

Results of the Experimentation of *Magnets* Wireless Backbone

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Abstract— This report provides a comprehensive performance evaluation of the *Magnets* WiFi backbone deployed in a metropolitan area of Berlin. The backbone consists of six 108 Mbps links using directional antennas and spans over 2.3 km. Built with off-the-shelf hardware, it features mixed 802.11a/g technology, link distances between 330 m and 930 m and support for two enhanced MAC/PHY layer modes at the access points (AP) to improve their performance. We assess the influence of distance, 802.11 technology and AP modes on throughput, delay, packet loss and jitter between two adjoining nodes as well as over multiple hops.

I. INTRODUCTION

Wireless broadband technology has recently extended its availability into the realm of access networks. It promises to combine the reliability, robustness, and wide coverage of cellular networks with the high bandwidth known from wired connections, at a fraction of the fiber costs. Therefore, wireless broadband networks have the potential to bring us one step closer towards the vision of ubiquitous high-speed Internet access [1]. Unfortunately, our understanding of the fundamental parameters of wireless access networks, ranging from capacity constraints, scalable deployment and efficient management, up to revenue potential for Telecom Operators is still in its infancy.

The *Magnets* project¹ aims at deploying, analyzing and evaluating metro area heterogeneous wireless network infrastructures in the Berlin urban area. The *Magnets* architecture consists of three basic network parts: (i) a high-speed 802.11-based *wireless backbone* consisting of point to point links; (ii) an 802.11-based wireless access *mesh network*; and (iii) a *heterogeneous access network* that combines multiple wireless technologies, such as GPRS, UMTS, WiFi and WiMax [2]. This report presents a comprehensive performance evaluation of the *Magnets* backbone. The backbone connects 5 buildings in the heart of Berlin via directional antennas, spanning over 2.3 km in length, as depicted in Figure 1. All nodes reside on top of high-rise buildings and have unobstructed line of sight. The distances between the buildings varies between 330 m and 930 m, resulting in a total span of approximately 2.3 km between T-Labs and T-Systems. All transmissions are in the

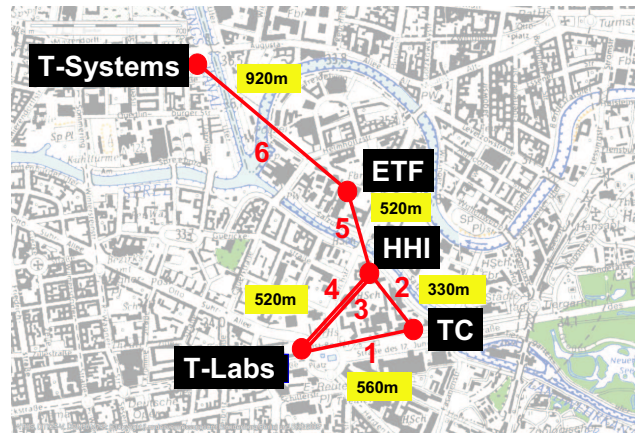


Fig. 1. *Magnets* WiFi backbone in the heart of Berlin.

unlicensed ISM spectrum (2.4 and 5 GHz) and all backbone components (antennas, access points) consist of off-the-shelf hardware supporting both 802.11a and 802.11g modes at 54 Mbps. Tables I, I and III provide further details about the links, the APs and the routers respectively ².

The *Magnets* backbone provides a large parameter space that can be separated into 3 groups, as shown in Table IV: link parameters, topology parameters and traffic parameters. This report provides a comprehensive measurement study of a subset of the parameter space. More measurements will be performed in the future.

Besides the generic setup parameters, the APs provide two low-layer proprietary modes: a *Turbo Mode* and a *Burst Mode*[3]. The *Turbo Mode* doubles the transmission rate by enlarging the channel from 20 MHz to 40 MHz. In the 2.4 GHz, the *Turbo Mode* is centered around channel 6, using a spectrum between 2417 MHz to 2457 MHz. In the 5 GHz range, 3 orthogonal Turbo Mode channels are available in the lower band range band and 2 channels in the upper band range. The *Burst Mode* enables an AP to increase its sending rate. In contrast to “normal” mode where the sender has to wait a certain period equal to the Distributed Inter-Frame Space

¹<http://www.deutsche-telekom-laboratories.de/~networks/magnets.html>

²Also consider deployment pictures at <http://www.deutsche-telekom-laboratories.de/~karrer/magnets.html>

TABLE I
Magnets WiFi SETUP

Link	Link ID	Length (m)	Freq (GHz)	Protocol
T-Systems - ETF	110-108	920	5	802.11a
ETF - HHI	107-105	520	2.4	802.11bg
HHI - TC	86-81	330	2.4	802.11bg
TC - TLABS	78-73	560	5	802.11a
TLABS - HHI 1	89-94	520	2.4	802.11bg
TLABS - HHI 2	97-102	520	2.4	802.11bg

TABLE II
Magnets NODE CONFIGURATION AND HARDWARE DETAILS

AP	AP Location	AP type	Processor	Network Interfaces
1.	TLabs : TC	OAP54	IXP425@533MHz	2x LAN, W-LAN Atheros 5213/5112
2.	TLabs : HHI1	OAP54	IXP425@533MHz	2x LAN, W-LAN Atheros 5213/5112
3.	TLabs : HHI2	OAP54	IXP425@533MHz	2x LAN, W-LAN Atheros 5213/5112
4.	TC : TLABS	OAP54	IXP425@533MHz	2x LAN, W-LAN Atheros 5213/5112
5.	TC : HHI	OAP54	IXP425@533MHz	2x LAN, W-LAN Atheros 5213/5112
6.	HHI : TLABS1	OAP54	IXP425@533MHz	2x LAN, W-LAN Atheros 5213/5112
7.	HHI : TLABS2	OAP54	IXP425@533MHz	2x LAN, W-LAN Atheros 5213/5112
8.	HHI : ETF	OAP54	IXP425@533MHz	2x LAN, W-LAN Atheros 5213/5112
9.	HHI : TC	OAP54	IXP425@533MHz	2x LAN, W-LAN Atheros 5213/5112
10.	ETF : HHI	IAP54	IXP420@266MHz	1x LAN, W-LAN Atheros 5213/5112
11.	ETF : TSystems	IAP54	IXP420@266MHz	1x LAN, W-LAN Atheros 5213/5112
12.	TSystems : ETF	OAP54	IXP425@533MHz	2x LAN, W-LAN Atheros 5213/5112

(DIFS) after receiving an ack until it can send a new packet. In Burst Mode, the sender only waits for the shorter SIFS (Short Inter-Frame Space) period.

We use an active measurement approach to investigate the performance of the *Magnets* backbone evaluating the statistics of four QoS parameters (throughput, jitter, delay, and packet loss). A software platform called D-ITG (Distributed Internet Traffic Generator) [4] generates synthetic traffic between two chosen end points. D-ITG is composed of five blocks: sender (ITGSend), receiver (ITGRecv), log server (ITGLog), manager (ITGManager), and decoder (ITGDec, used to analyze the produced log files in order to extract the QoS parameter statistics).

We have performed a large set of experiments with different traffic profiles. We present the results related to two CBR traffic profiles denominated as *low* and *high* traffic. The *low traffic profile* consists of 1024 bytes packets sent at a frequency of 128 pkt/s, corresponding to an offered bitrate of 1048 Kbps. For the *high traffic profile*, 1024 bytes packets are injected at a rate of 11000 pkt/s, corresponding to an offered bitrate of 90 Mbps. The latter traffic profile provides measurements under saturation.

Traffic was generated for a duration of 120 seconds. This duration has been chosen to correctly evaluate TCP performance out of its transient phase. All packets sent and received are timestamped and logged. The round trip time, jitter and packet loss samples are directly calculated from logs (on a per packet basis) and then averaged over intervals of 50 milliseconds. For bandwidth, the amount of bytes transmitted or received in each interval is summed up at an interval of 50 milliseconds. In order to minimize the effect of random errors, we performed 20 (interleaved) test repetitions and averaged the results. During the measurement stage between May and June 2006, 40 GB of data traces were collected.

TABLE III
Magnets ROUTERS

Processor	IntelP4, 3 GHz
Memory	1 GB
HDD	80 GB
OS	Linux version 2.6.15
Routing	OSPF ³

TABLE IV
Magnets BACKBONE AND TRAFFIC PARAMETER SPACE.

Link	Frequency Channel <i>Turbo Mode</i> <i>Burst mode</i>	2.4 and 5 GHz 3 and 19 orthogonal channels on/off on/off
Topology	src-dst interference hop length	any of the 5 nodes single link / all links 1 – 6 hops
Traffic	Pattern Rate Packet size Protocol	CBR, VBR $\in \{1Mbps, 90Mbps\}$ 1024 Bytes TCP, UDP

II. ACKNOWLEDGMENTS

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TABLE V
73-78 - 128-1024 - CONCISE UDP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.05e+000(4e-005)	7.86e-001(0.4)	1.335e+000(0.3)	9.8e-001(1e-015)	8.12e-002(0.003)	1.64e-001(9e-017)
Jitter [s]	1.16e-004(4e-006)	3.70e-006(2e-006)	9.82e-004(0.0002)	6.35e-005(3e-006)	1.55e-004(4e-006)	4.93e-005(3e-006)
Packet Loss [pkt/s]	4.18e-004(0.004)	0.00e+000(0)	1.00e+000(9)	0.00e+000(0)	2.04e-002(0.2)	0.00e+000(0)
Delay [s]	1.77e-002(0.006)	7.63e-003(0.002)	2.21e-002(0.008)	1.81e-002(0.007)	3.51e-003(0.003)	3.85e-003(0.003)

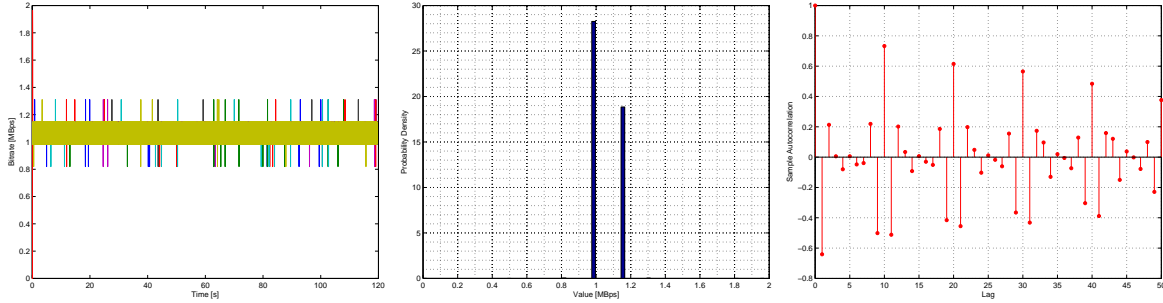


Fig. 2. 73-78 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP bitrate

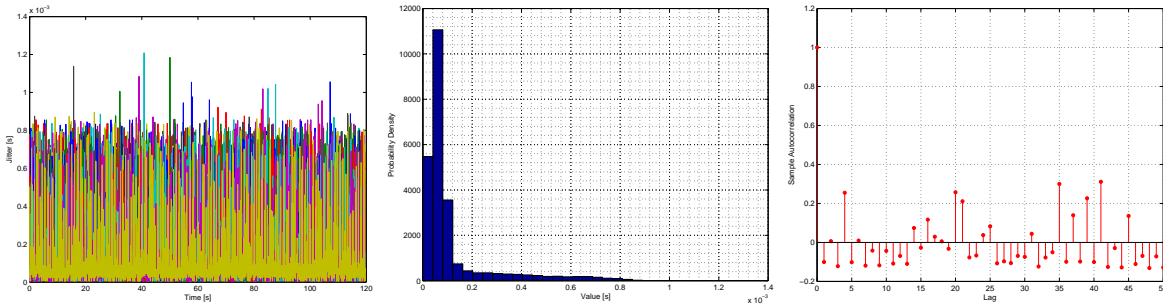


Fig. 3. 73-78 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP jitter

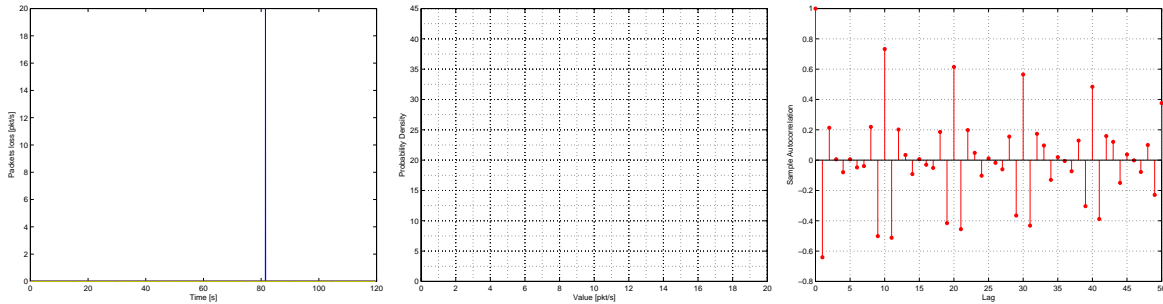


Fig. 4. 73-78 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP packet loss

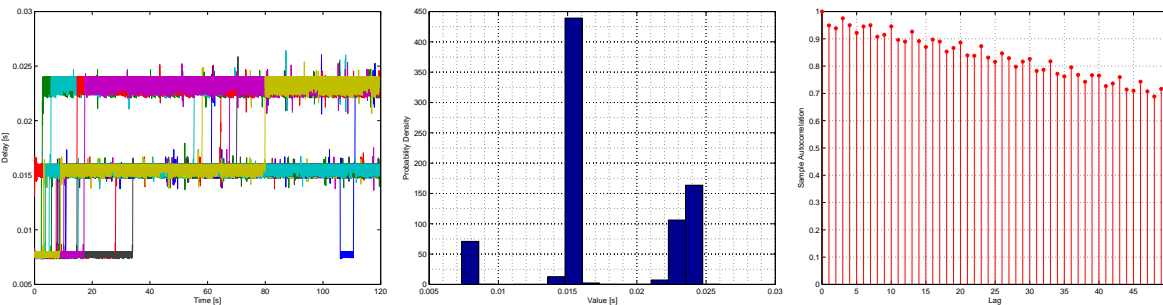


Fig. 5. 73-78 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP delay

TABLE VI
73-78 - 128-1024 - CONCISE TCP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.05e+000(5e-005)	7.45e-001(0.2)	1.34e+000(0.1)	9.83e-001(1e-015)	1.46e-001(0.02)	1.64e-001(9e-017)
Jitter [s]	3.96e-003(1e-005)	1.62e-005(3e-005)	6.65e-003(0.0009)	4.06e-003(1e-005)	8.98e-004(3e-005)	1.41e-003(1e-005)
Delay [s]	1.81e-002(0.007)	7.41e-003(0.0007)	2.40e-002(0.01)	1.85e-002(0.009)	3.85e-003(0.004)	3.08e-003(0.003)

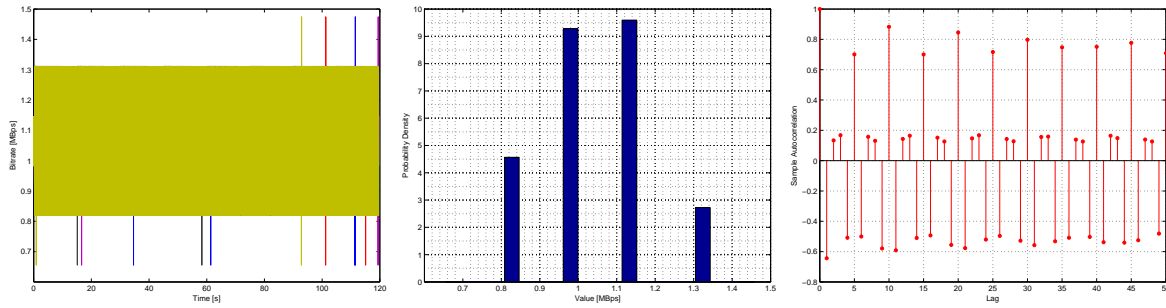


Fig. 6. 73-78 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP bitrate

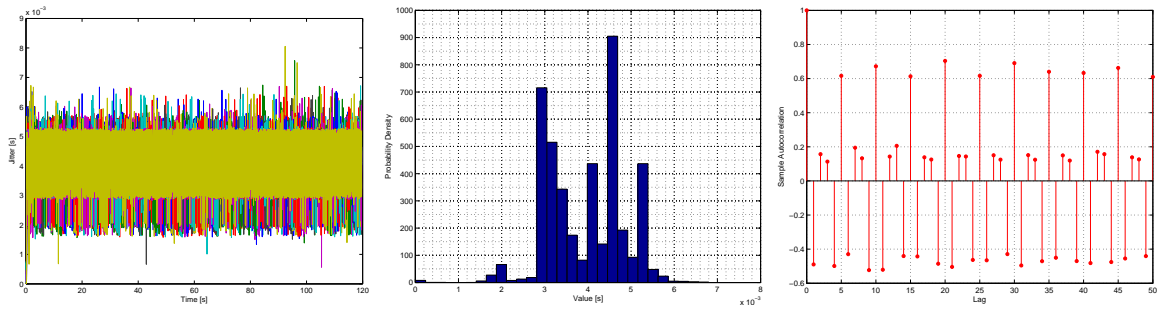


Fig. 7. 73-78 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP jitter

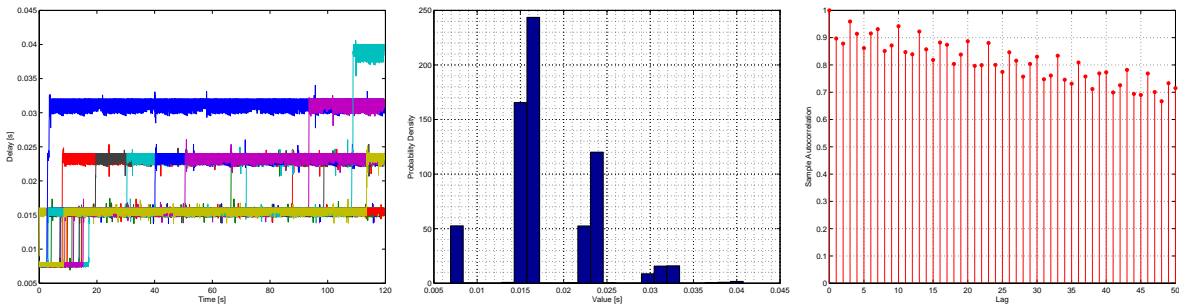


Fig. 8. 73-78 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP delay

TABLE VII

73-78 - 11000-1024 - CONCISE UDP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	2.78e+001(0.9)	0.00e+000(0)	2.962e+001(1)	2.8e+001(0.3)	2.14e+000(2)	1.25e+000(0.08)
Jitter [s]	1.34e-004(3e-005)	0.00e+000(0)	7.00e-003(0.01)	7.82e-005(2e-006)	2.21e-004(0.0002)	4.60e-005(4e-005)
Packet Loss [pkt/s]	7.61e+003(1e+002)	0.00e+000(0)	7.21e+004(5e+005)	7.62e+003(1e+001)	1.84e+003(1e+004)	2.30e+002(5e+001)
Delay [s]	2.92e-002(0.001)	0.00e+000(0)	1.43e-001(0.02)	2.92e-002(0.002)	2.10e-002(0.005)	2.76e-002(0.01)

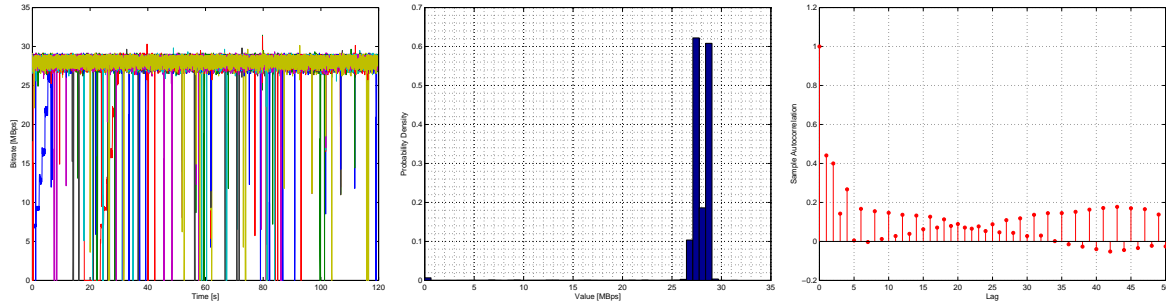


Fig. 9. 73-78 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP bitrate

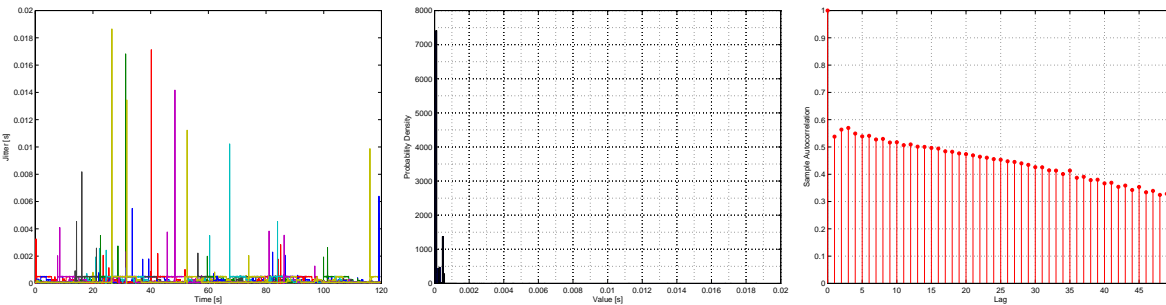


Fig. 10. 73-78 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP jitter

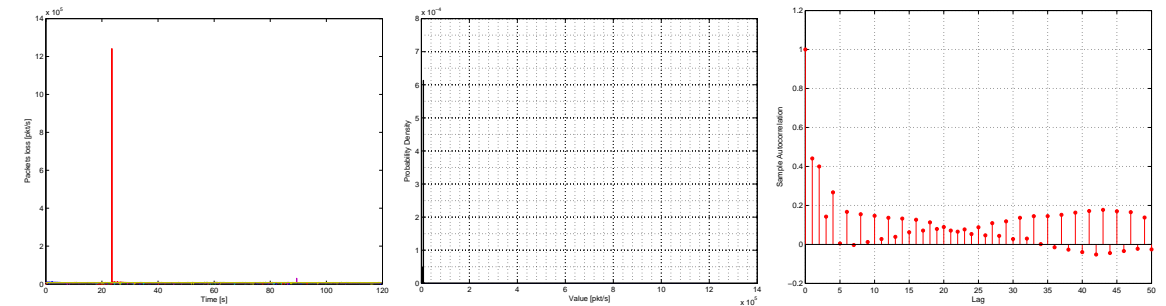


Fig. 11. 73-78 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP packet loss

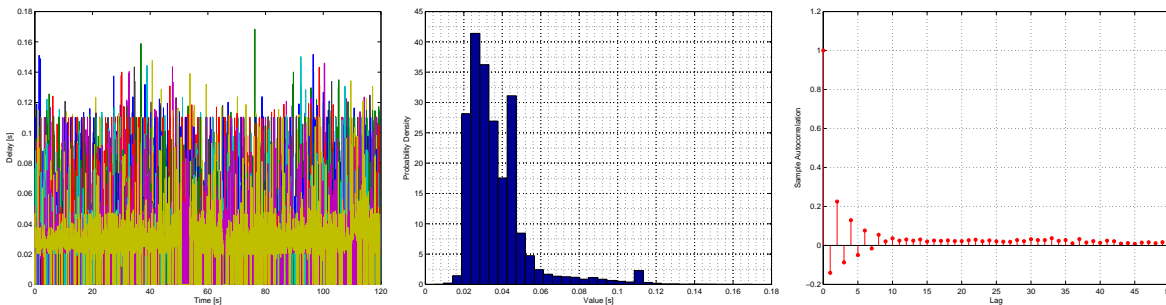


Fig. 12. 73-78 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP delay

TABLE VIII
73-78 - 11000-1024 - CONCISE TCP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	2.58e+001(1)	1.79e+001(1e+001)	3.00e+001(4)	2.60e+001(0.2)	1.56e+000(3)	1.90e+000(0.3)
Jitter [s]	6.52e-004(0.0003)	3.89e-004(0.0003)	2.55e-002(0.2)	6.07e-004(1e-005)	6.30e-004(0.005)	1.14e-004(6e-006)
Delay [s]	3.49e-001(0.06)	0.00e+000(0)	1.15e+000(0.9)	3.66e-001(0.09)	1.90e-001(0.09)	1.91e-001(0.05)

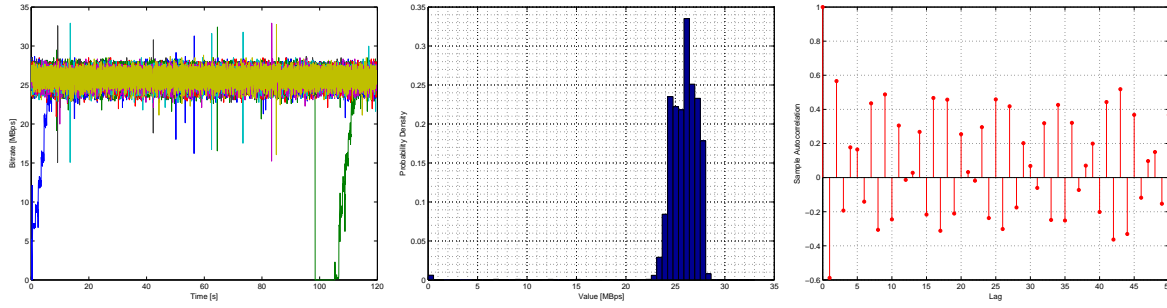


Fig. 13. 73-78 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP bitrate

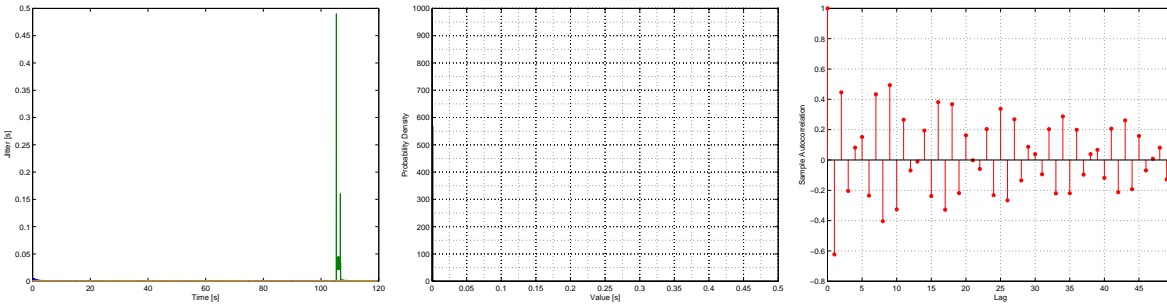


Fig. 14. 73-78 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP jitter

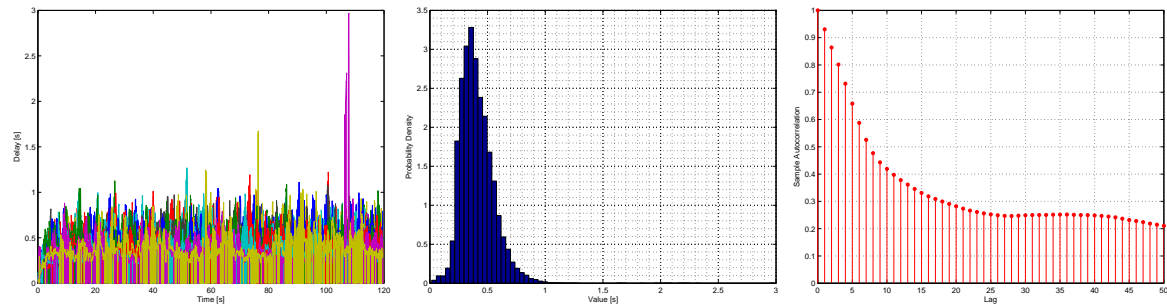


Fig. 15. 73-78 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP delay

TABLE IX
89-94 - 128-1024 - CONCISE UDP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.05e+000(0.0004)	7.05e-001(0.5)	1.556e+000(2)	9.8e-001(1e-015)	8.67e-002(0.03)	1.64e-001(9e-017)
Jitter [s]	6.30e-004(0.0003)	1.46e-005(1e-005)	6.90e-003(0.02)	5.04e-004(0.0001)	5.81e-004(0.0008)	5.54e-004(8e-005)
Packet Loss [pkt/s]	5.43e-003(0.05)	0.00e+000(0)	6.00e+000(5e+001)	0.00e+000(0)	1.60e-001(1)	0.00e+000(0)
Delay [s]	2.18e-002(0.01)	7.97e-003(0.003)	2.74e-002(0.01)	2.27e-002(0.01)	3.39e-003(0.004)	3.62e-003(0.004)

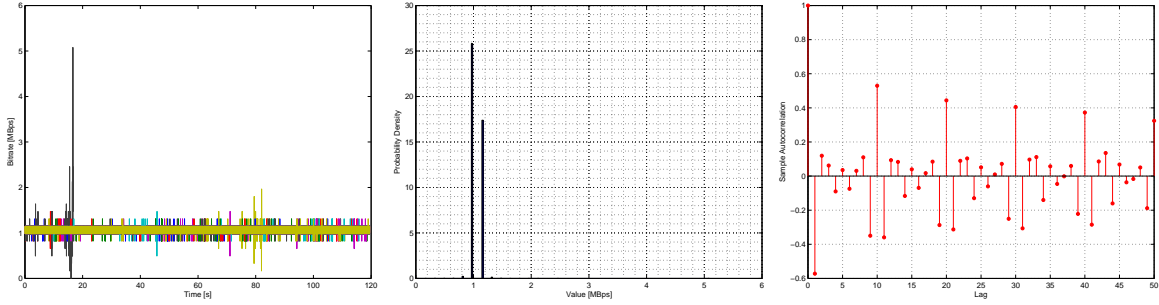


Fig. 16. 89-94 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP bitrate

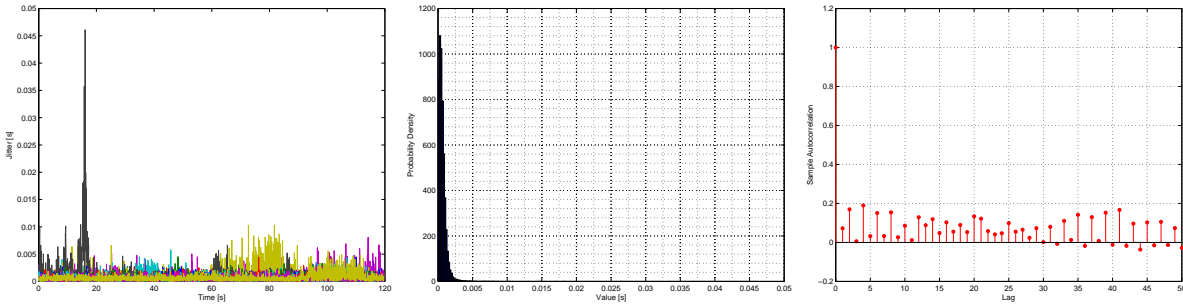


Fig. 17. 89-94 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP jitter

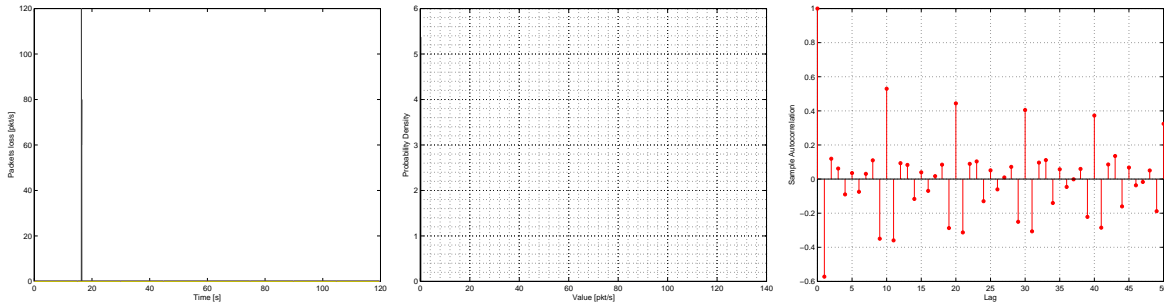


Fig. 18. 89-94 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP packet loss

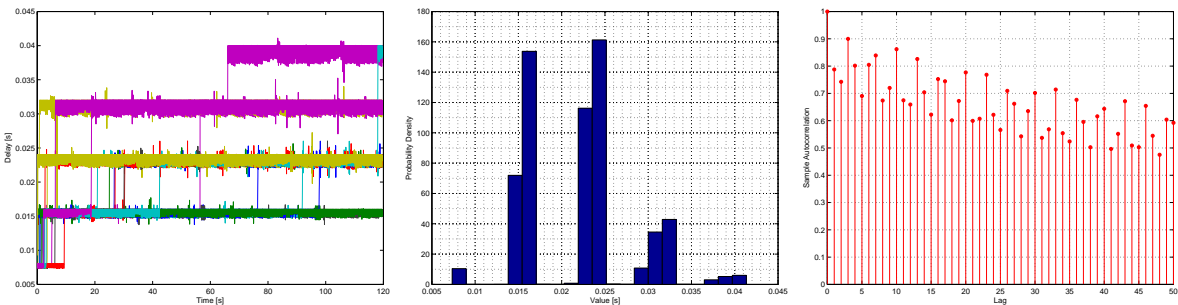


Fig. 19. 89-94 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP delay

TABLE X
 89-94 - 128-1024 - CONCISE TCP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.05e+000(4e-005)	6.88e-001(0.2)	1.38e+000(0.2)	9.83e-001(1e-015)	1.45e-001(0.009)	1.64e-001(9e-017)
Jitter [s]	4.11e-003(5e-005)	2.60e-004(0.0005)	7.96e-003(0.002)	4.12e-003(5e-005)	9.11e-004(3e-005)	1.39e-003(2e-005)
Delay [s]	2.87e-002(0.01)	7.65e-003(0.002)	4.09e-002(0.02)	2.80e-002(0.02)	8.39e-003(0.008)	1.29e-002(0.01)

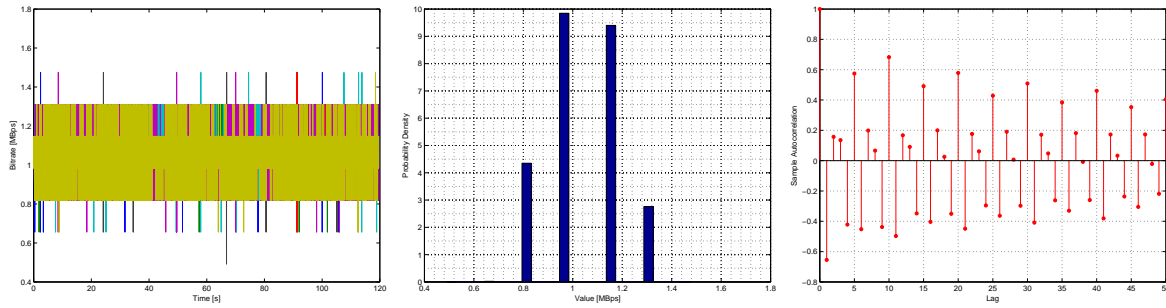


Fig. 20. 89-94 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP bitrate

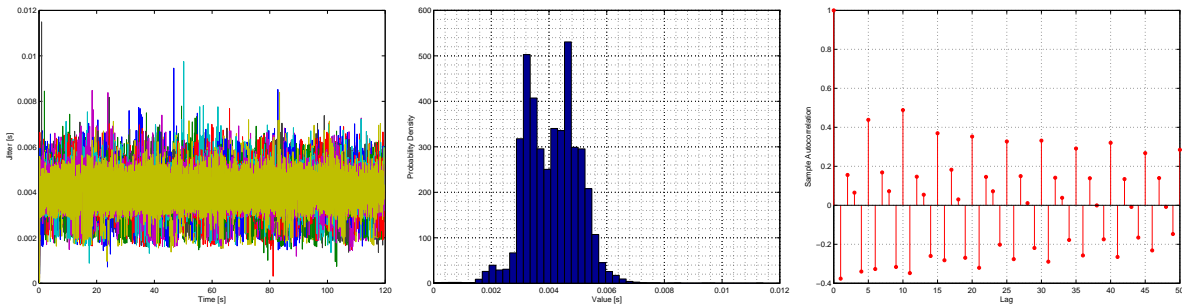


Fig. 21. 89-94 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP jitter

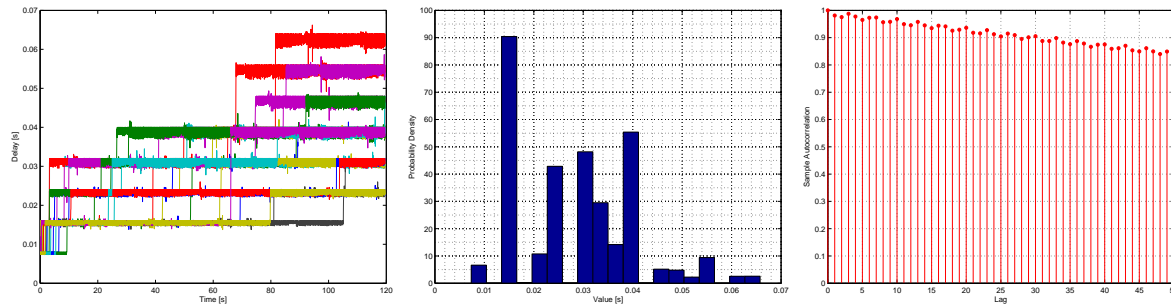


Fig. 22. 89-94 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP delay

TABLE XI

89-94 - 11000-1024 - CONCISE UDP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.65e+001(3)	1.97e-001(2)	2.302e+001(1)	1.7e+001(3)	2.73e+000(0.6)	3.38e+000(0.4)
Jitter [s]	4.41e-004(0.0002)	1.48e-005(9e-005)	3.51e-003(0.003)	3.84e-004(0.0002)	2.31e-004(0.0001)	1.98e-004(7e-005)
Packet Loss [pkt/s]	8.99e+003(4e+002)	0.00e+000(0)	1.67e+004(5e+003)	8.92e+003(3e+002)	1.05e+003(4e+002)	1.05e+003(3e+002)
Delay [s]	3.29e-002(0.01)	0.00e+000(0)	1.17e-001(0.07)	3.16e-002(0.01)	1.38e-002(0.006)	1.63e-002(0.005)

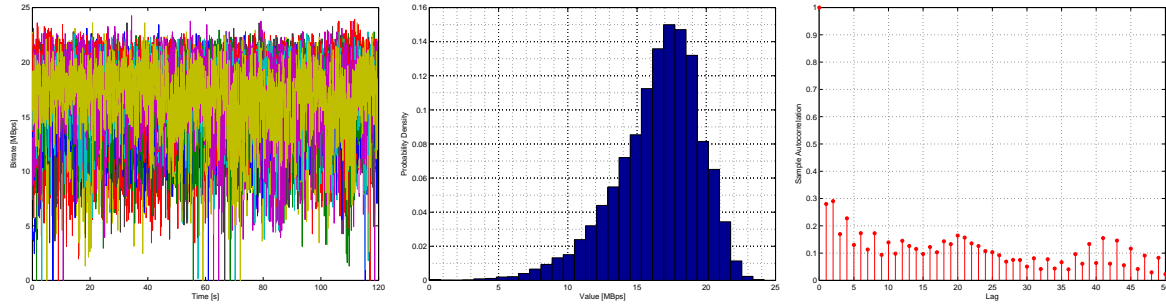


Fig. 23. 89-94 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP bitrate

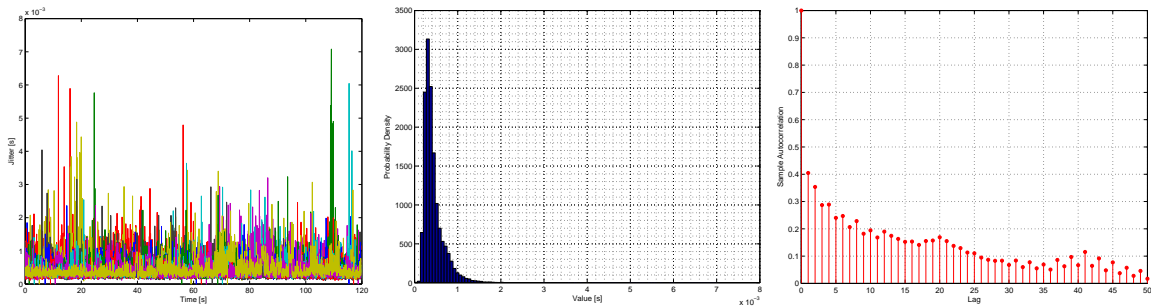


Fig. 24. 89-94 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP jitter

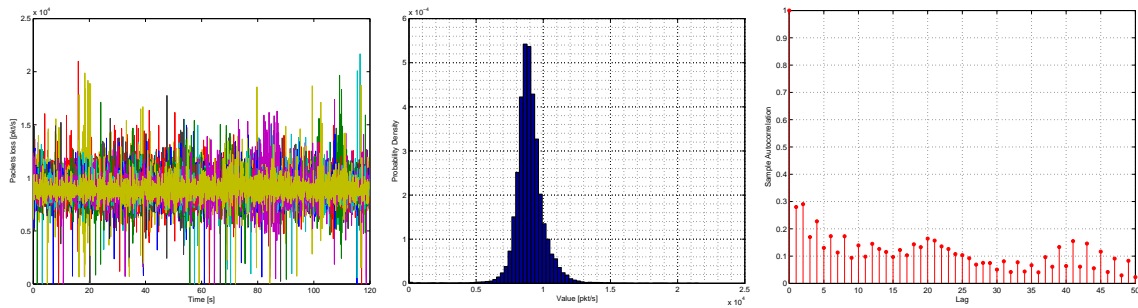


Fig. 25. 89-94 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP packet loss

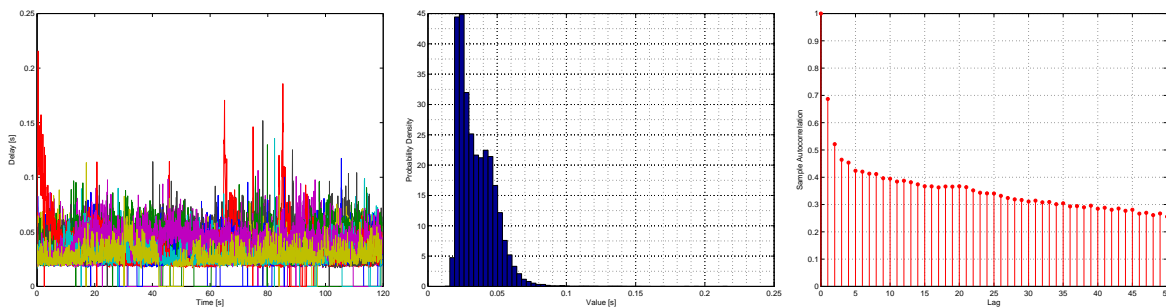


Fig. 26. 89-94 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP delay

TABLE XII
 89-94 - 11000-1024 - CONCISE TCP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.51e+001(1)	1.68e+000(2)	2.66e+001(4)	1.53e+001(1)	2.71e+000(0.4)	3.17e+000(0.3)
Jitter [s]	1.09e-003(0.0001)	3.43e-004(0.0004)	4.85e-003(0.006)	1.06e-003(9e-005)	3.11e-004(0.0002)	3.10e-004(4e-005)
Delay [s]	2.43e-001(0.03)	0.00e+000(0)	5.76e-001(0.2)	2.91e-001(0.03)	1.30e-001(0.02)	1.08e-001(0.06)

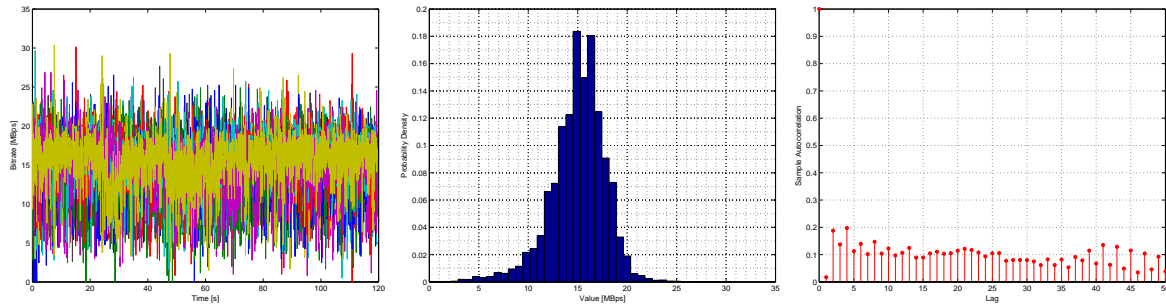


Fig. 27. 89-94 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP bitrate

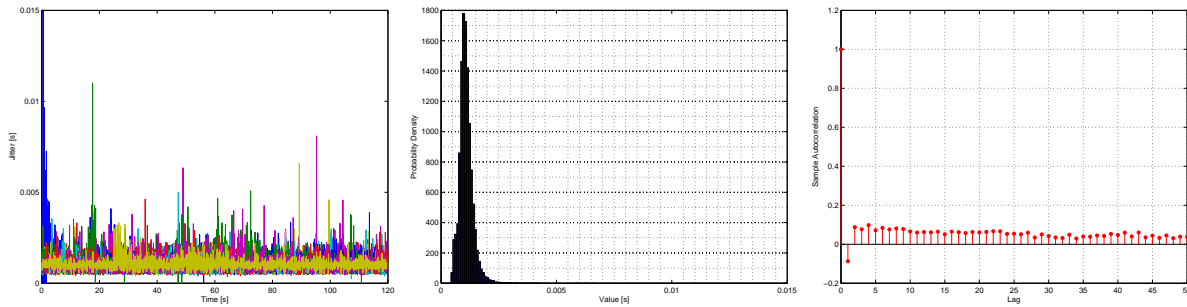


Fig. 28. 89-94 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP jitter

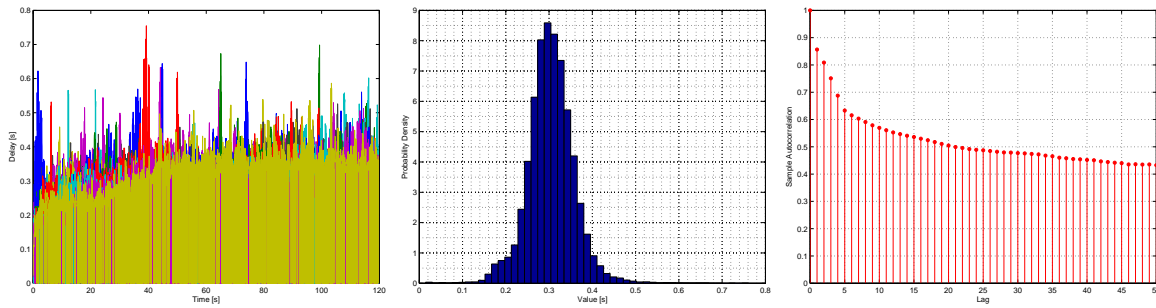


Fig. 29. 89-94 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP delay

TABLE XIII

97-102 - 128-1024 - CONCISE UDP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.05e+000(7e-005)	7.78e-001(0.2)	1.352e+000(0.2)	9.8e-001(1e-015)	8.44e-002(0.004)	1.64e-001(9e-017)
Jitter [s]	5.95e-004(0.0003)	1.30e-005(5e-006)	4.58e-003(0.003)	3.90e-004(0.0003)	6.24e-004(0.0003)	6.95e-004(0.0002)
Packet Loss [pkt/s]	0.00e+000(0)	0.00e+000(0)	0.00e+000(0)	0.00e+000(0)	0.00e+000(0)	0.00e+000(0)
Delay [s]	1.88e-002(0.006)	7.60e-003(0.002)	2.33e-002(0.008)	1.90e-002(0.007)	2.59e-003(0.003)	3.36e-003(0.003)

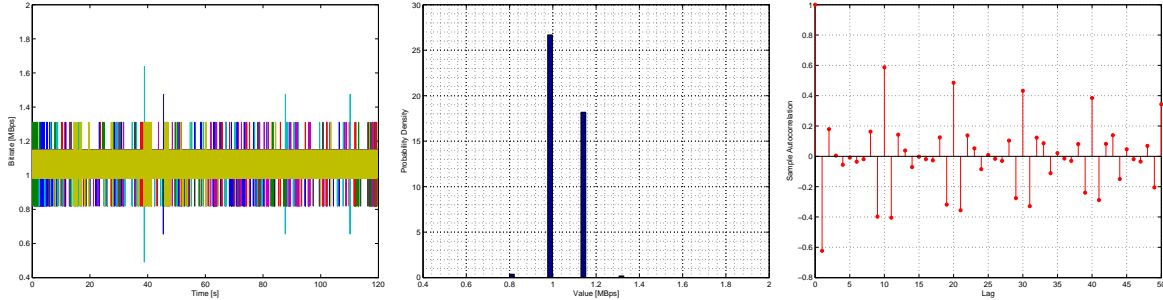


Fig. 30. 97-102 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP bitrate

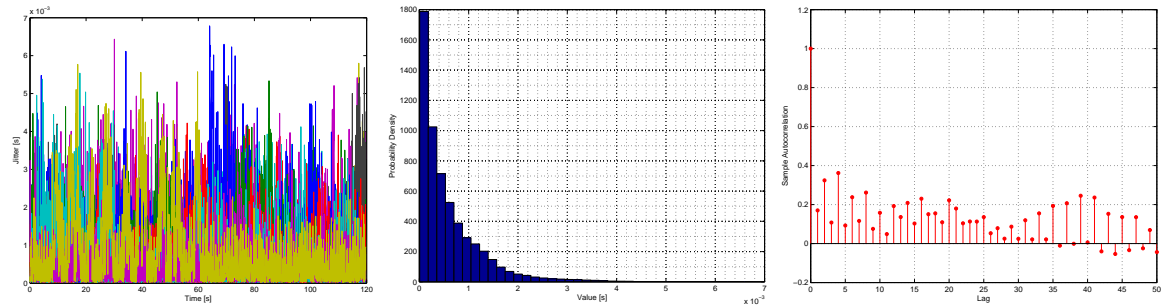


Fig. 31. 97-102 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP jitter

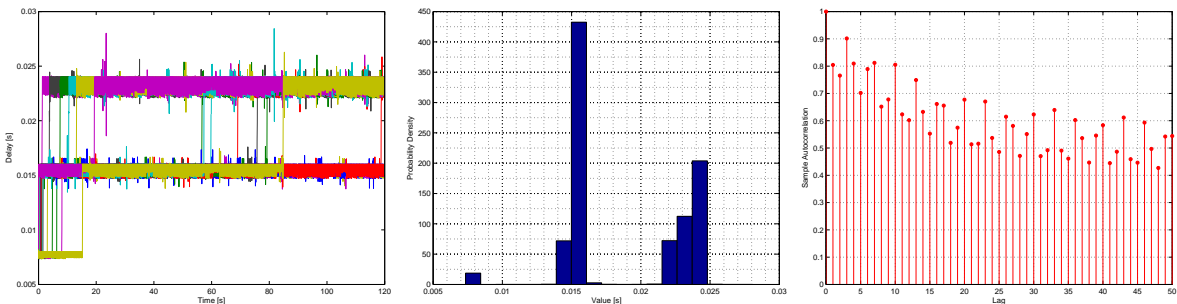


Fig. 32. 97-102 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP delay

TABLE XIV
 97-102 - 128-1024 - CONCISE TCP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.05e+000(5e-005)	6.47e-001(0.2)	1.43e+000(0.2)	9.83e-001(1e-015)	1.46e-001(0.006)	1.64e-001(9e-017)
Jitter [s]	4.17e-003(0.0002)	1.34e-004(0.0004)	7.93e-003(0.001)	4.17e-003(0.0002)	9.54e-004(0.0001)	1.44e-003(7e-005)
Delay [s]	2.32e-002(0.02)	7.52e-003(0.0005)	2.97e-002(0.02)	2.53e-002(0.02)	5.04e-003(0.009)	6.41e-003(0.01)

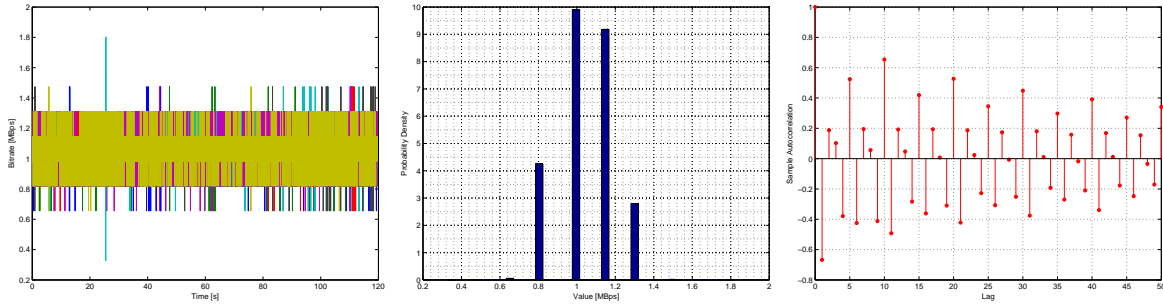


Fig. 33. 97-102 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP bitrate

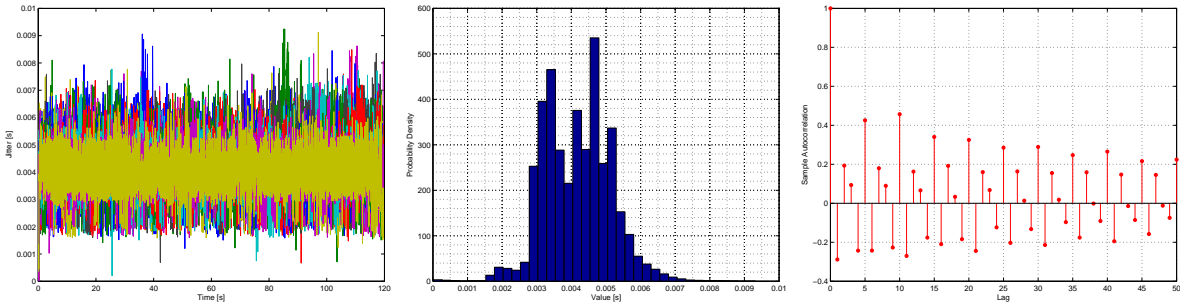


Fig. 34. 97-102 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP jitter

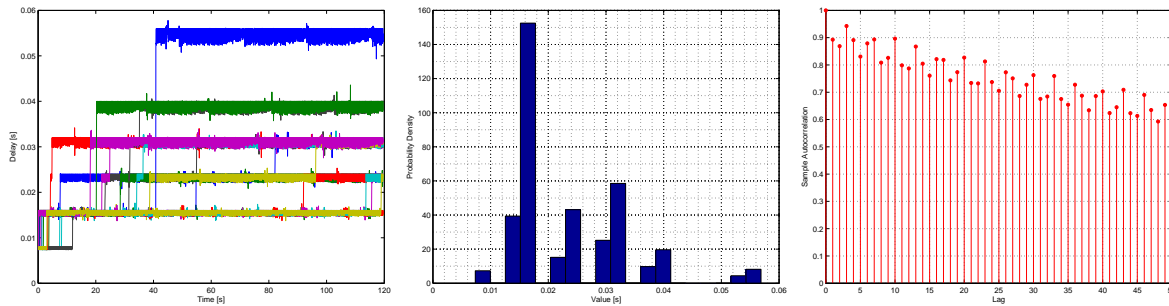


Fig. 35. 97-102 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP delay

TABLE XV
 97-102 - 11000-1024 - CONCISE UDP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.87e+001(2)	0.00e+000(0)	2.375e+001(1)	1.9e+001(2)	2.58e+000(2)	2.27e+000(0.5)
Jitter [s]	3.03e-004(9e-005)	0.00e+000(0)	2.29e-003(0.003)	2.64e-004(6e-005)	1.58e-004(0.0001)	9.32e-005(3e-005)
Packet Loss [pkt/s]	8.72e+003(2e+002)	0.00e+000(0)	1.62e+004(1e+004)	8.68e+003(2e+002)	7.09e+002(2e+002)	6.47e+002(8e+001)
Delay [s]	5.17e-002(0.02)	0.00e+000(0)	1.66e-001(0.08)	5.02e-002(0.02)	2.25e-002(0.01)	2.29e-002(0.007)

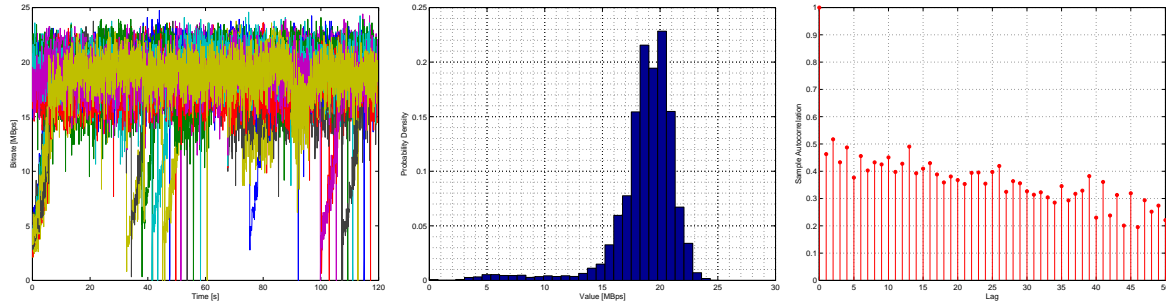


Fig. 36. 97-102 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP bitrate

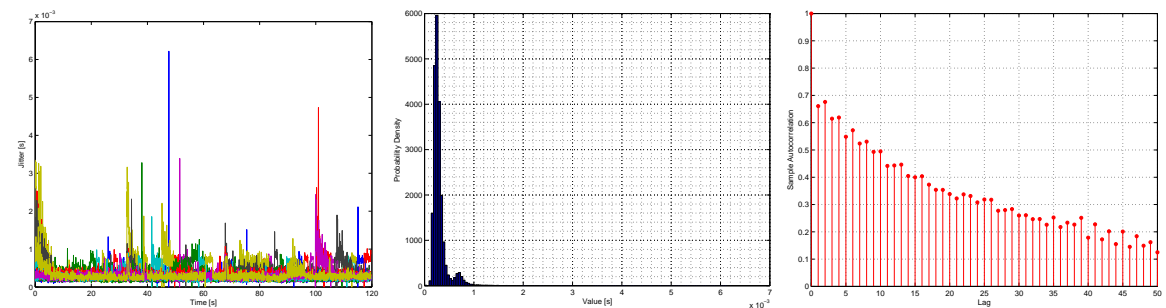


Fig. 37. 97-102 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP jitter

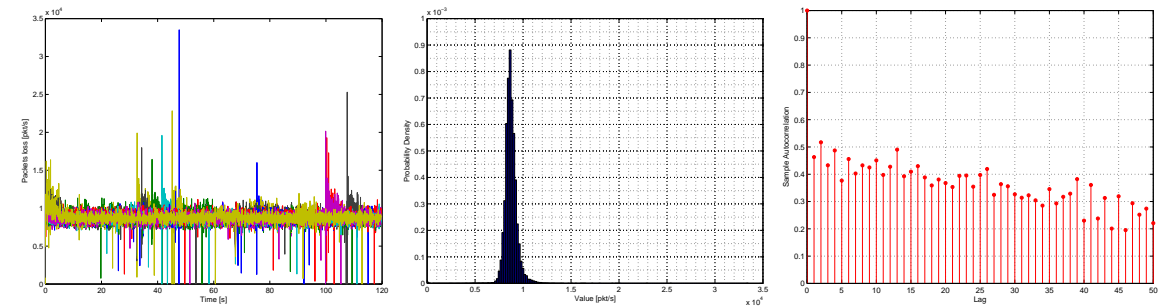


Fig. 38. 97-102 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP packet loss

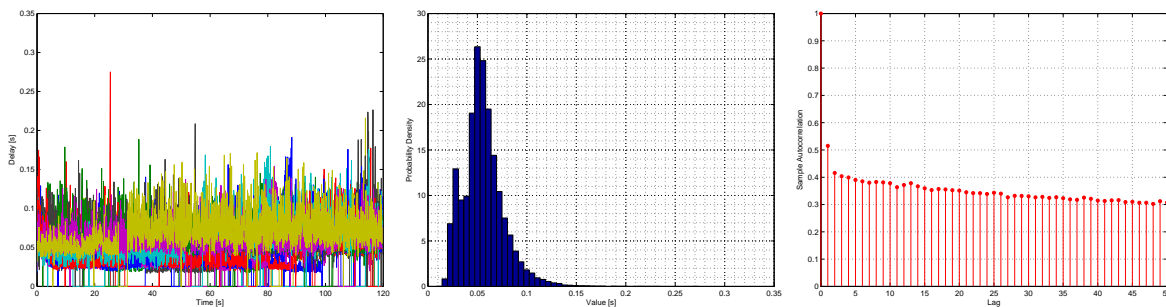


Fig. 39. 97-102 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP delay

TABLE XVI
 97-102 - 11000-1024 - CONCISE TCP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.47e+001(3)	0.00e+000(0)	3.11e+001(5)	1.51e+001(3)	3.45e+000(0.7)	2.84e+000(0.5)
Jitter [s]	1.29e-003(0.0004)	0.00e+000(0)	1.34e-001(0.4)	1.07e-003(0.0002)	3.47e-003(0.009)	3.39e-004(0.0002)
Delay [s]	2.57e-001(0.04)	2.01e-001(0.09)	3.73e-001(0.2)	1.61e+000(2)	0.00e+000(0)	3.37e-001(0.04)

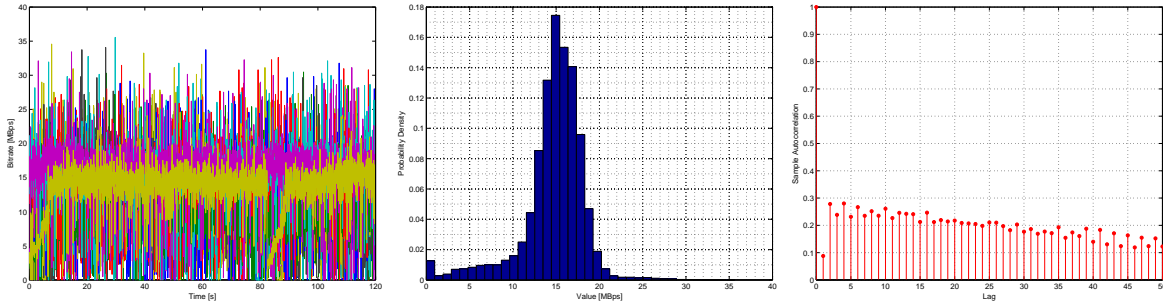


Fig. 40. 97-102 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP bitrate

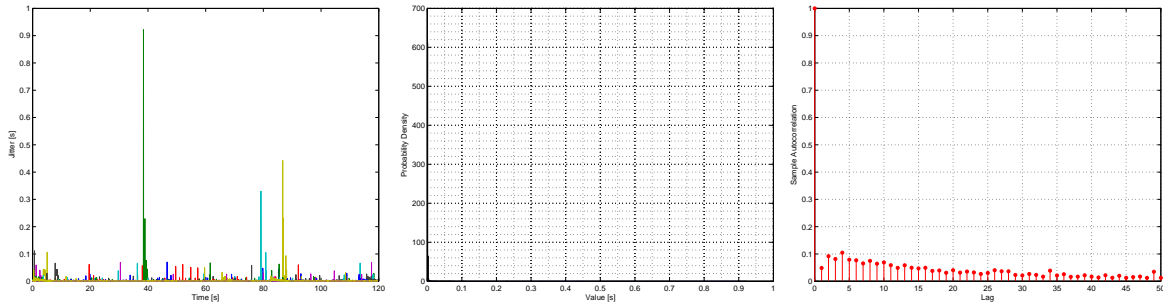


Fig. 41. 97-102 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP jitter

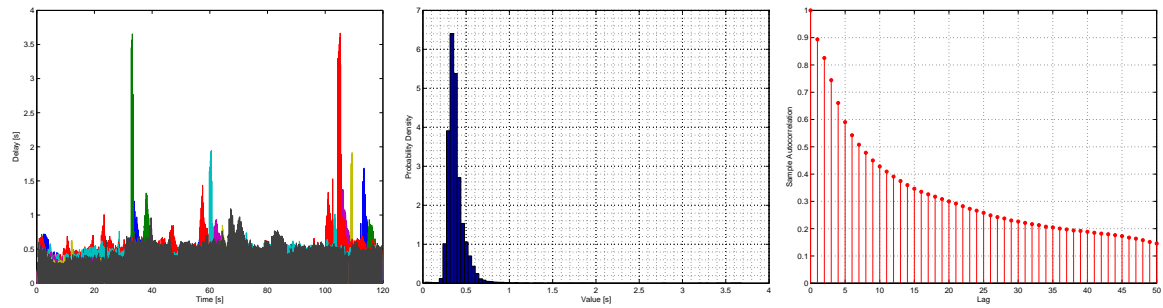


Fig. 42. 97-102 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP delay

TABLE XVII
 86-81 - 128-1024 - CONCISE UDP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.05e+000(0.0001)	5.57e-001(0.2)	1.556e+000(0.2)	9.8e-001(1e-015)	1.04e-001(0.01)	1.64e-001(9e-017)
Jitter [s]	7.77e-004(0.0003)	4.85e-006(7e-007)	7.51e-003(0.001)	3.39e-004(0.0001)	1.32e-003(0.0003)	5.00e-004(0.0002)
Packet Loss [pkt/s]	0.00e+000(0)	0.00e+000(0)	0.00e+000(0)	0.00e+000(0)	0.00e+000(0)	0.00e+000(0)
Delay [s]	3.00e-002(0.004)	9.03e-003(0.008)	3.43e-002(0.005)	3.13e-002(0.005)	3.92e-003(0.004)	3.69e-003(0.004)

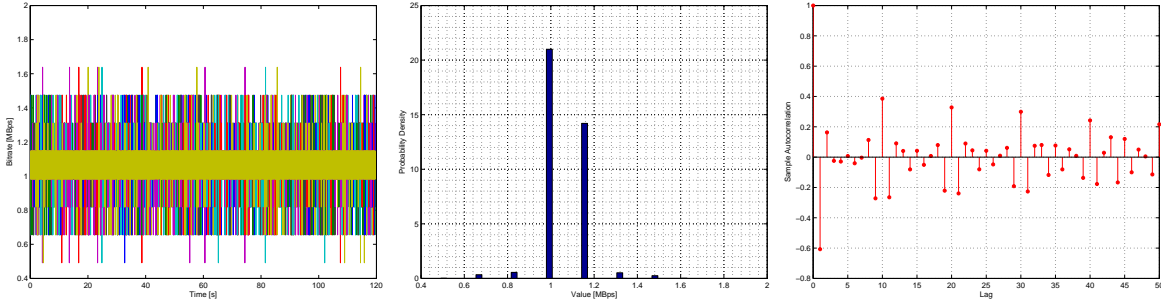


Fig. 43. 86-81 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP bitrate

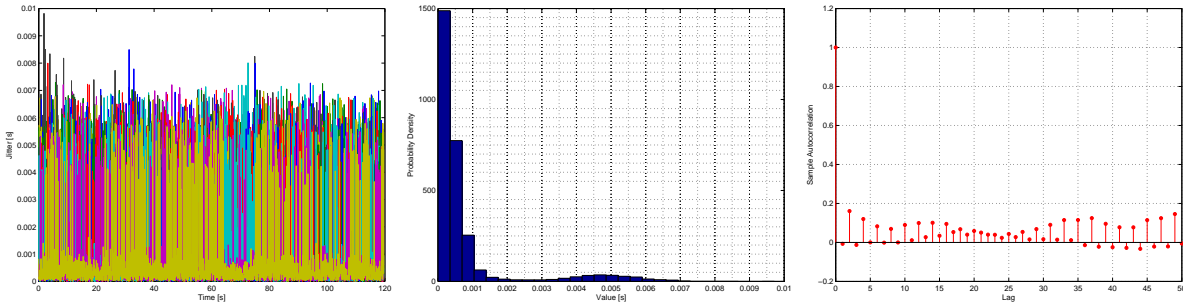


Fig. 44. 86-81 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP jitter

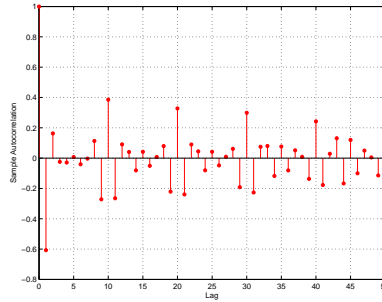


Fig. 45. 86-81 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP packet loss

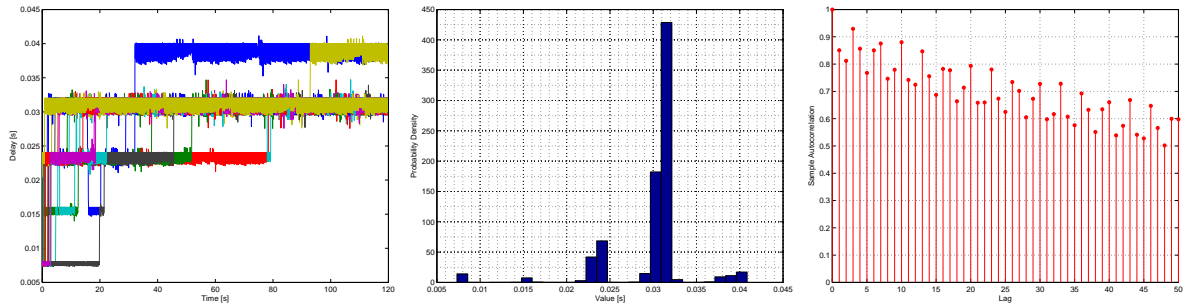


Fig. 46. 86-81 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP delay

TABLE XVIII
 86-81 - 128-1024 - CONCISE TCP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.05e+000(6e-005)	5.49e-001(0.2)	1.63e+000(0.1)	9.83e-001(1e-015)	1.56e-001(0.008)	1.64e-001(9e-017)
Jitter [s]	4.24e-003(0.0001)	1.15e-004(0.0001)	9.66e-003(0.0008)	4.18e-003(0.0001)	1.16e-003(0.0001)	1.56e-003(7e-005)
Delay [s]	4.19e-002(0.01)	7.74e-003(0.003)	4.65e-002(0.01)	4.34e-002(0.02)	4.97e-003(0.004)	3.11e-003(0.002)

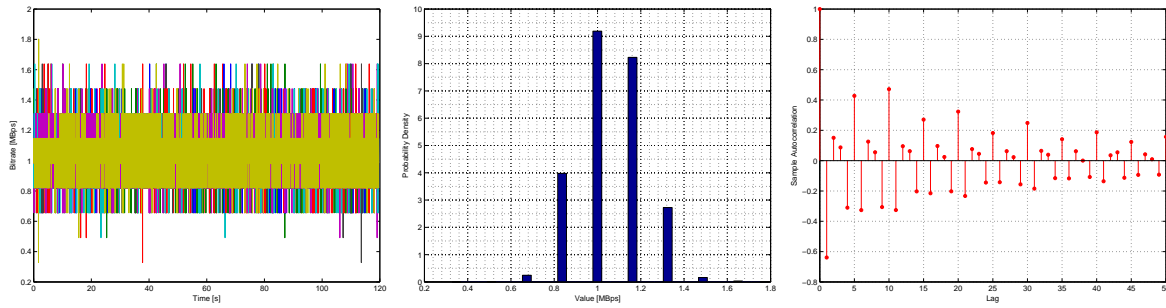


Fig. 47. 86-81 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP bitrate

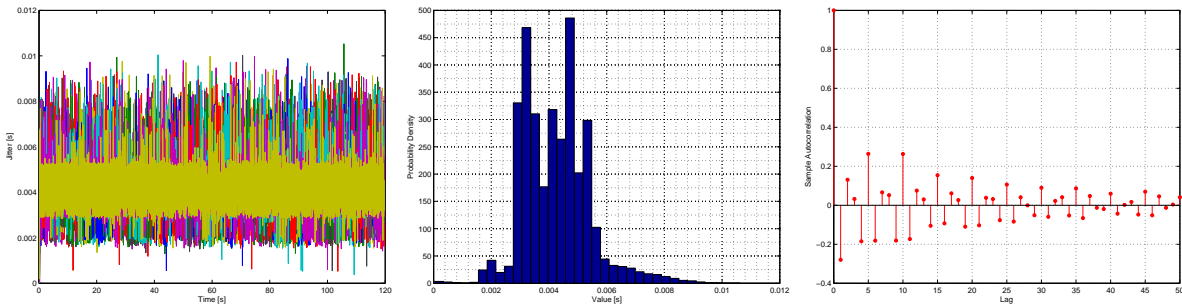


Fig. 48. 86-81 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP jitter

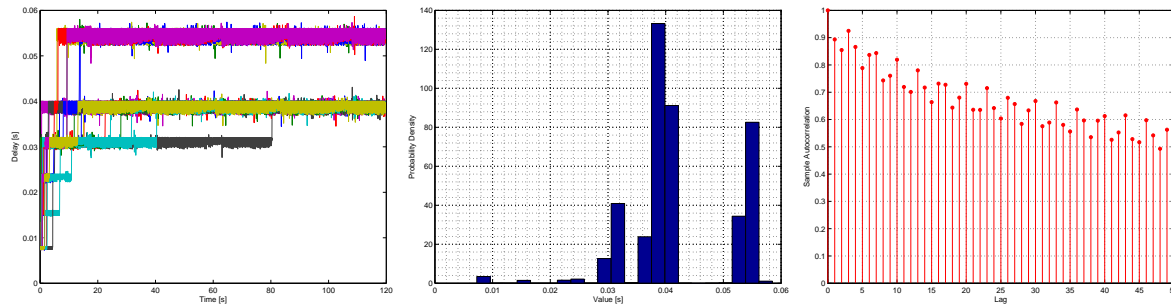


Fig. 49. 86-81 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP delay

TABLE XIX

86-81 - 11000-1024 - CONCISE UDP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.59e+001(4)	2.92e+000(6)	2.417e+001(2)	1.6e+001(4)	3.62e+000(1)	5.25e+000(0.7)
Jitter [s]	5.22e-004(0.0004)	1.11e-004(9e-005)	8.89e-003(0.02)	4.21e-004(0.0002)	4.45e-004(0.0008)	2.82e-004(0.0001)
Packet Loss [pkt/s]	9.06e+003(5e+002)	9.63e+002(2e+003)	2.15e+004(2e+004)	8.93e+003(4e+002)	1.28e+003(1e+003)	1.19e+003(4e+002)
Delay [s]	2.10e-002(0.003)	2.52e-003(0.01)	9.37e-002(0.1)	2.09e-002(0.001)	8.26e-003(0.007)	3.73e-003(0.0007)

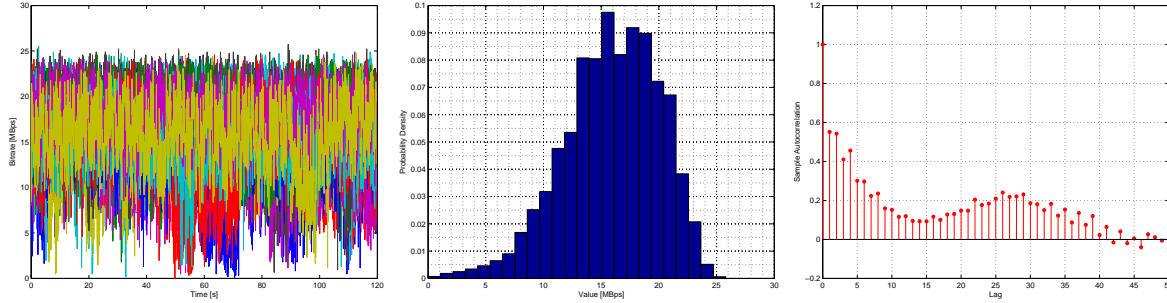


Fig. 50. 86-81 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP bitrate

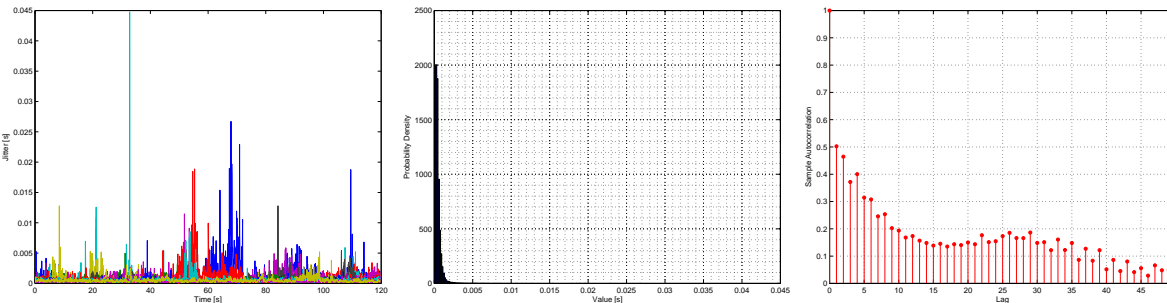


Fig. 51. 86-81 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP jitter

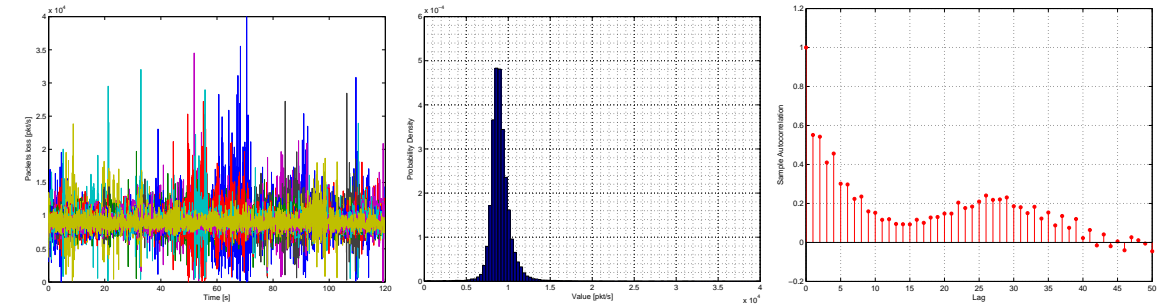


Fig. 52. 86-81 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP packet loss

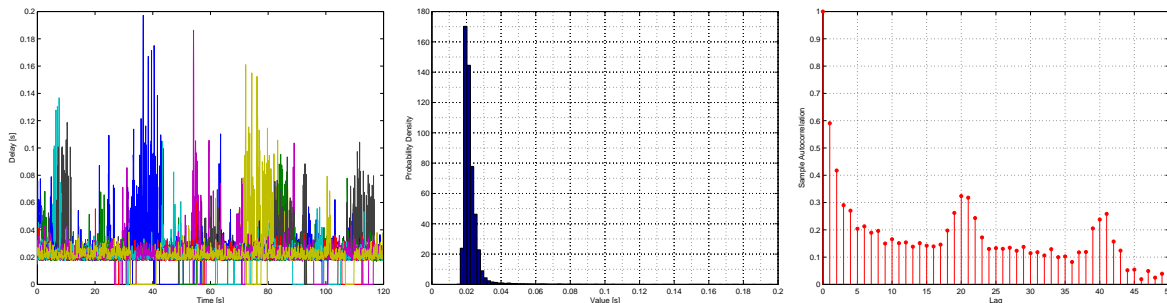


Fig. 53. 86-81 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP delay

TABLE XX

86-81 - 11000-1024 - CONCISE TCP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.66e+001(2)	5.41e+000(5)	2.41e+001(2)	1.70e+001(2)	3.08e+000(0.7)	4.56e+000(0.3)
Jitter [s]	9.86e-004(0.0002)	5.75e-004(0.0003)	5.83e-003(0.02)	9.27e-004(0.0001)	3.05e-004(0.0006)	2.57e-004(5e-005)
Delay [s]	2.05e-001(0.1)	5.81e-003(0.02)	6.60e-001(2)	2.07e-001(0.1)	7.11e-002(0.1)	6.20e-002(0.04)

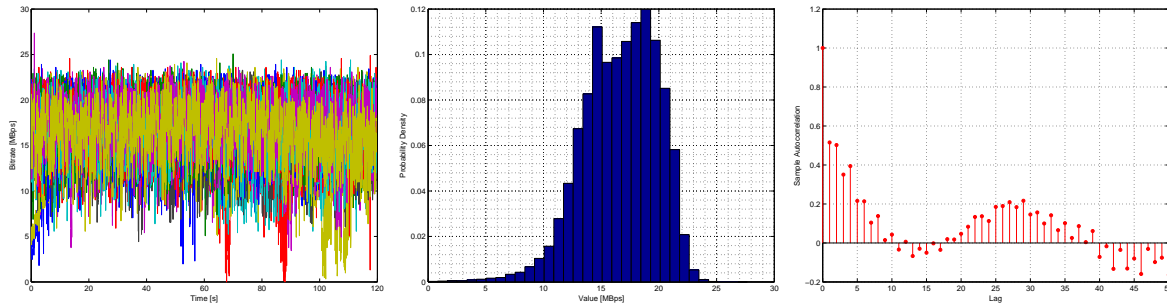


Fig. 54. 86-81 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP bitrate

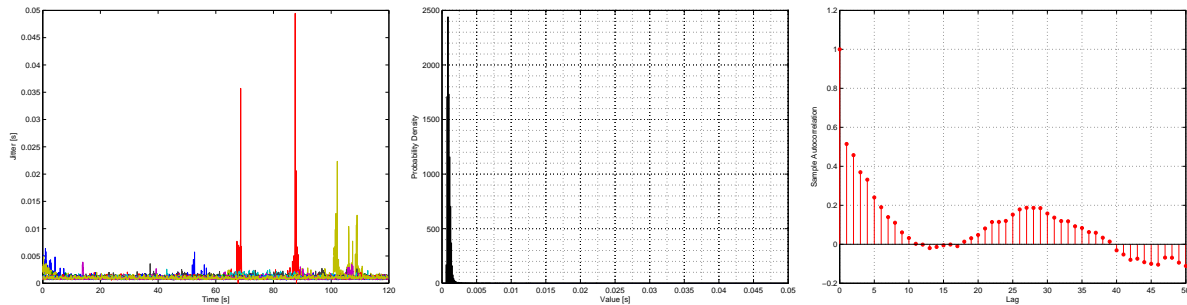


Fig. 55. 86-81 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP jitter

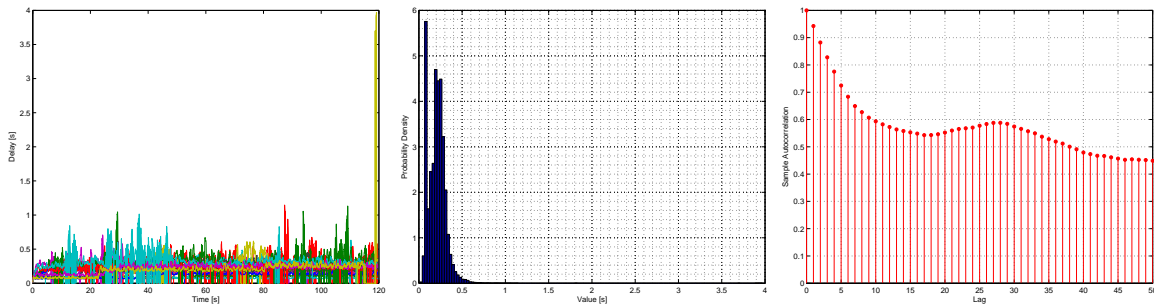


Fig. 56. 86-81 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP delay

TABLE XXI

86-81-73 - 128-1024 - CONCISE UDP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.05e+000(6e-005)	8.27e-001(0.07)	1.286e+000(0.1)	9.8e-001(1e-015)	8.21e-002(0.004)	1.64e-001(9e-017)
Jitter [s]	5.73e-004(0.0004)	2.04e-005(1e-005)	4.12e-003(0.002)	4.58e-004(0.0003)	4.73e-004(0.0004)	5.25e-004(0.0002)
Packet Loss [pkt/s]	4.18e-004(0.004)	0.00e+000(0)	1.00e+000(9)	0.00e+000(0)	2.04e-002(0.2)	0.00e+000(0)
Delay [s]	1.81e-002(0.007)	7.65e-003(0.005)	2.41e-002(0.02)	1.77e-002(0.006)	3.34e-003(0.007)	3.74e-003(0.006)

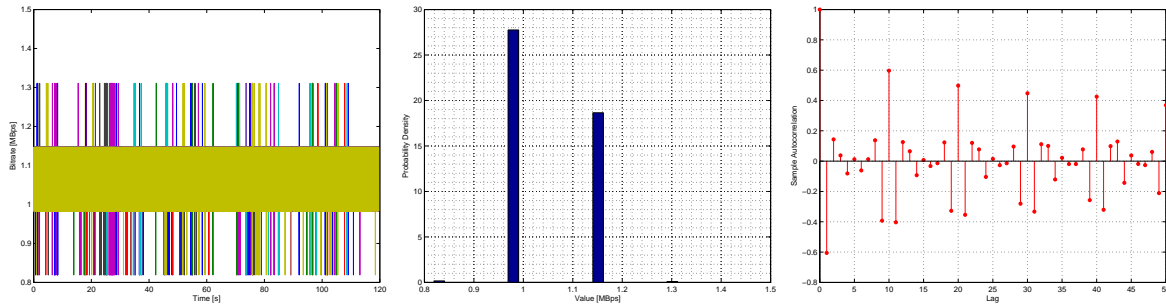


Fig. 57. 86-81-73 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP bitrate

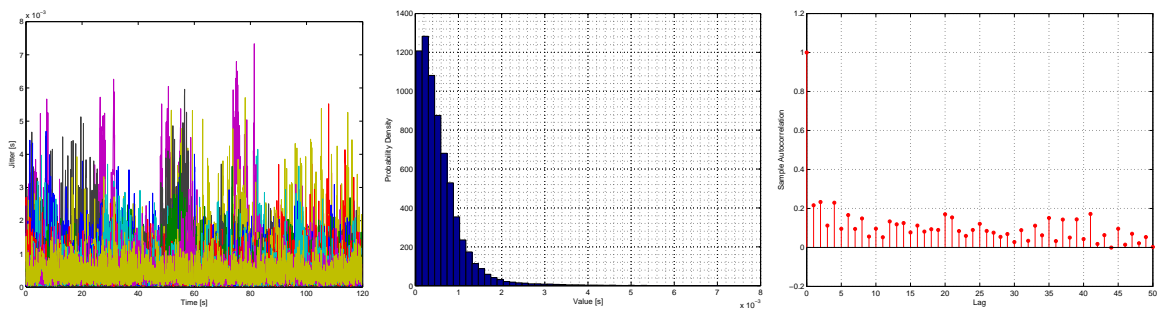


Fig. 58. 86-81-73 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP jitter

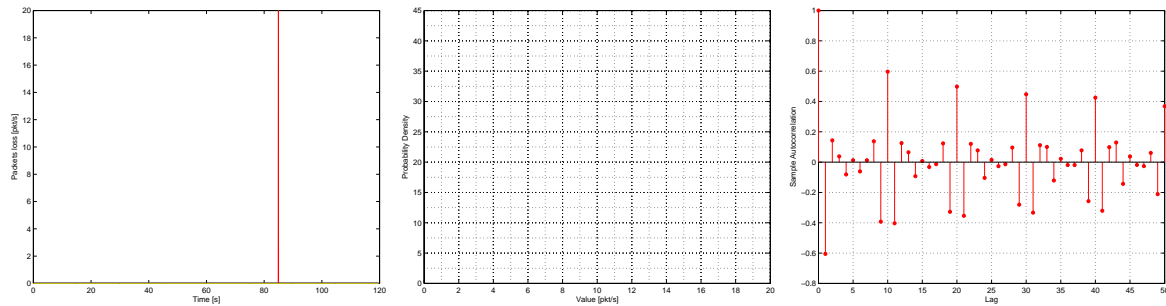


Fig. 59. 86-81-73 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP packet loss

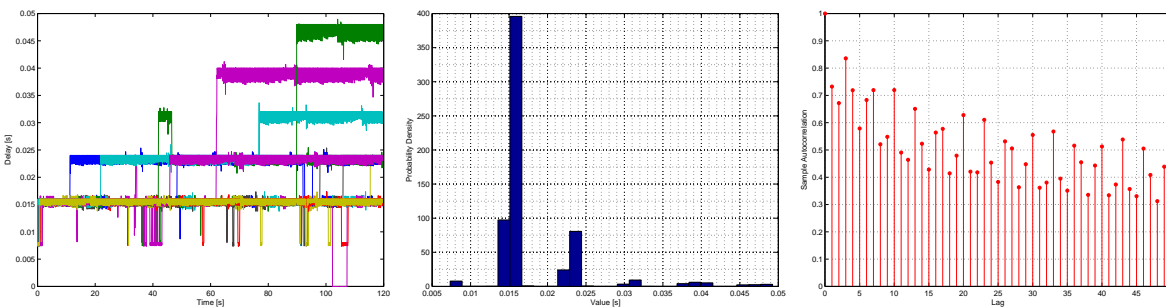


Fig. 60. 86-81-73 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP delay

TABLE XXII

86-81-73 - 128-1024 - CONCISE TCP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.05e+000(6e-005)	6.64e-001(0.4)	2.14e+000(7)	9.83e-001(1e-015)	1.64e-001(0.1)	1.64e-001(9e-017)
Jitter [s]	4.19e-003(0.0002)	1.93e-004(0.0006)	1.76e-002(0.09)	4.19e-003(0.0002)	1.05e-003(0.001)	1.38e-003(5e-005)
Delay [s]	3.30e-002(0.03)	6.38e-003(0.005)	5.74e-002(0.05)	3.01e-002(0.04)	1.71e-002(0.02)	2.01e-002(0.02)

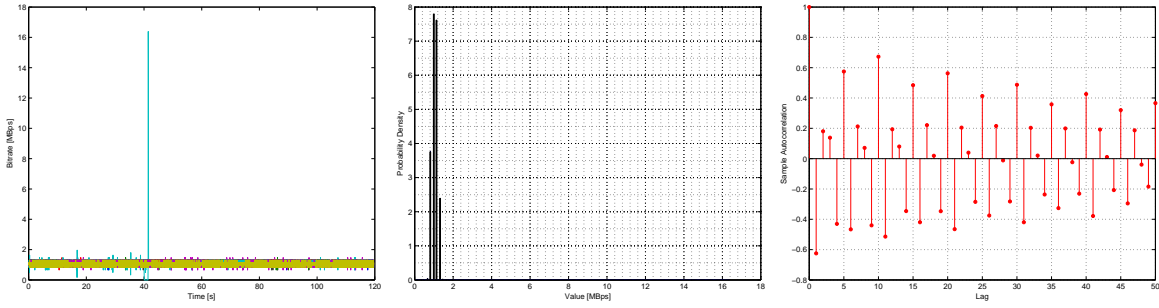


Fig. 61. 86-81-73 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP bitrate

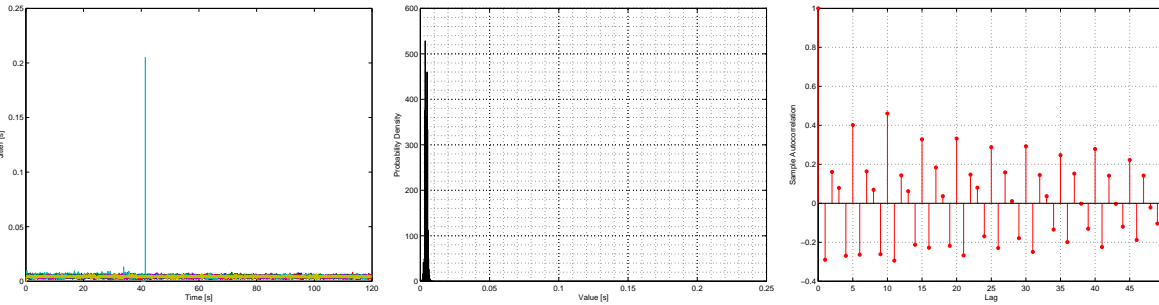


Fig. 62. 86-81-73 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP jitter

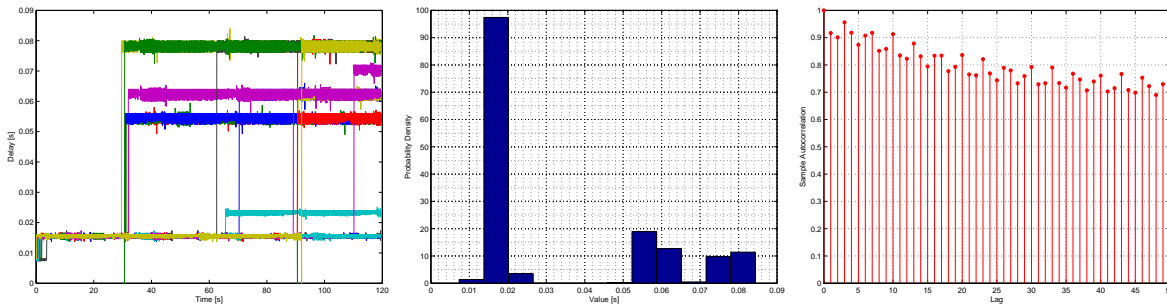


Fig. 63. 86-81-73 - 128-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP delay

TABLE XXIII

86-81-73 - 11000-1024 - CONCISE UDP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.78e+001(1)	9.09e-001(3)	2.555e+001(2)	1.9e+001(2)	3.79e+000(0.7)	4.97e+000(0.2)
Jitter [s]	2.94e-004(6e-005)	1.92e-005(7e-005)	1.97e-003(0.002)	2.62e-004(7e-005)	1.47e-004(4e-005)	1.72e-004(1e-005)
Packet Loss [pkt/s]	8.82e+003(2e+002)	7.68e+002(3e+003)	5.06e+004(2e+005)	8.75e+003(2e+002)	1.32e+003(4e+003)	8.52e+002(7e+001)
Delay [s]	2.45e-002(0.003)	1.03e-003(0.009)	6.11e-002(0.04)	2.50e-002(0.001)	7.03e-003(0.004)	3.51e-003(0.0005)

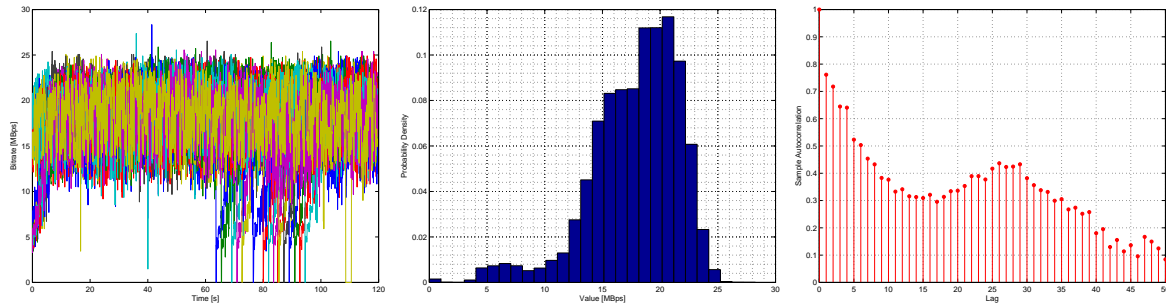


Fig. 64. 86-81-73 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP bitrate

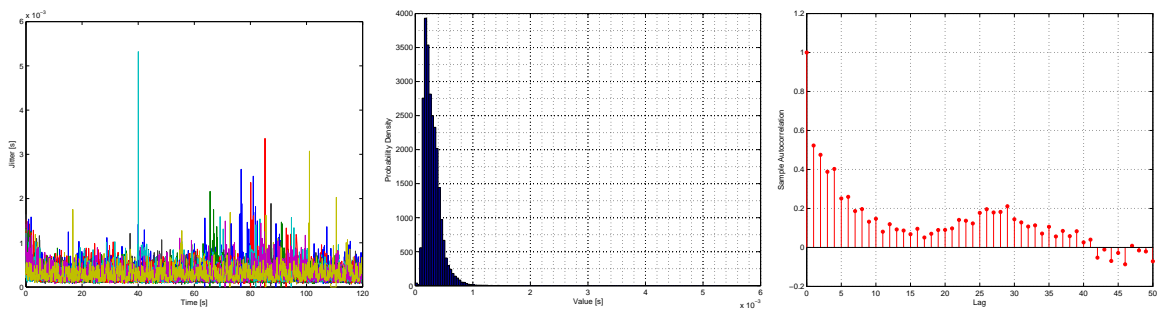


Fig. 65. 86-81-73 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP jitter

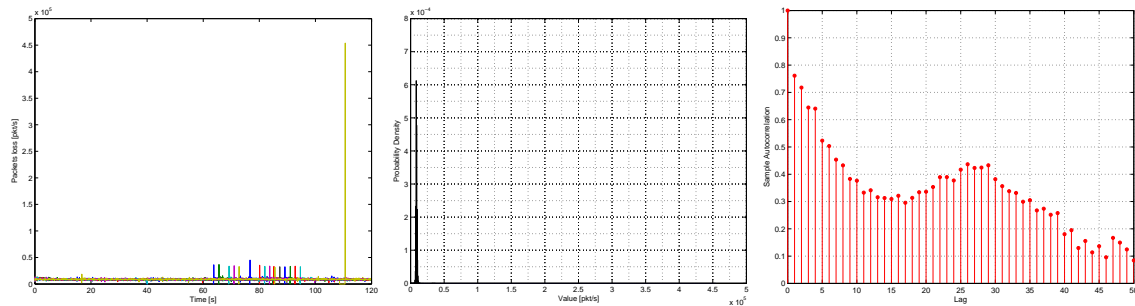


Fig. 66. 86-81-73 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP packet loss

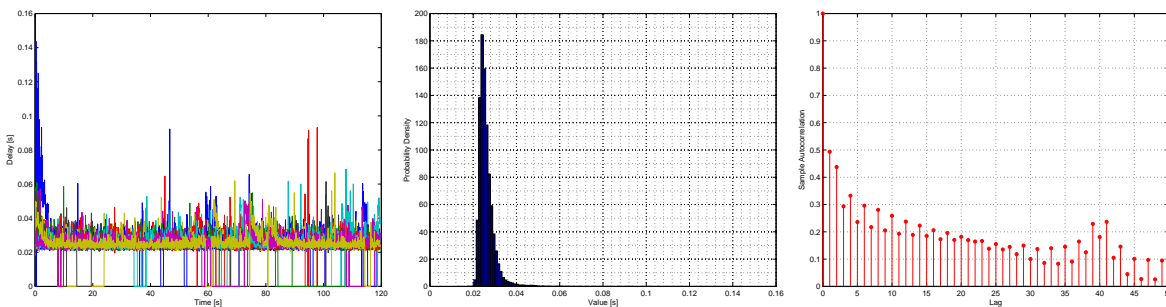


Fig. 67. 86-81-73 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP delay

TABLE XXIV

86-81-73 - 11000-1024 - CONCISE TCP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	1.63e+001(4)	0.00e+000(0)	3.14e+001(3)	1.69e+001(4)	4.75e+000(2)	5.78e+000(1)
Jitter [s]	1.36e-003(0.001)	0.00e+000(0)	5.06e-001(2)	9.21e-004(0.0002)	1.13e-002(0.04)	3.10e-004(0.0001)
Delay [s]	2.39e-001(0.04)	6.24e-002(0.05)	5.01e-002(0.05)	7.83e-001(0.8)	0.00e+000(0)	2.32e-001(0.02)

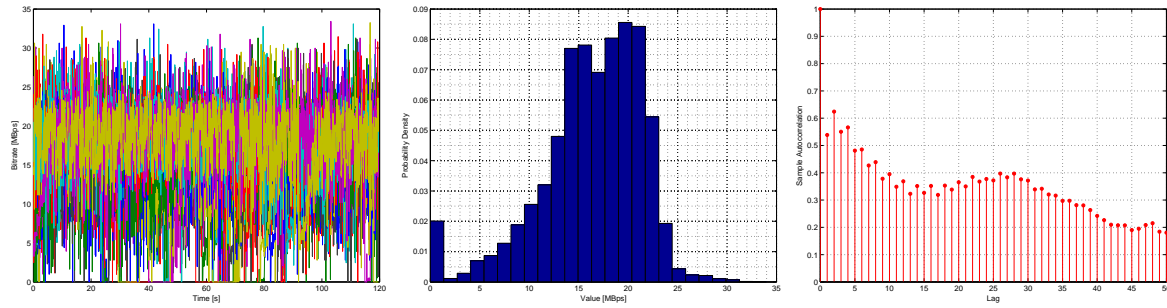


Fig. 68. 86-81-73 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP bitrate

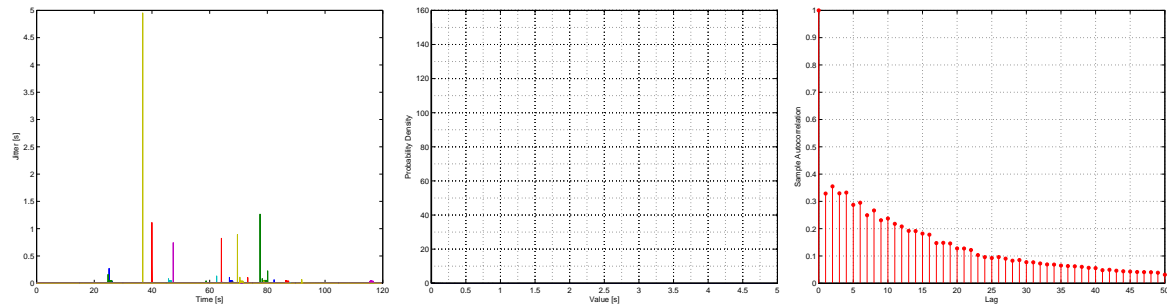


Fig. 69. 86-81-73 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP jitter

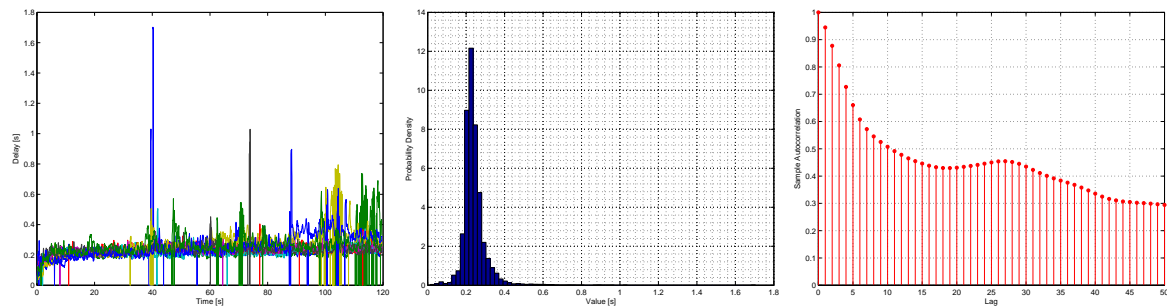


Fig. 70. 86-81-73 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP delay

TABLE XXV
86-81 - VIDEO - CONCISE UDP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	5.33e+000(0.001)	3.59e+000(2)	7.294e+000(3)	5.3e+000(0.01)	3.82e-001(0.07)	5.01e-001(0.04)
Jitter [s]	5.67e-004(0.0002)	2.25e-004(3e-005)	1.94e-003(0.003)	5.30e-004(0.0002)	2.05e-004(0.0002)	2.44e-004(0.0001)
Packet Loss [pkt/s]	2.96e-002(0.2)	0.00e+000(0)	3.80e+001(3e+002)	0.00e+000(0)	9.09e-001(6)	0.00e+000(0)

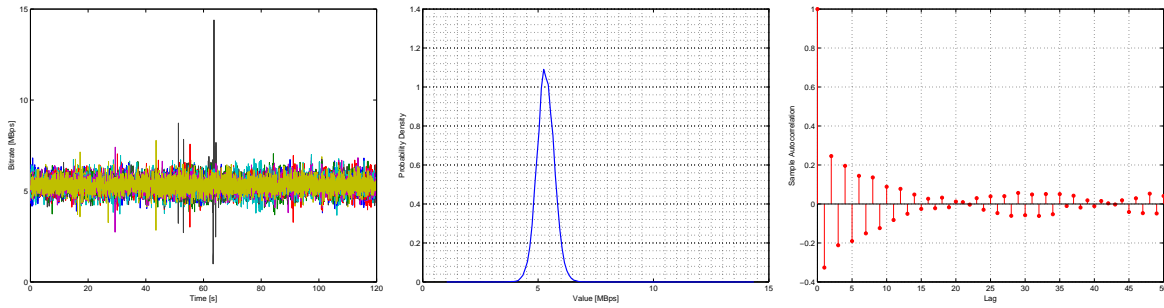


Fig. 71. 86-81 - video - Time plot (left), PDF (center) and Autocorrelation (right) of UDP bitrate

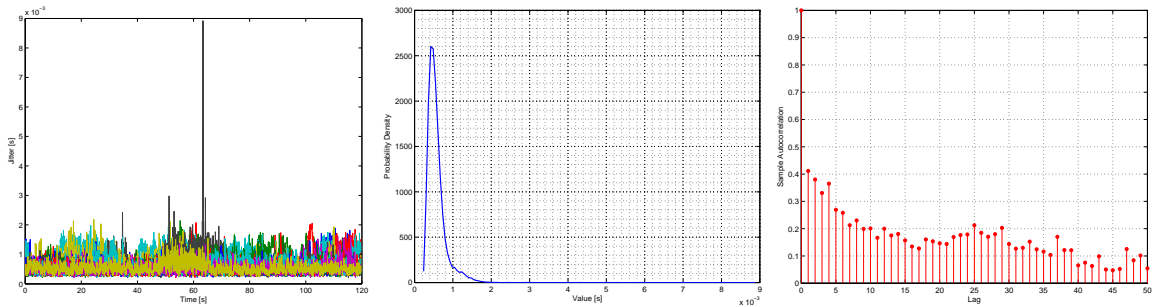


Fig. 72. 86-81 - video - Time plot (left), PDF (center) and Autocorrelation (right) of UDP jitter

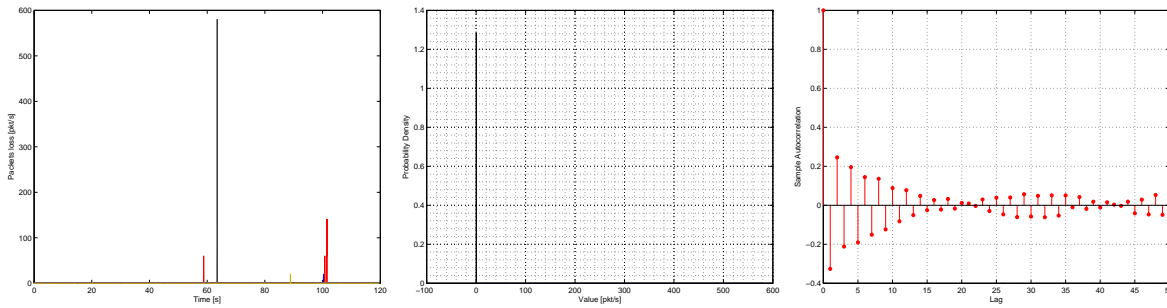


Fig. 73. 86-81 - video - Time plot (left), PDF (center) and Autocorrelation (right) of UDP packet loss

TABLE XXVI

89-94 -TURBOBURST- 11000-1024 - CONCISE UDP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	5.52e+001(1)	1.46e+001(2e+001)	6.060e+001(2)	5.5e+001(0.7)	3.30e+000(2)	3.83e+000(0.2)
Jitter [s]	6.31e-005(1e-005)	3.19e-005(4e-005)	4.94e-004(0.0007)	5.51e-005(4e-006)	3.82e-005(5e-005)	1.13e-005(3e-006)
Packet Loss [pkt/s]	4.26e+003(1e+002)	7.31e+002(1e+003)	7.73e+003(7e+003)	4.29e+003(9e+001)	4.17e+002(3e+002)	4.77e+002(3e+001)
Delay [s]	2.02e-002(0.002)	0.00e+000(0)	1.33e-001(0.04)	1.85e-002(0.002)	1.18e-002(0.005)	8.05e-003(0.002)

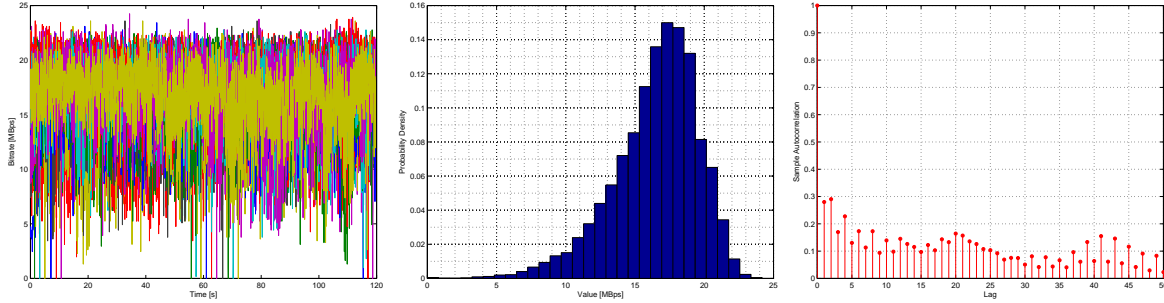


Fig. 74. 89-94 - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP bitrate

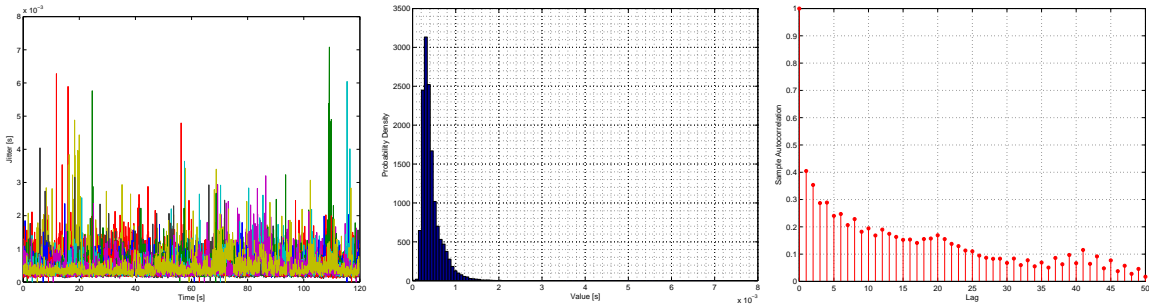


Fig. 75. 89-94 -turboburst- 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP jitter

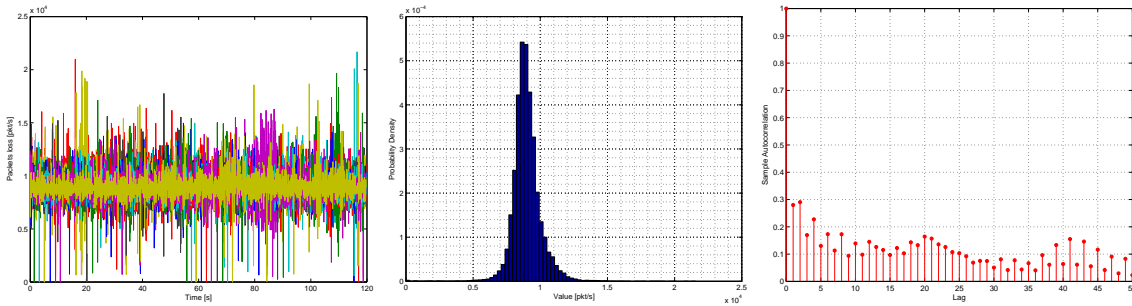


Fig. 76. 89-94 -turboburst- 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP packet loss

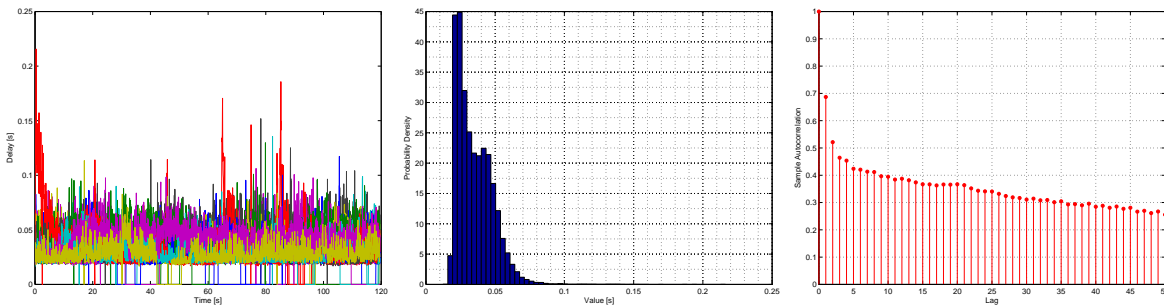


Fig. 77. 89-94 - turboburst - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of UDP delay

TABLE XXVII

89-94 - TURBOBURST - 11000-1024 - CONCISE TCP STATISTICS - WIDTH OF 95% CONFIDENCE INTERVAL IN PARENTHESIS

	Average	Minimum	Maximum	Median	StdDev	IQR
Bitrate [Mbps]	4.85e+001(8)	1.31e+000(6)	6.66e+001(5)	4.97e+001(8)	6.58e+000(3)	7.30e+000(4)
Jitter [s]	3.48e-004(0.0001)	4.41e-005(0.0002)	2.81e-002(0.1)	3.21e-004(6e-005)	6.06e-004(0.002)	6.02e-005(3e-005)
Delay [s]	1.30e-001(0.05)	0.00e+000(0)	4.83e-001(0.4)	1.20e-001(0.02)	5.07e-002(0.08)	6.67e-002(0.09)

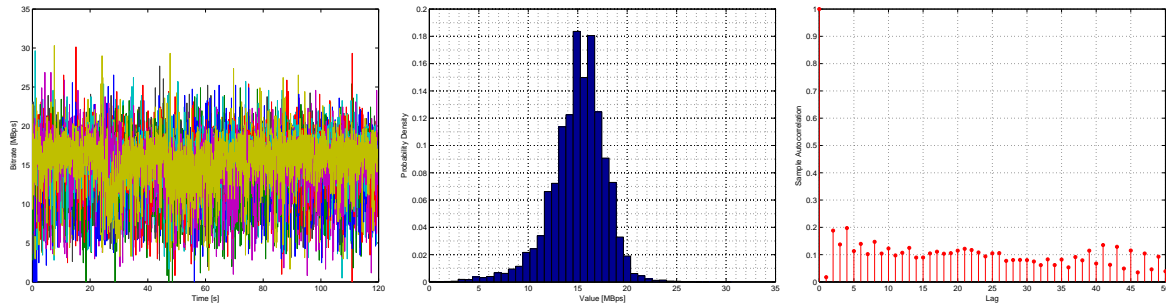


Fig. 78. 89-94 - turboburst - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP bitrate

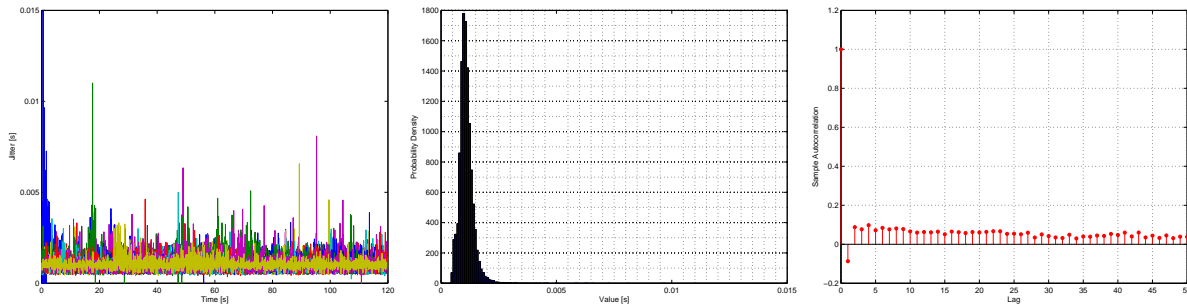


Fig. 79. 89-94 - turboburst - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP jitter

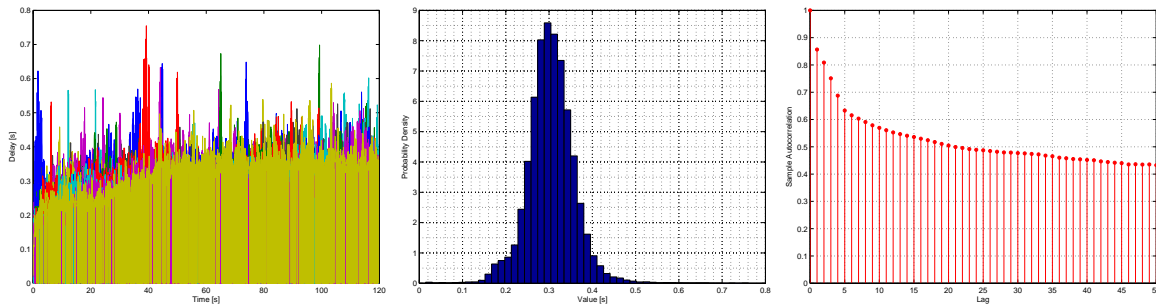


Fig. 80. 89-94 - turboburst - 11000-1024 - Time plot (left), PDF (center) and Autocorrelation (right) of TCP delay

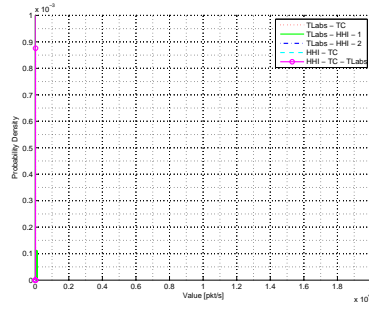


Fig. 81. UDP - 128-1024 - PDFs of packetloss of all the considered links

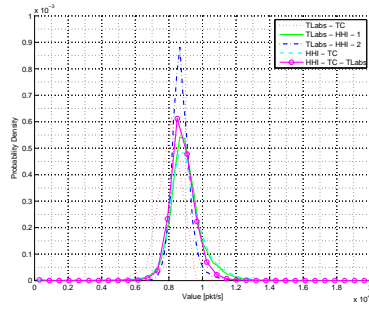


Fig. 82. UDP - 11000-1024 - PDFs of packetloss of all the considered links

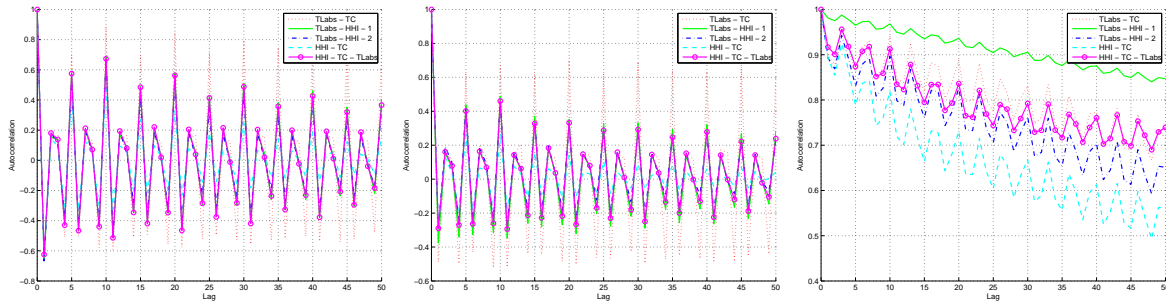


Fig. 83. tcp - 128-1024 - ACFs of bitrate (left), jitter (center), and delay (right) of all the considered links

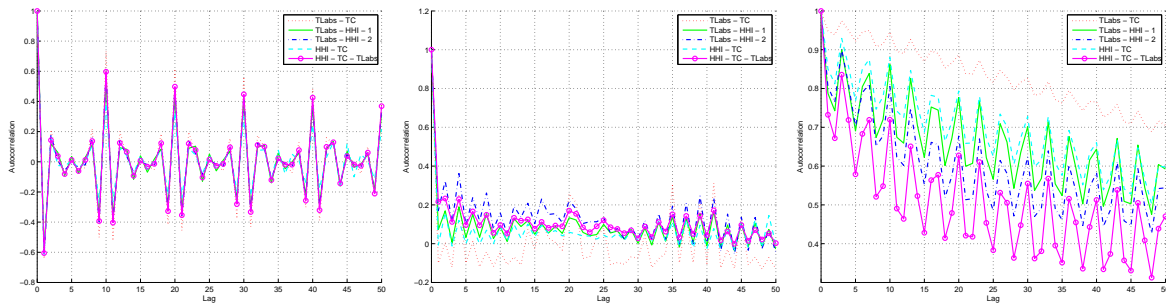


Fig. 84. udp - 128-1024 - ACFs of bitrate (left), jitter (center), and delay (right) of all the considered links

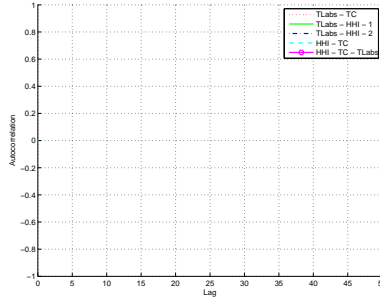


Fig. 85. UDP - 128-1024 - ACFs of packetloss of all the considered links

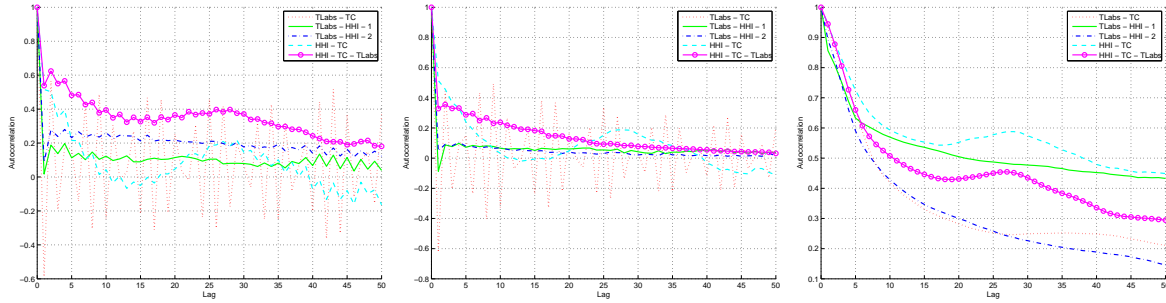


Fig. 86. tcp - 11000-1024 - ACFs of bitrate (left), jitter (center), and delay (right) of all the considered links

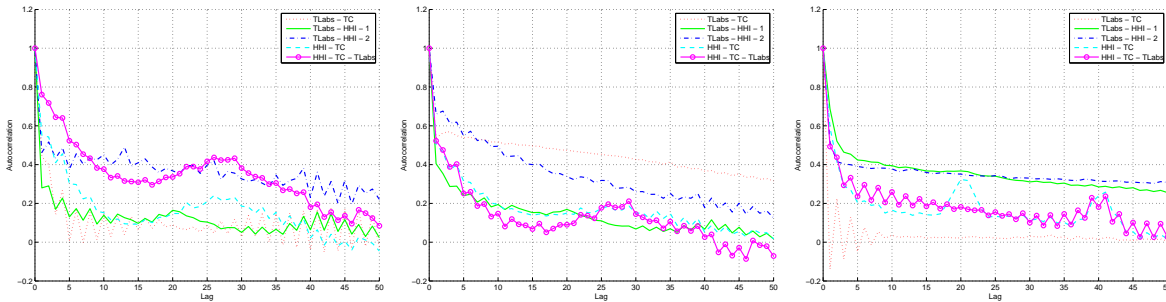


Fig. 87. udp - 11000-1024 - ACFs of bitrate (left), jitter (center), and delay (right) of all the considered links

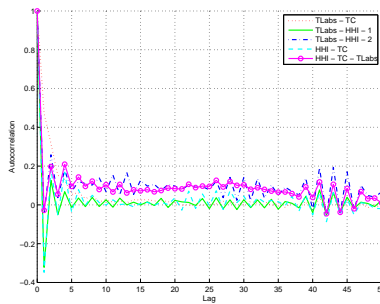


Fig. 88. UDP - 11000-1024 - ACFs of packetloss of all the considered links