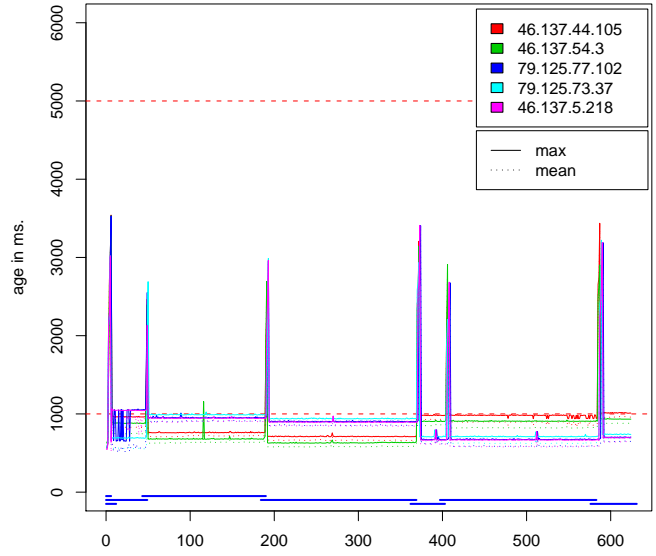
Client Data Age – 2011-06-05 05:13:12



Age in ms. of data on one client – sampling every second

(Test run 57)

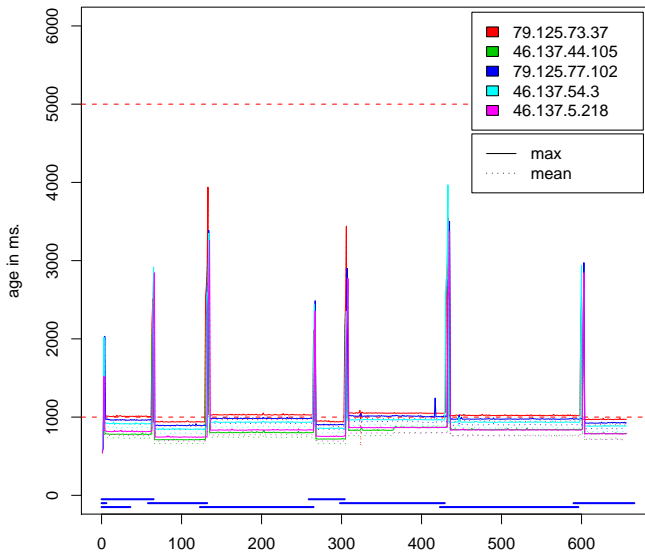
Client Data Age – 2011-06-05 05:24:18



Age in ms. of data on one client – sampling every second

(Test run 58)

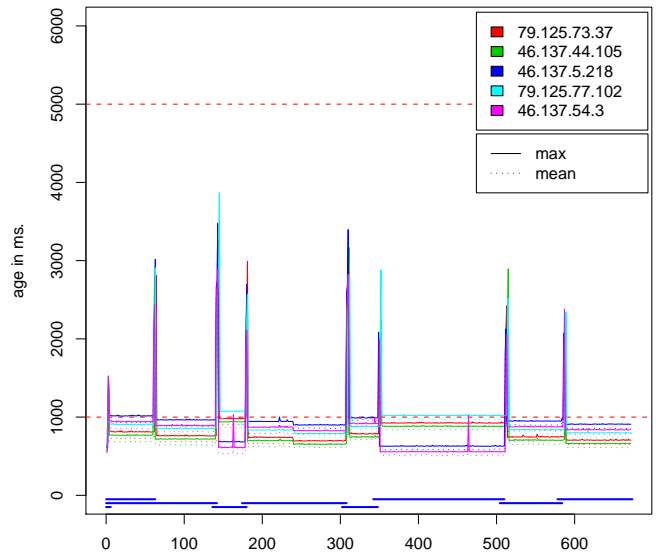
Client Data Age – 2011-06-05 05:35:57



Age in ms. of data on one client – sampling every second

(Test run 59)

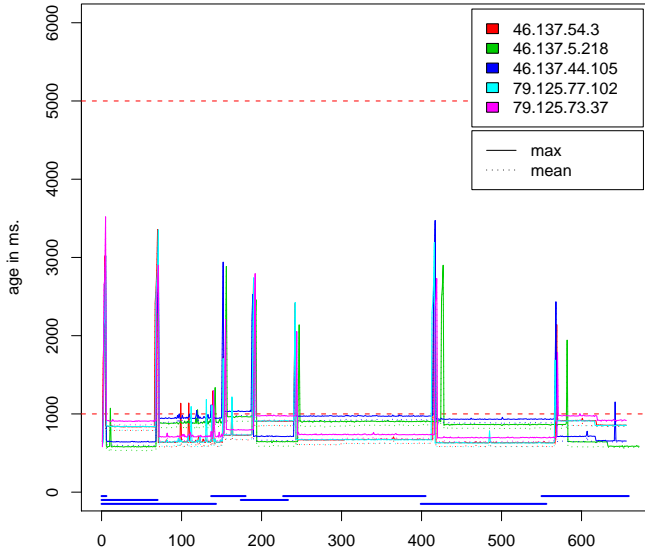
Client Data Age – 2011-06-05 05:47:45



Age in ms. of data on one client – sampling every second

(Test run 60)

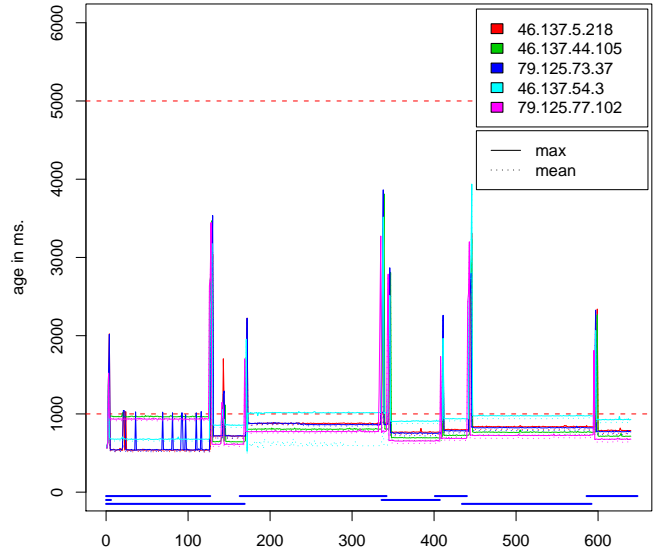
Client Data Age – 2011-06-05 05:59:19



Age in ms. of data on one client – sampling every second

(Test run 61)

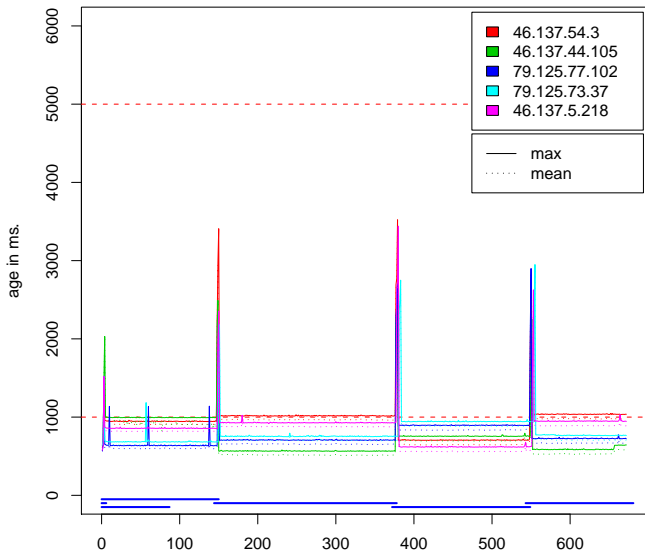
Client Data Age – 2011-06-05 06:10:40



Age in ms. of data on one client – sampling every second

(Test run 62)

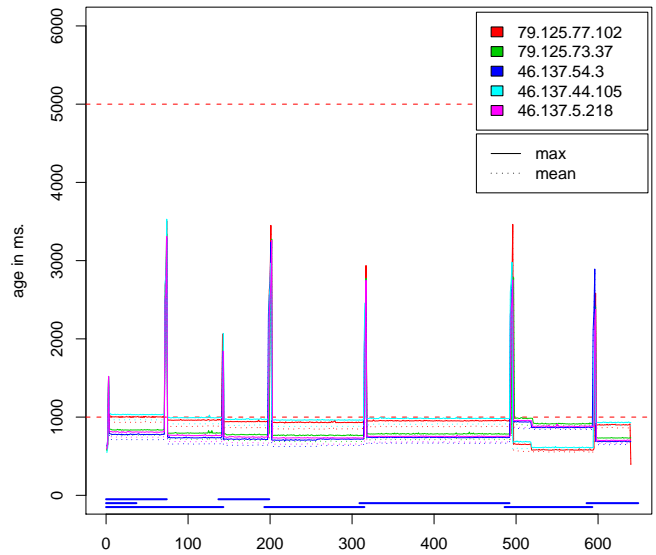
Client Data Age – 2011-06-05 06:22:33



Age in ms. of data on one client – sampling every second

(Test run 63)

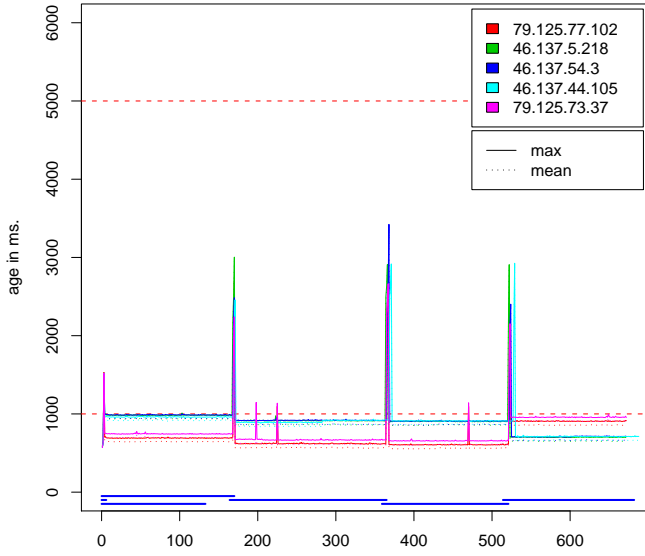
Client Data Age – 2011-06-05 06:33:56



Age in ms. of data on one client – sampling every second

(Test run 64)

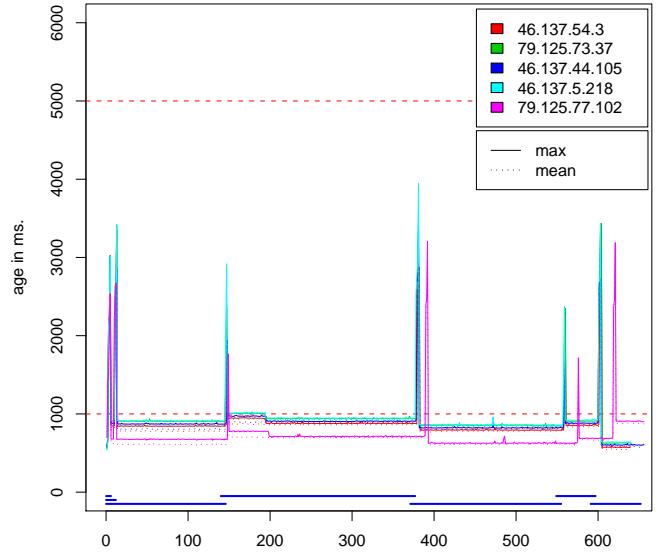
Client Data Age – 2011-06-05 06:45:51



Age in ms. of data on one client – sampling every second

(Test run 65)

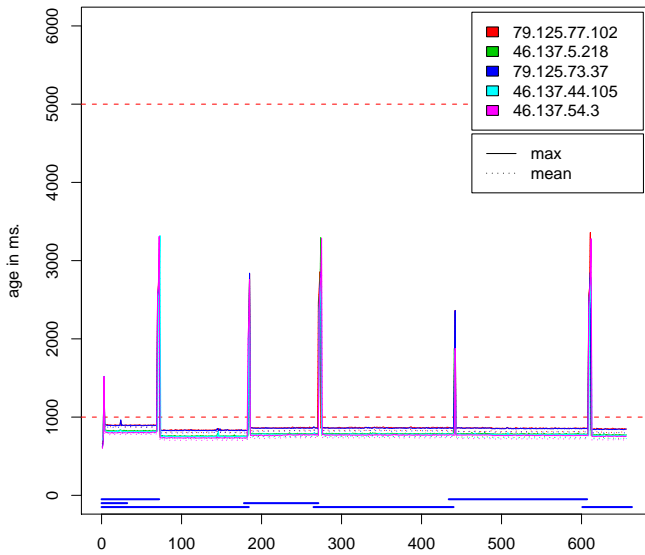
Client Data Age – 2011-06-05 06:57:15



Age in ms. of data on one client – sampling every second

(Test run 66)

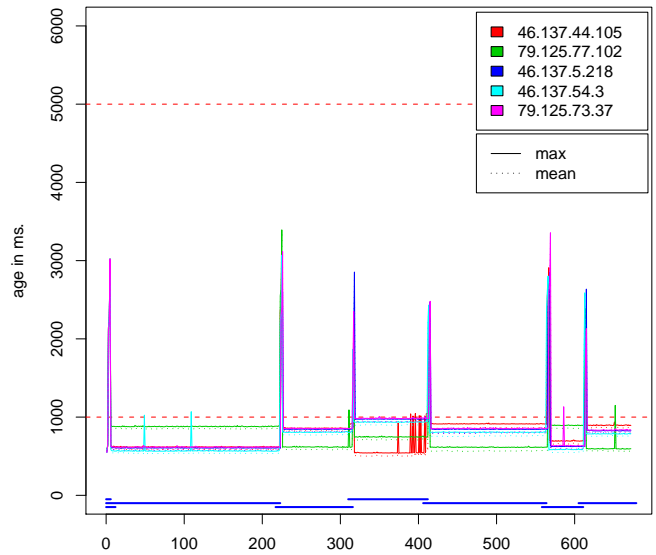
Client Data Age – 2011-06-05 07:08:51



Age in ms. of data on one client – sampling every second

(Test run 67)

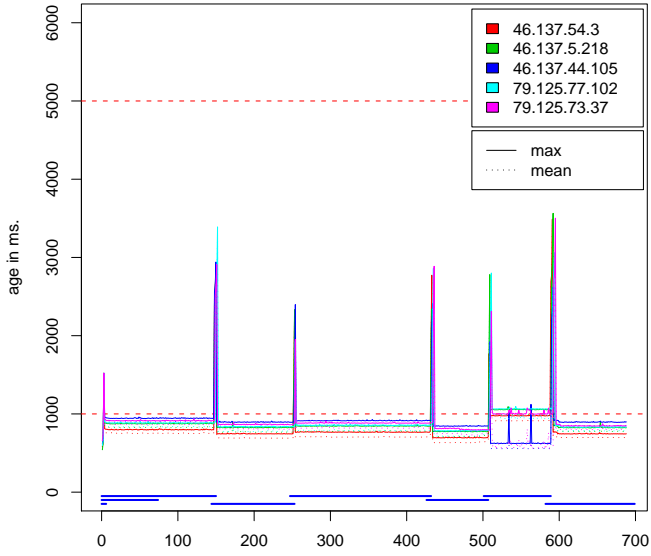
Client Data Age – 2011-06-05 07:20:48



Age in ms. of data on one client – sampling every second

(Test run 68)

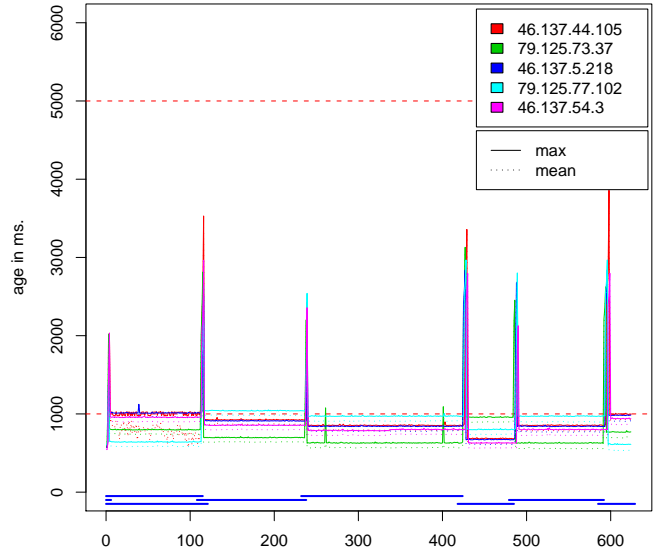
Client Data Age – 2011-06-05 07:32:59



Age in ms. of data on one client – sampling every second

(Test run 69)

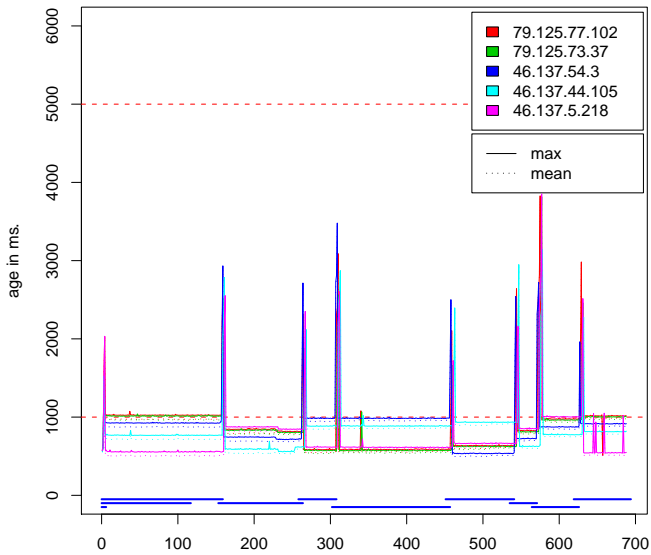
Client Data Age – 2011-06-05 07:44:01



Age in ms. of data on one client – sampling every second

(Test run 70)

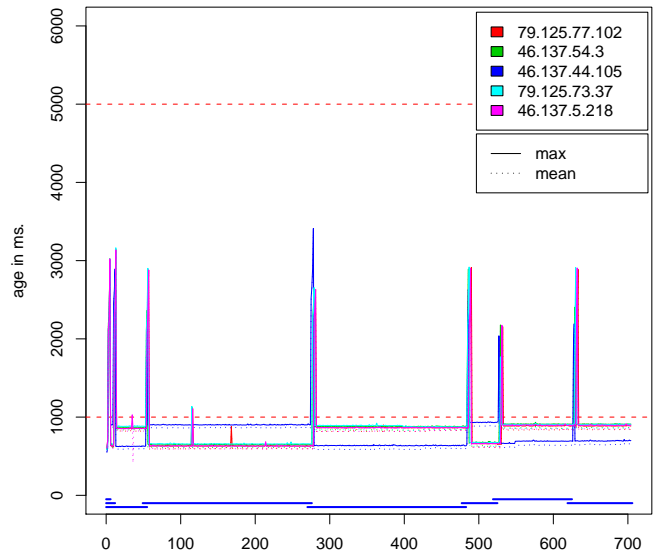
Client Data Age – 2011-06-05 07:56:08



Age in ms. of data on one client – sampling every second

(Test run 71)

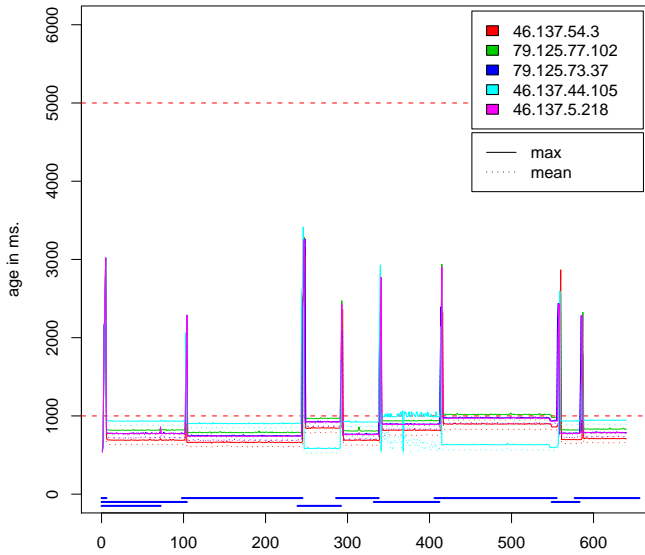
Client Data Age – 2011-06-05 08:08:28



Age in ms. of data on one client – sampling every second

(Test run 72)

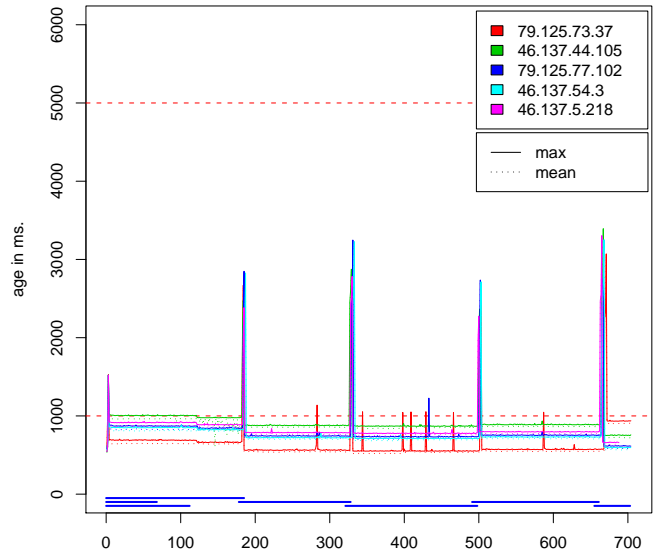
Client Data Age – 2011-06-05 08:19:58



Age in ms. of data on one client – sampling every second

(Test run 73)

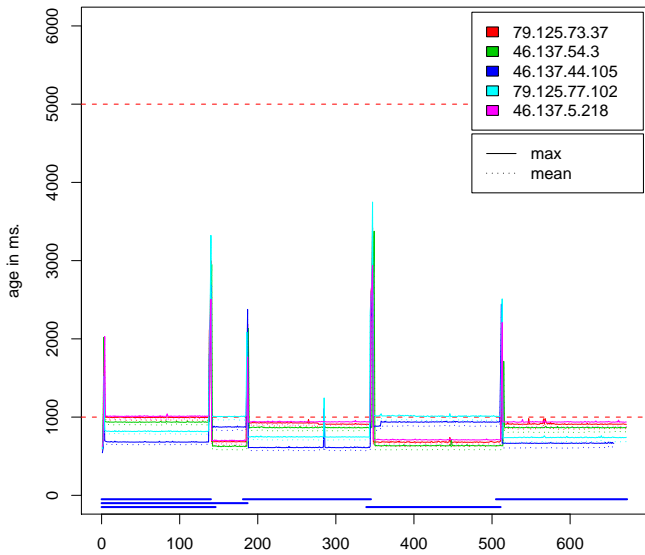
Client Data Age – 2011-06-05 08:32:14



Age in ms. of data on one client – sampling every second

(Test run 74)

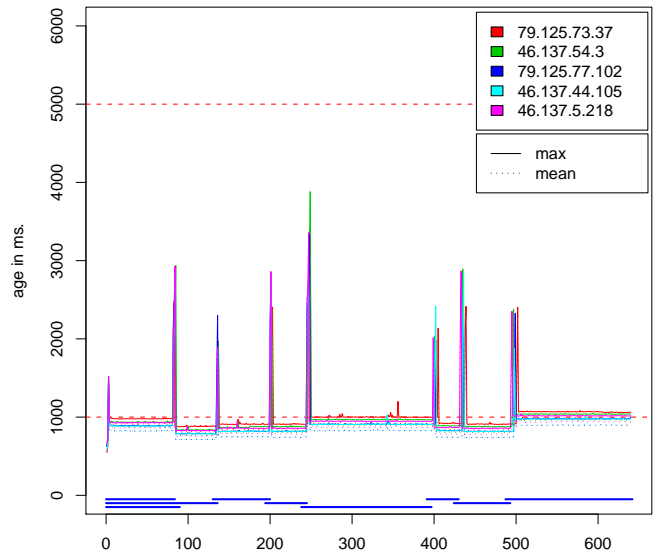
Client Data Age – 2011-06-05 08:44:00



Age in ms. of data on one client – sampling every second

(Test run 75)

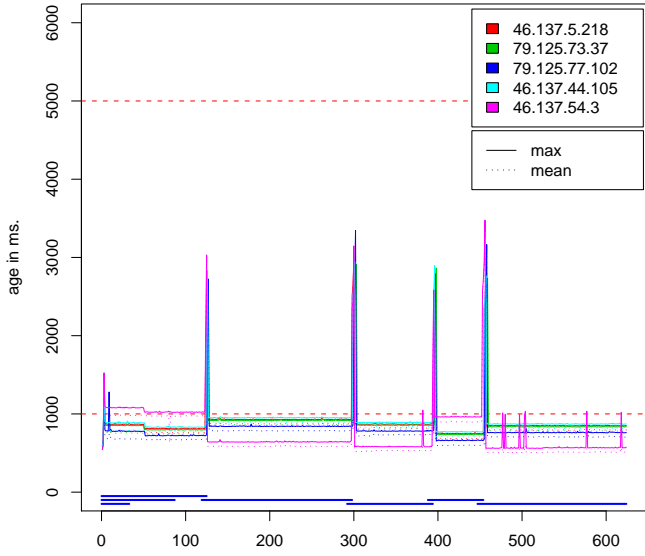
Client Data Age – 2011-06-05 08:55:18



Age in ms. of data on one client – sampling every second

(Test run 76)

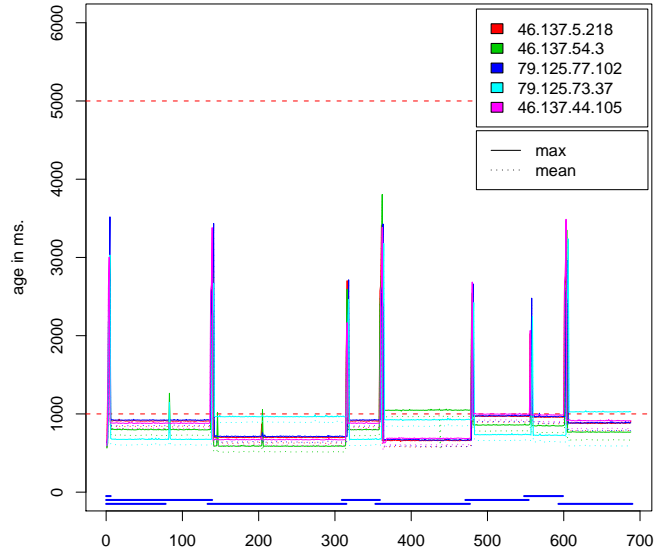
Client Data Age – 2011-06-05 09:06:15



Age in ms. of data on one client – sampling every second

(Test run 77)

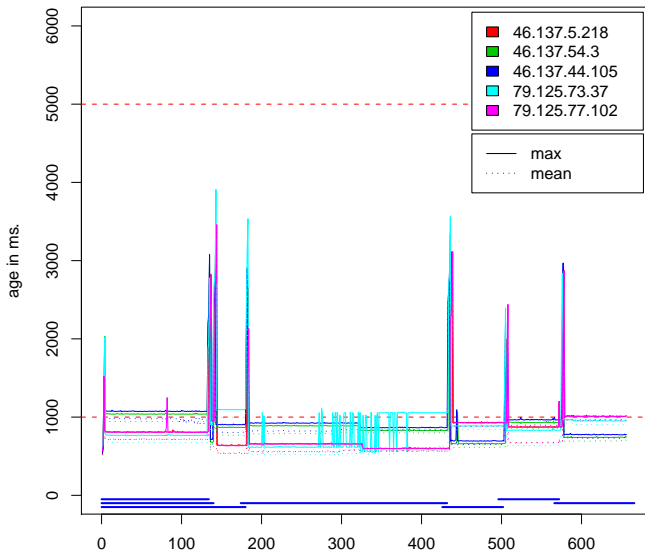
Client Data Age – 2011-06-05 09:18:18



Age in ms. of data on one client – sampling every second

(Test run 78)

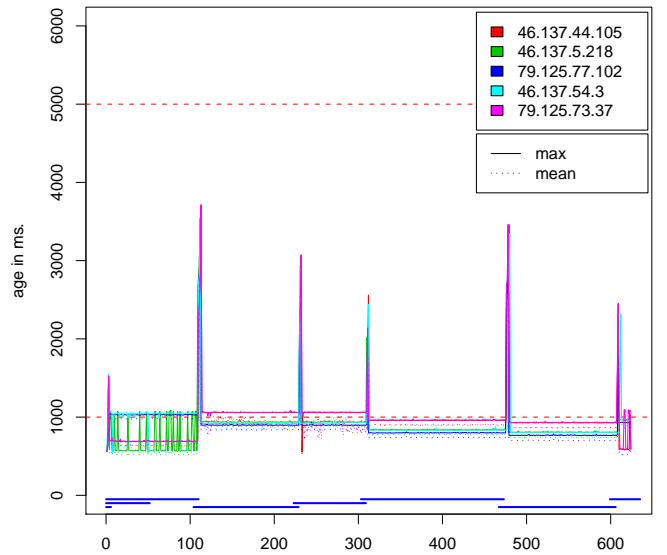
Client Data Age – 2011-06-05 09:29:58



Age in ms. of data on one client – sampling every second

(Test run 79)

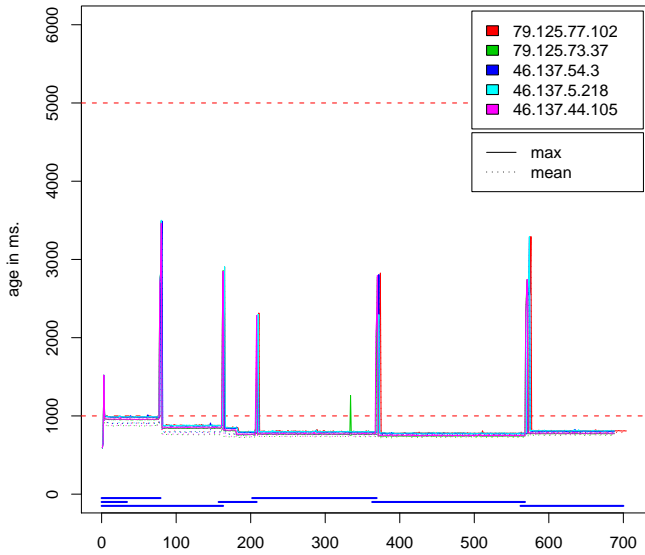
Client Data Age – 2011-06-05 09:41:14



Age in ms. of data on one client – sampling every second

(Test run 80)

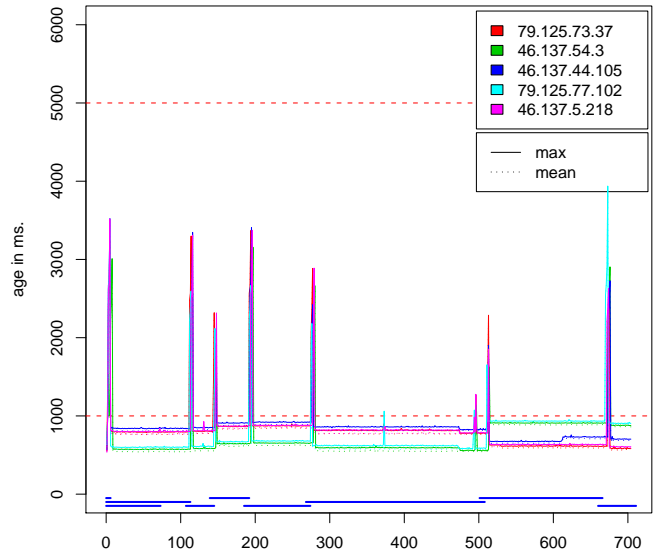
Client Data Age – 2011-06-05 09:53:26



Age in ms. of data on one client – sampling every second

(Test run 81)

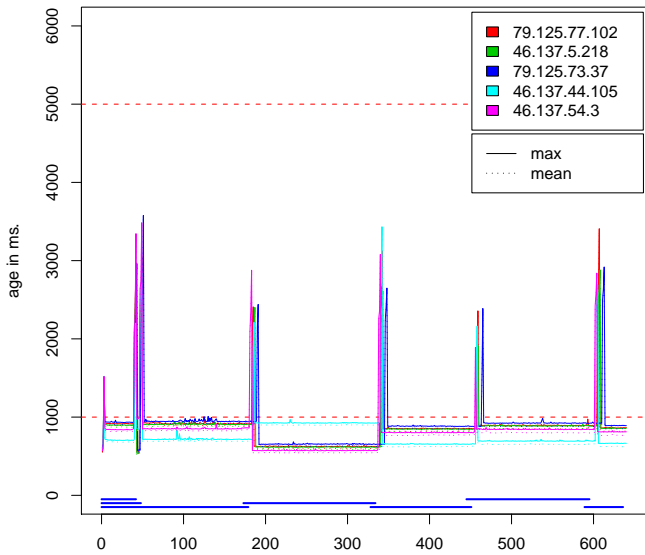
Client Data Age – 2011-06-05 10:05:56



Age in ms. of data on one client – sampling every second

(Test run 82)

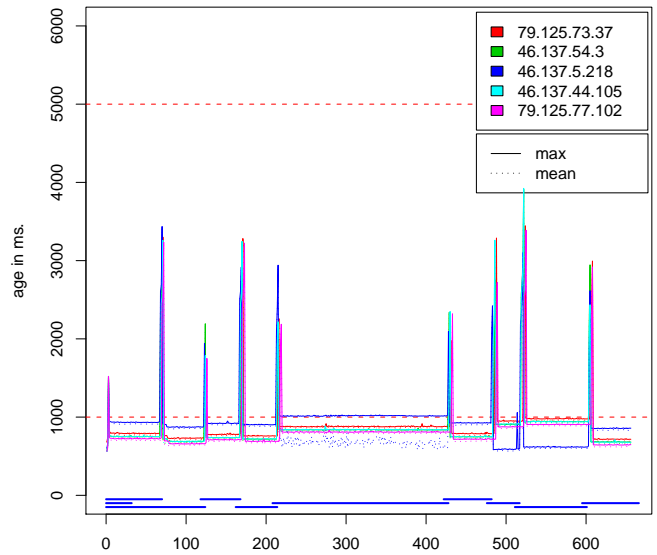
Client Data Age – 2011-06-05 10:17:07



Age in ms. of data on one client – sampling every second

(Test run 83)

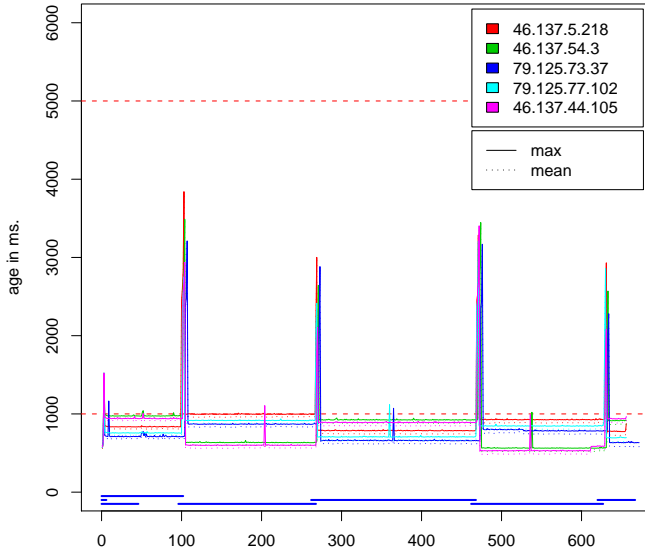
Client Data Age – 2011-06-05 10:28:48



Age in ms. of data on one client – sampling every second

(Test run 84)

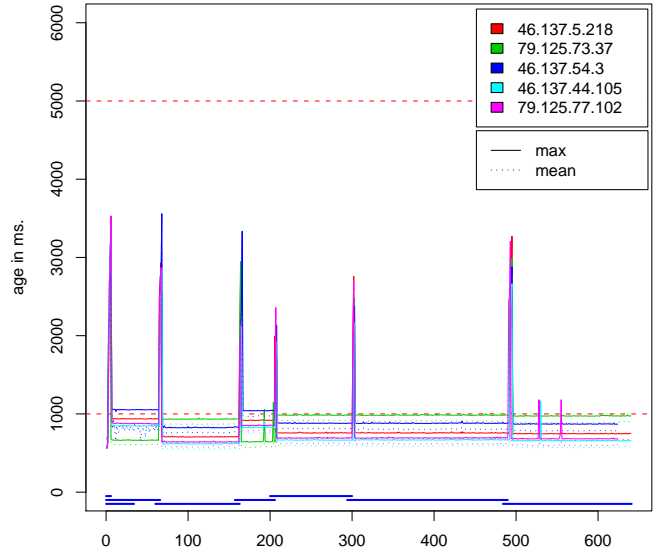
Client Data Age – 2011-06-05 10:40:28



Age in ms. of data on one client – sampling every second

(Test run 85)

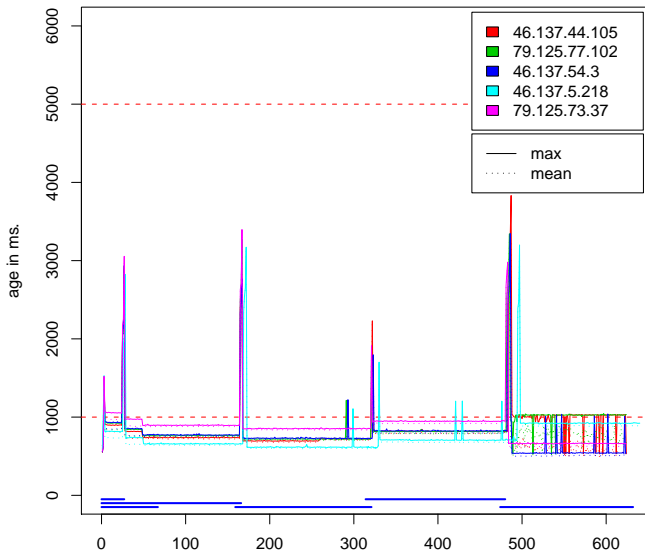
Client Data Age – 2011-06-05 10:51:44



Age in ms. of data on one client – sampling every second

(Test run 86)

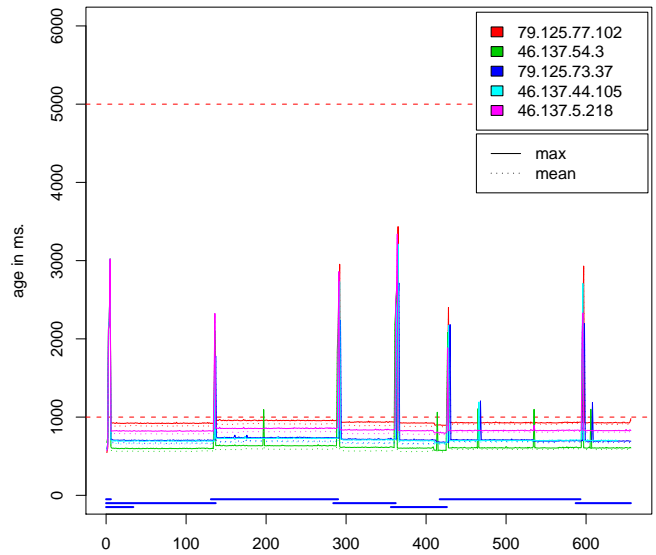
Client Data Age – 2011-06-05 11:02:48



Age in ms. of data on one client – sampling every second

(Test run 87)

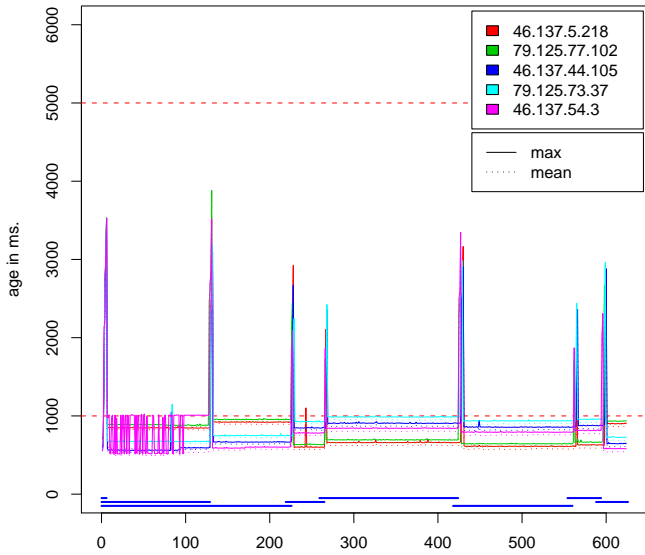
Client Data Age – 2011-06-05 11:14:16



Age in ms. of data on one client – sampling every second

(Test run 88)

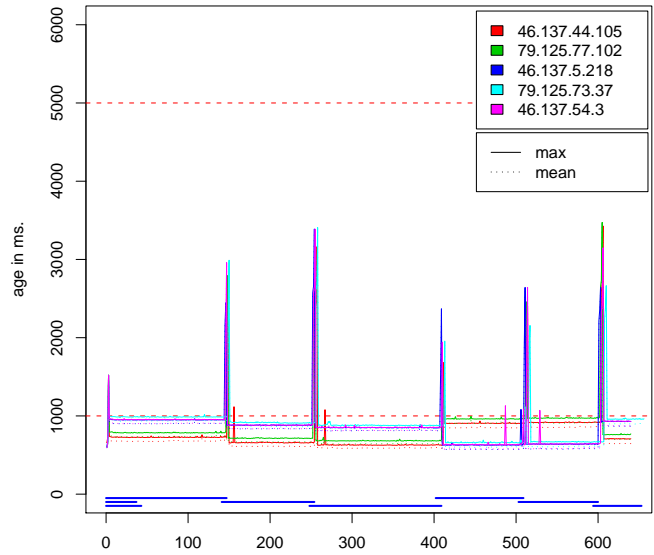
Client Data Age – 2011-06-05 11:25:17



Age in ms. of data on one client – sampling every second

(Test run 89)

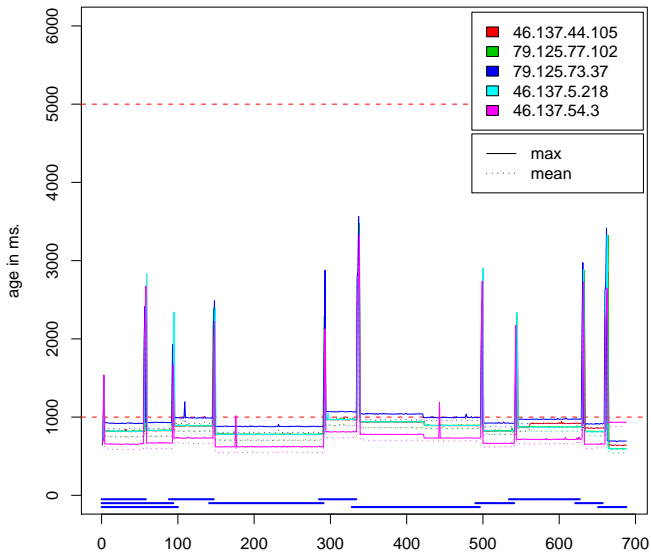
Client Data Age – 2011-06-05 11:36:44



Age in ms. of data on one client – sampling every second

(Test run 90)

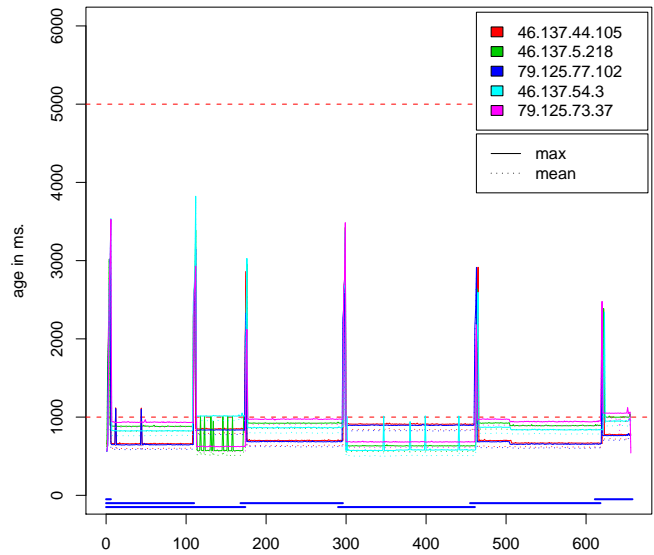
Client Data Age – 2011-06-05 11:48:50



Age in ms. of data on one client – sampling every second

(Test run 91)

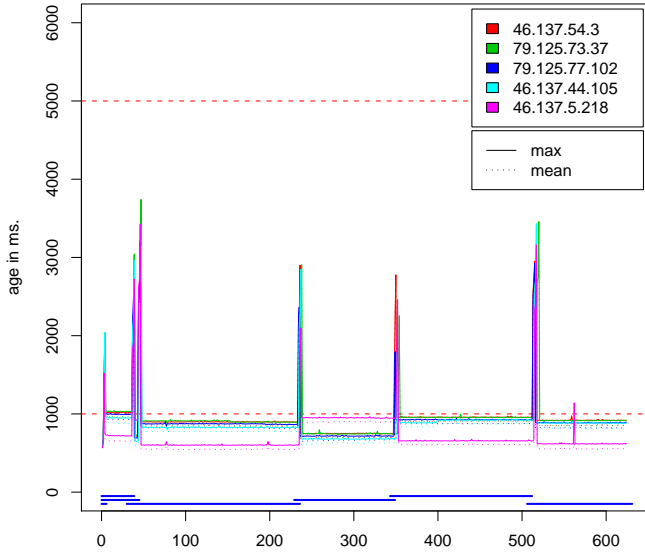
Client Data Age – 2011-06-05 12:00:23



Age in ms. of data on one client – sampling every second

(Test run 92)

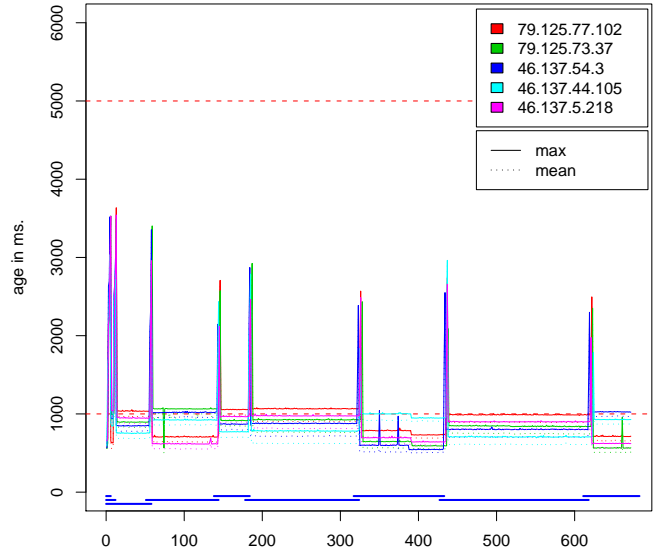
Client Data Age – 2011-06-05 12:11:27



Age in ms. of data on one client – sampling every second

(Test run 93)

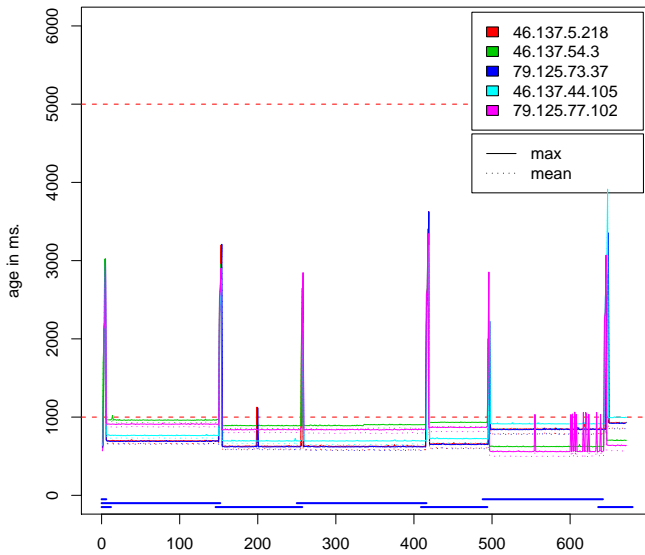
Client Data Age – 2011-06-05 12:23:25



Age in ms. of data on one client – sampling every second

(Test run 94)

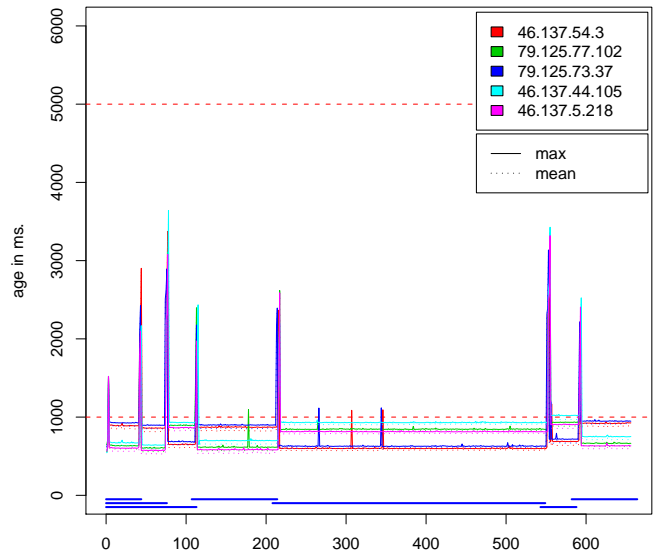
Client Data Age – 2011-06-05 12:35:19



Age in ms. of data on one client – sampling every second

(Test run 95)

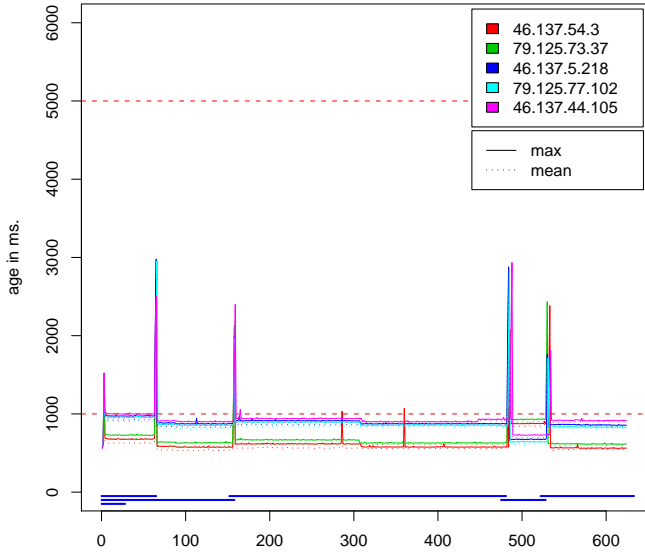
Client Data Age – 2011-06-05 12:46:56



Age in ms. of data on one client – sampling every second

(Test run 96)

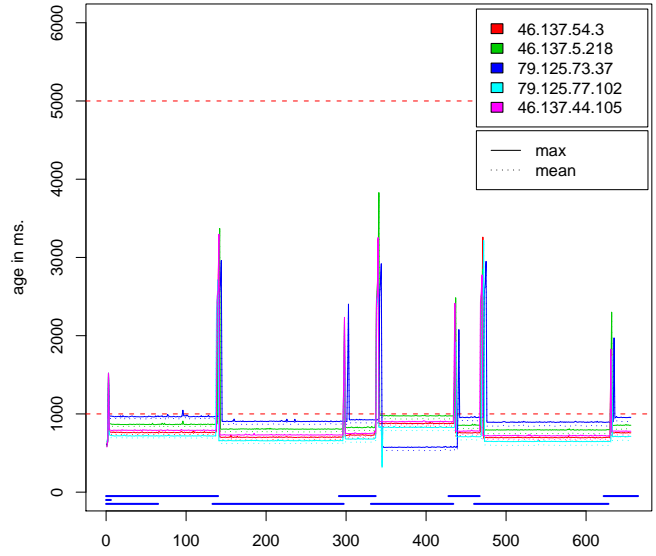
Client Data Age – 2011-06-05 12:58:04



Age in ms. of data on one client – sampling every second

(Test run 97)

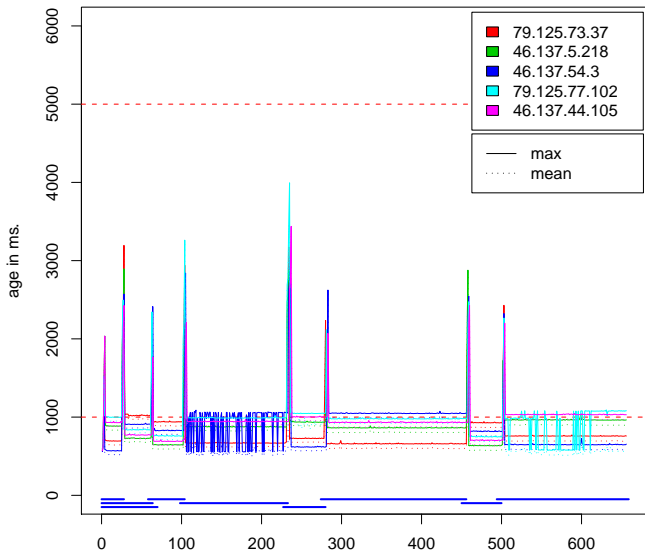
Client Data Age – 2011-06-05 13:09:44



Age in ms. of data on one client – sampling every second

(Test run 98)

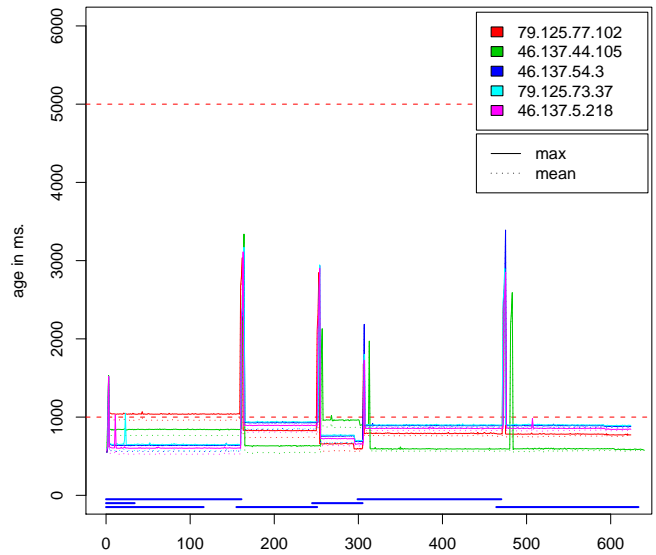
Client Data Age – 2011-06-05 13:21:16



Age in ms. of data on one client – sampling every second

(Test run 99)

Client Data Age – 2011-06-05 13:32:28



Age in ms. of data on one client – sampling every second

(Test run 100)