Technical University Berlin

Telecommunication Networks Group

Measurements of a Wireless Link in different RF-isolated Environments

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Abstract

In this report two measurement campaigns are described, using a measurement setup based on an IEEE 802.11 compliant PHY. The intention of both campaigns is to investigate the error behaviour of the wireless link in clearly defined scenarios with no interference and simple propagation environments. While the first campaign was designed to record data in a pseudo-optimal environment, the measurement setup in campaign two is exposed to strong RF reflection patterns induced by massive walls in a building. Both environments were designed to avoid any influence by other RF sources, most important influences through other 802.11 compliant radio sources. The report finds some results related to the efficiency of space diversity. Furthermore it contains some results on transmission speeds.

Contents

Chapter 1

Introduction

This report describes the results of a measurement project at the Telecommunication Networks Group (TKN), Technical University Berlin, former Department of Electrical Engineering. Two graduate students and a member of the scientific staff of TKN were involved.

The aim of the project was to investigate the bit error behaviour of a wireless link in environments, where we have good control over the interference and wave propagation environment, and where we could investigate the influence of selected parameters, without having to worry about not knowing the remaining environment. In other environments, e.g. at our institute and in the buildings nearby, there may be several interferers present we do not know.

The measurement setup and evaluation methodology used in this work relies heavily on the results and terminology of earlier work at TKN. The most important references are [3] and [4].

The project work consists of two measurement campaigns.[1] Each measurement campaign consists of several measurements. The first measurement campaign was taken on an open field, away from buildings. It investigates the influence of distance and receiver diversity. The second campaign was taken in a sports gym. It aims at looking at the influence of simple multipath scenarios, using the fact that the gym has a very regular wall structure.

[1]The notions related to the measurements are defined as follows (see [4]): a *measurement campaign* consists of one or more *measurements*. A measurement is distinguished by the set of fixed and variable parameters from other measurements, and it consists of a number of packet streams. A packet stream is generated by the transmitter station and consists of a fixed number of packets, which are all transmitted with the same parameters (modulation type, packet size, gap time, and so forth). The receiver tries to capture all packets from the wireless link and logs them into a logfile. The contents of the logfile is denoted as *trace*. If no errors occured, the trace is identical to the generated packet stream.

Chapter 2

Methodology

The measurement setup and evaluation methodology is basically the same as described in [3] and [4]. A schematic sketch of the setup is shown in Figure 2.1.

In general, campaigns were always first designed and then processed. After that the recorded data was processed by statistical tools. The tools correspond to the tools used in [3] beside the analyzing tool for so called bit shifter packets. It uses a simple strategy where it identifies bit shifter packets by looking up a certain bit string in the trace source files. If this string is observed in a majority of one packets data, the data is registered as bit shifter. Based on this, the statistics for bit shifter packets are obtained. However, it should be mentioned that this is only a heuristic.

In the following chapters not all recorded traces are shown. Instead, first always multiple trace statistics are presented followed by single trace statistics. At the end of each measurement, tables are presented holding some more statistical values of traces. Always only substantial traces are presented. Substantial traces are those that show up at least a minimum amount of errors. The traces not shown did not own this minimal amount of errors. The threshold was chosen to be less than 2 packets wrong out of 20000. Also, complete errorless traces fall into this category. In these cases, all graphs were discarded for the documentation. The statistical values are still mentioned in the tables.

Regarding the parameters used, most of them are explained during the campaigns. Nevertheless, throughout the whole project scrambling was never activated. This is due to the phenomenon of bit shifted packets ([3]). Since at the beginning at the project the exact reason for the occurrence of bit shifters was unknown, the project participants decided not to work with scrambling. As it turned out, scrambling was not a reason for bit shifter packets.

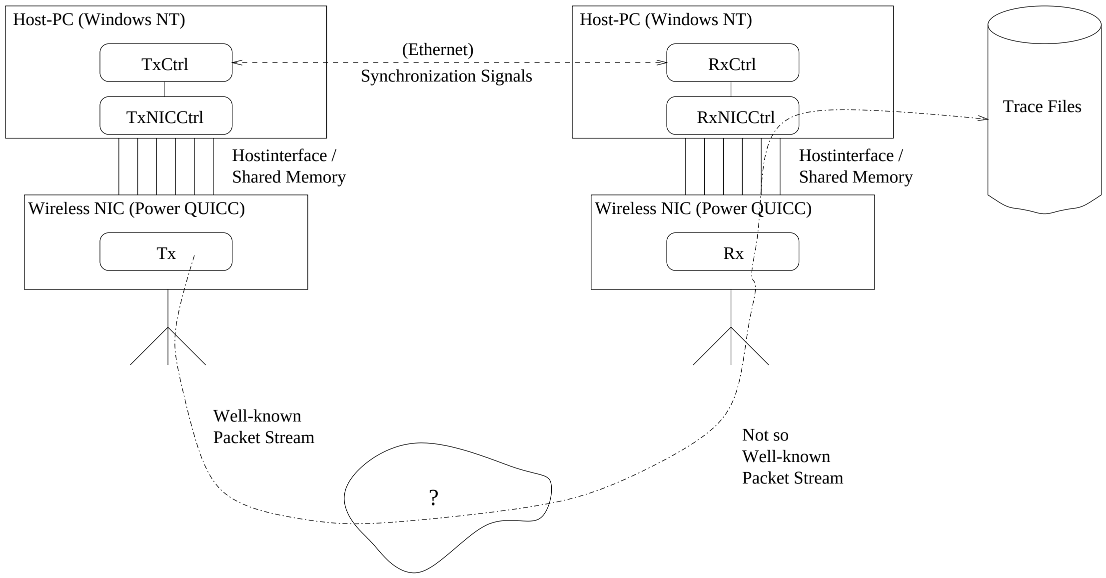


Figure 2.1: Computer Setup used in both Measurement Campaigns

Chapter 3

Campaign 1: Open Field Measurements, Barnim near Berlin, November the 20th, 2000

The first campaign was performed on the countryside in the north of Berlin. We planned to find a location off-road, on a field for example. Since we were going to be outdoor, the weather conditions were important. At this day the sun shone most of the time, so we did not have any problems with rain or snow, which probably would have stopped our campaign. The temperature was about five degrees Celsius. At this temperature we did not expect any problems in using the computer equipment.

We chose a small trail between two fields some kilometers away from the nearest village. The trail had stone made slabs in two lines, so cars were able to pass the trail. Beside some bushes and our cars nothing else was located around us in a radius of 500 meters.

To provide a power source for the two computers we had a gas-driven generator, which we positioned about 20 meters away from both computers. In all our traces the two computers were in a line of sight setting (LOS). Hence, the antennas of the radio modems were pointed to each other. The exact measurement setup is shown in Figure 3.1.

At first we began at 12:00 AM with some test traces to warm up the equipment. After 15 minutes we started the measurements. We finished the campaign at 05:00 PM.

The scenario background of campaign one relied on the assumption that the environment did not possessed any major other radio sources in the same band. The second assumption was that RF reflections in the area are as little as possible, and only due to the ground. Therefore the environment was chosen to be idle in the sense of no major RF interference effects as well as no interfering radio sources influence the measurement setup.

Campaign One was divided into three different measurements.

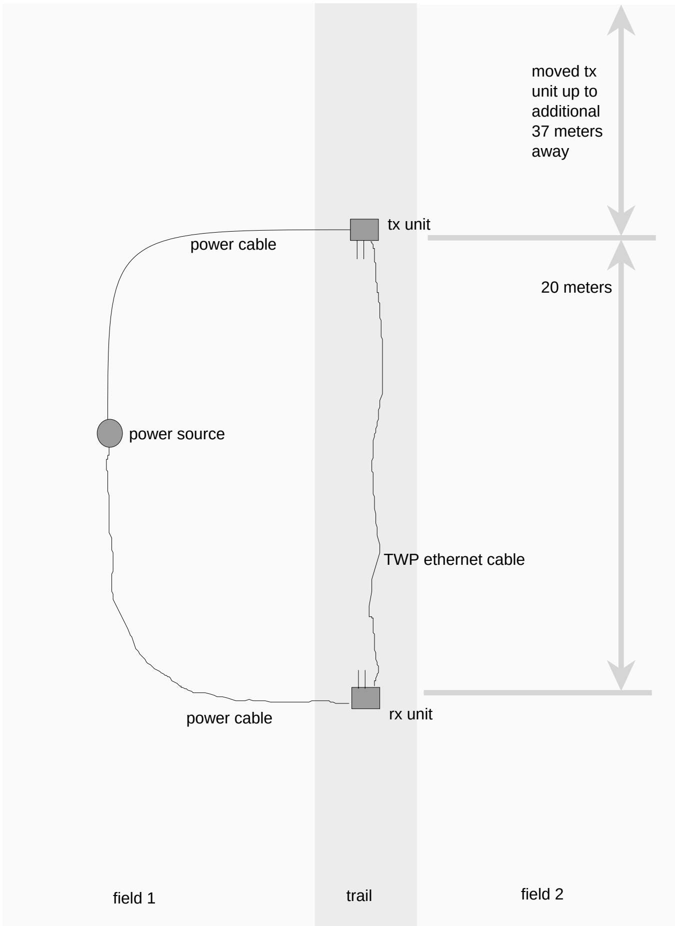


Figure 3.1: Measurement Setup of Campaign One

3.1 Measurement One

The first measurement was designed to observe the effect of space diversity depending on the modulation scheme and packet sizes. As indicated, only the ground was a potential reflector, providing a second propagation path. Basically, two modulation types were used to transmit traces consisting of big packets (2 KByte) and small packets (200 Byte). Compared to the

Parameter	**Value**
PreambleLength	128 bits
ScramblingEnabled	False
Gap Time	1000 μsec
SFD Threshold	152
Frequency	12
NumPackets	20000
Rx-Tx-Distance	$\approx$ 20 meter
CRCUsageEnabled	False

Table 3.1: Fixed Parameters for Campaign One, Measurement One

Parameter	**Value**
Diversity	True vs. False
NumChunks	Large(56) vs. Small(6)
ModulationCode	1 MBit BPSK vs.2 MBit QPSK vs.11 MBit CCK

Table 3.2: Variable Parameters for Campaign One, Measurement One

common sizes of IP packets, which are mostly around 500 bytes to 1500 bytes for personal computers, those two values are characteristically large respectively small. For each setting one trace was conveyed without space diversity enabled and one with space diversity enabled. The whole measurement was repeated once to increase the reliability of the recorded data. Therefore, for each sequence eight traces were recorded.

3.1.1 Measurement Parameters

The tables 3.1 and 3.2 display the set of fixed and variable parameters used during this measurement. The traces are numbered. In Table 3.3 the mapping from trace numbers to the variable parameters is shown.

3.1.2 Occurences during the Measurement

During this measurement, two cars passed while the measurement setup was active. But we did not need to move the setup. This occurred while processing trace 05 and trace 03 of the first sequence. Also while processing trace 08 of the second sequence, the transceiver had to

Trace No.	Description
Trace 01	Diversity Off, 11 MBit CCK, Packetsize Large
Trace 02	Diversity Off, 11 MBit CCK, Packetsize Small
Trace 03	Diversity On, 11 MBit CCK, Packetsize Large
Trace 04	Diversity On, 11 MBit CCK, Packetsize Small
Trace 05	Diversity Off, 2 MBit QPSK, Packetsize Large
Trace 06	Diversity Off, 2 MBit QPSK, Packetsize Small
Trace 07	Diversity On, 2 MBit QPSK, Packetsize Large
Trace 08	Diversity On, 2 MBit QPSK, Packetsize Small

Table 3.3: Trace Key of Campaign One, Measurement One

reboot because the system hang up. After the computer was up, the trace was repeated and behaved normal. Also, trace 04 of the second sequence was lost due to a copy failure.

3.1.3 Measurement Results

In the primary measurement results we have higher bit error rates using smaller packets as shown in figures 3.2 and 3.3 and listed in the primary measurement results in Tables 3.12 and 3.14. The error position histograms in Tables 3.6 and 3.7 show a high amount of bit errors occurring mostly at the first bit positions within a packet. Since the errors tend to occur at the beginning of one packet, increasing the packets size means a lower overall BER.

The difference in our primary results between enabled and disabled receiver space diversity is that enabling receiver space diversity results in lower bit error rates and shorter mean error bursts with a lower variance. This is shown in Tables 3.16 and 3.17.

For traces with space diversity enabled the autocovariance of error runlengths at different burst orders k_0 is noticeably lower than for traces with space diversity disabled. This applies to traces using the CCK modulation type as well as to traces using the QPSK modulation type.

Since the trail surface is generally very rough and very mixed, we did not expect strong interference patterns. But even in this near-optimal environment space diversity shows a noticeable impact by decreasing the bit error rate. For traces with space diversity enabled the bit error rate decreased by $10^(- 2)$ as listed in Tables 3.12 and 3.14. A very interesting metric, which, however, we have not explored, is the number of times the receiver switches the antenna.

The primary statistics of traces using the 802.11 PHY CCK modulation show very high bit and packet error rates. Using CCK modulation at the distance of 20 meters results in an unreliable transmission using our setup.

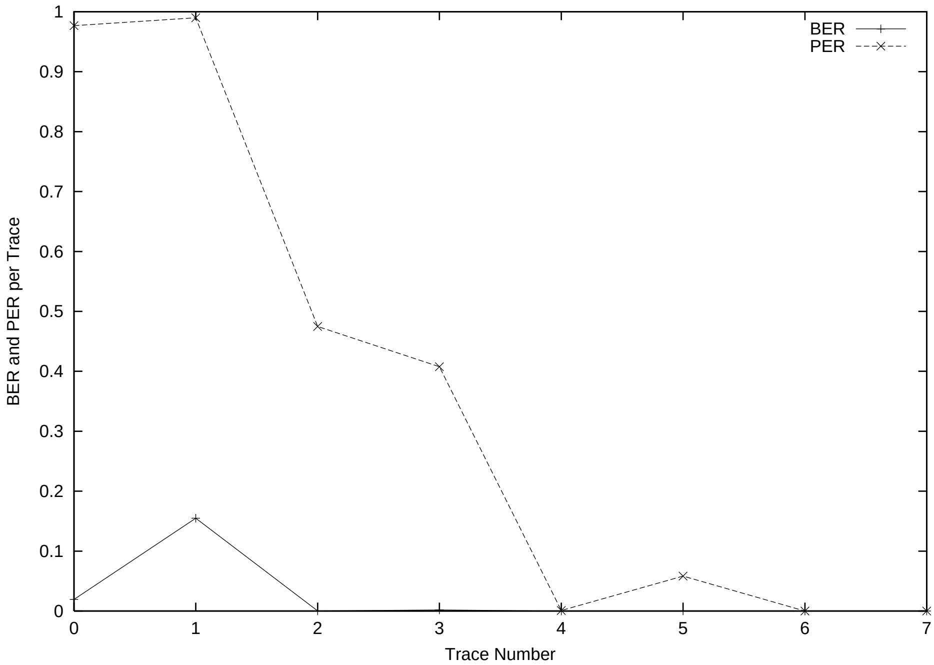


Figure 3.2: BER and PER per Trace vs.Tracenumber First Sequence

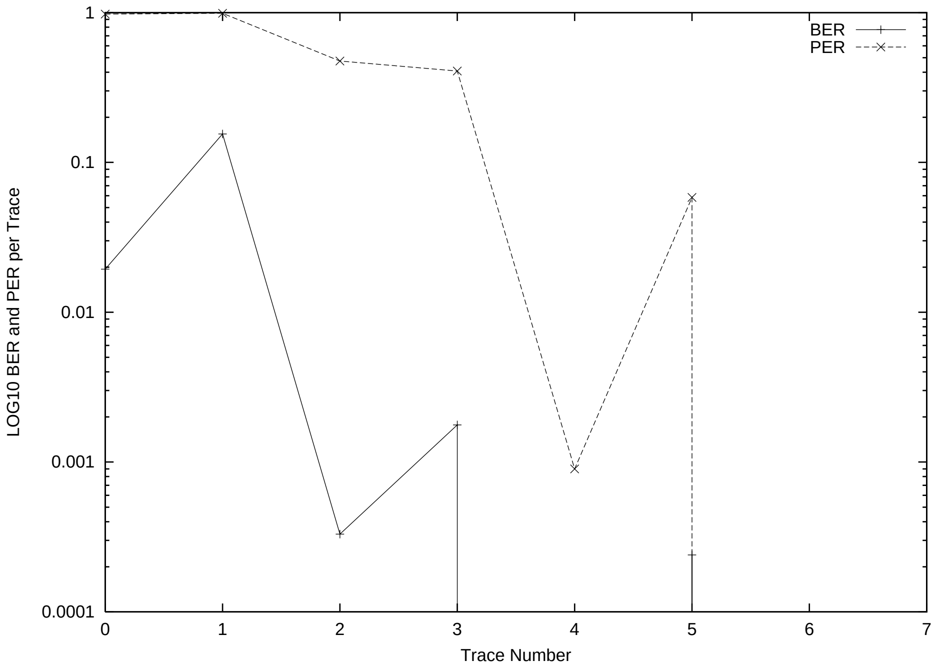


Figure 3.3: Log 10 Scaling of BER and PER per Trace vs. Tracenumber First Sequence

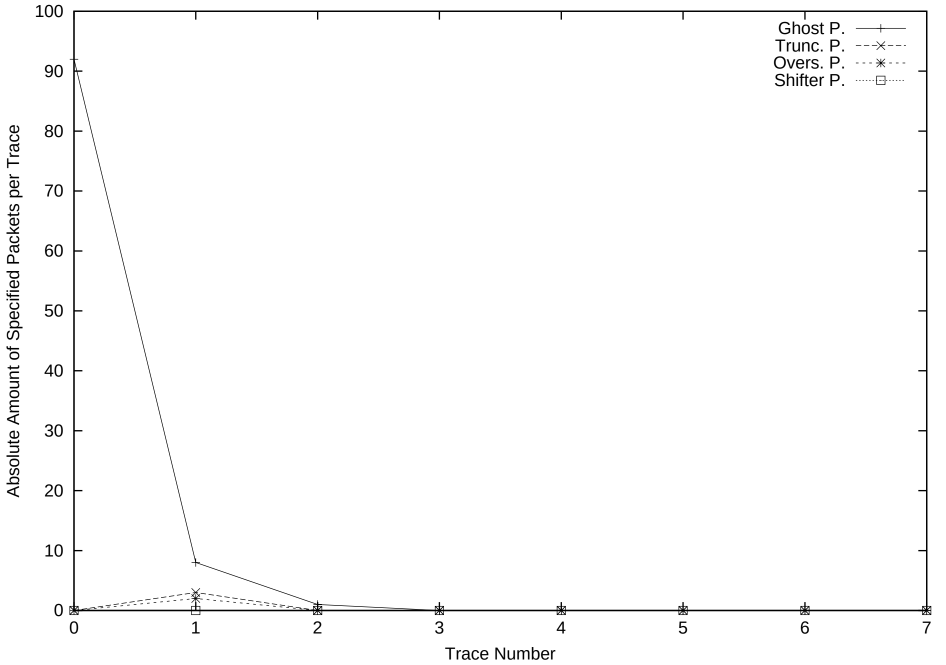
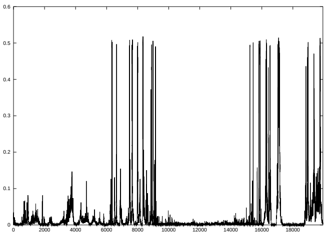
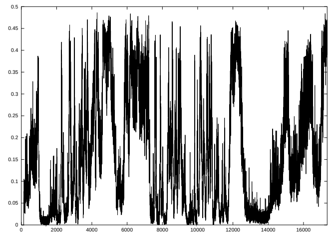


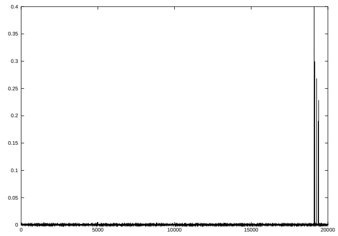
Figure 3.4: Number of Ghost, Truncated, Oversized and Shifter Packets vs. Tracenumber First Sequence



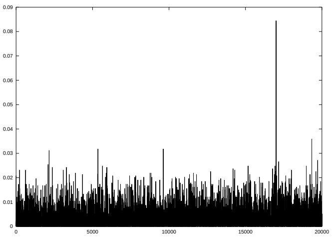
Trace 01



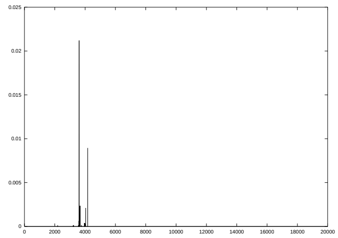
Trace 02



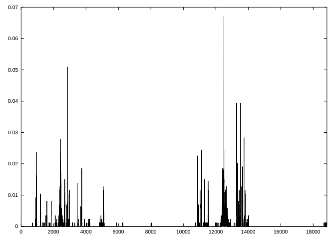
Trace 03



Trace 04



Trace 05



Trace 06

Table 3.4: BER per packet vs. packet number: Campaign One, First Sequence of Measurement One

Trace No.	**Burst Order**	**E(Burst Length)**	**VAR(Burst Length)**	**E(EFree BurstLength)**	**VAR(EFree BurstLength)**	**E(Wrong Bits per Burst)**	**VAR(Wrong Bits per Burst)**
Trace 01	1	1.57712	1.20612	79.7383	556798.	1.57712	1.20612
Trace 01	8	9.66572	5492.20	226.480	1584138	4.58010	1478.37
Trace 01	15	20.6786	63611.9	347.360	2428139	7.13819	16286.5
Trace 01	50	57.6940	1249291	586.805	4118355	12.5001	287823.

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 01	100	131.346	1119824	883.195	6241965	19.6773	2061266
Trace 02	1	1.68785	1.44277	9.20732	2054.29	1.68785	1.44277
Trace 02	8	17.1383	1311.88	32.4371	8644.07	7.67999	278.675
Trace 02	15	55.5031	27440.8	64.1957	19146.2	18.5415	4635.75
Trace 02	50	266.557	1612486	165.493	55604.2	65.5125	2342103
Trace 02	100	720.053	1806647	299.492	101048.	153.311	2093884
Trace 03	1	1.35255	0.53981	4072.72	1936404	1.35255	0.53981
Trace 03	8	6.72457	284.198	8366.49	3620751	2.77986	50.4557
Trace 03	15	24.8478	6326.96	17327.4	5951828	5.76105	1073.54
Trace 03	50	61.2760	71052.8	29678.5	6538390	9.87412	7834.65
Trace 03	100	75.3584	153275.	32957.0	6183903	10.9674	12523.9
Trace 04	1	1.26080	0.26889	707.670	4144438	1.26080	0.26889
Trace 04	8	4.53076	42.9738	1130.53	6159411	2.01868	2.78017
Trace 04	15	19.2660	620.929	2244.92	9796527	4.02693	16.3168
Trace 04	50	48.9232	2845.52	3676.63	1089384	6.62630	44.9876
Trace 04	100	63.0090	3574.55	4118.27	1043678	7.43695	48.8738
Trace 05	1	1.28979	0.23438	656713.	1356338	1.28979	0.23438
Trace 05	8	3.73701	50.2847	1043514	2153761	2.05194	5.21808
Trace 05	15	11.6585	346.195	1565265	3227688	3.08292	18.7980
Trace 05	50	26.5200	2751.26	2135384	4398919	4.21333	47.3811
Trace 05	100	57.5789	21703.7	2803830	5769145	5.54386	155.212
Trace 06	1	1.23931	0.18581	5115.16	1597041	1.23931	0.18581
Trace 06	8	2.99203	29.8416	7410.14	2312409	1.79576	2.21898
Trace 06	15	8.95329	124.074	10264.2	3201902	2.48879	4.15520
Trace 06	50	14.9934	608.577	11822.8	3687917	2.86800	7.56839
Trace 06	100	28.6070	3459.49	13637.3	4255209	3.31108	14.4846
Trace 07	1	nan	0.00000	3225438	0.00000	0.00000	0.00000
Trace 07	8	nan	0.00000	3225438	0.00000	0.00000	0.00000
Trace 07	15	nan	0.00000	3225438	0.00000	0.00000	0.00000
Trace 07	50	nan	0.00000	3225438	0.00000	0.00000	0.00000
Trace 07	100	nan	0.00000	3225438	0.00000	0.00000	0.00000
Trace 08	1	nan	0.00000	3455827	0.00000	0.00000	0.00000
Trace 08	8	nan	0.00000	3455827	0.00000	0.00000	0.00000
Trace 08	15	nan	0.00000	3455827	0.00000	0.00000	0.00000
Trace 08	50	nan	0.00000	3455827	0.00000	0.00000	0.00000
Trace 08	100	nan	0.00000	3455827	0.00000	0.00000	0.00000

Table 3.16: Further Statistical Measurement Results of Campaign One, First Sequence of Measurement One

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 01	1	1.29712	0.30561	5548.51	3129344	1.29712	0.30561

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 01	8	5.72830	59.1215	9967.18	5183211	2.33094	3.73819
Trace 01	15	21.2812	773.475	19682.0	8329498	4.60535	23.2279
Trace 01	50	54.4083	3404.23	33252.4	9571578	7.78529	62.4994
Trace 01	100	67.4118	4024.76	36841.1	9286832	8.62726	66.5533
Trace 02	1	1.21384	0.20129	2297.48	3909883	1.21384	0.20129
Trace 02	8	3.52776	28.9976	3301.49	5290998	1.74543	1.92736
Trace 02	15	16.2184	435.250	6333.60	8250188	3.35458	9.33057
Trace 02	50	34.6873	1548.63	8961.98	9342080	4.75431	20.8553
Trace 02	100	42.6177	1993.78	9662.77	9405528	5.12924	22.1979
Trace 03	1	1.31742	0.38193	5692.23	3487791	1.31742	0.38193
Trace 03	8	5.94792	67.7731	10656.8	6003093	2.46728	5.56324
Trace 03	15	19.2500	911.957	19413.6	9241693	4.49674	43.8489
Trace 03	50	45.6918	13911.9	30499.6	1114839	7.06838	582.342
Trace 03	100	60.2965	47973.1	34438.4	1123749	7.98331	1796.85
Trace 05	1	nan	0.00000	3225438	0.00000	0.00000	0.00000
Trace 05	8	nan	0.00000	3225438	0.00000	0.00000	0.00000
Trace 05	15	nan	0.00000	3225438	0.00000	0.00000	0.00000
Trace 05	50	nan	0.00000	3225438	0.00000	0.00000	0.00000
Trace 05	100	nan	0.00000	3225438	0.00000	0.00000	0.00000
Trace 06	1	nan	0.00000	3455827	0.00000	0.00000	0.00000
Trace 06	8	nan	0.00000	3455827	0.00000	0.00000	0.00000
Trace 06	15	nan	0.00000	3455827	0.00000	0.00000	0.00000
Trace 06	50	nan	0.00000	3455827	0.00000	0.00000	0.00000
Trace 06	100	nan	0.00000	3455827	0.00000	0.00000	0.00000
Trace 07	1	1.26744	0.21917	3707214	6431408	1.26744	0.21917
Trace 07	8	3.76363	47.7804	5759420	9936040	1.98181	3.65421
Trace 07	15	12.2500	229.965	8716954	1491509	3.02777	8.52700
Trace 07	50	24.6785	1861.86	1112162	1889956	3.89285	22.7385
Trace 07	100	31.2692	3172.35	1194544	2025117	4.19230	29.4630
Trace 08	1	nan	0.00000	3455827	0.00000	0.00000	0.00000
Trace 08	8	nan	0.00000	3455827	0.00000	0.00000	0.00000
Trace 08	15	nan	0.00000	3455827	0.00000	0.00000	0.00000
Trace 08	50	nan	0.00000	3455827	0.00000	0.00000	0.00000
Trace 08	100	nan	0.00000	3455827	0.00000	0.00000	0.00000

Table 3.17: Further Statistical Measurement Results of Campaign One, Second Sequence of Measurement One

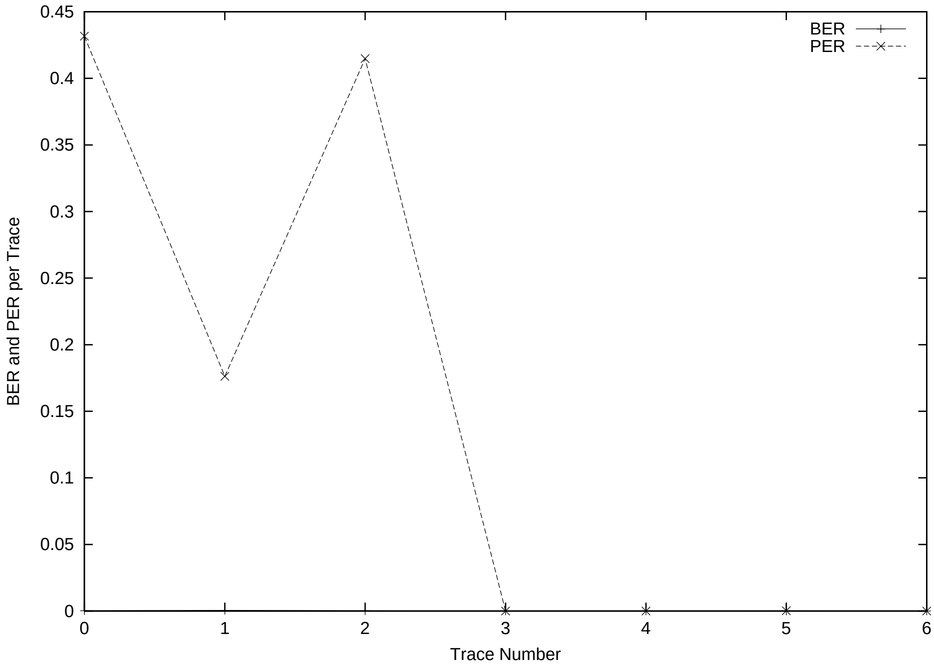


Figure 3.5: BER and PER per Trace vs.Tracenumber Second Sequence

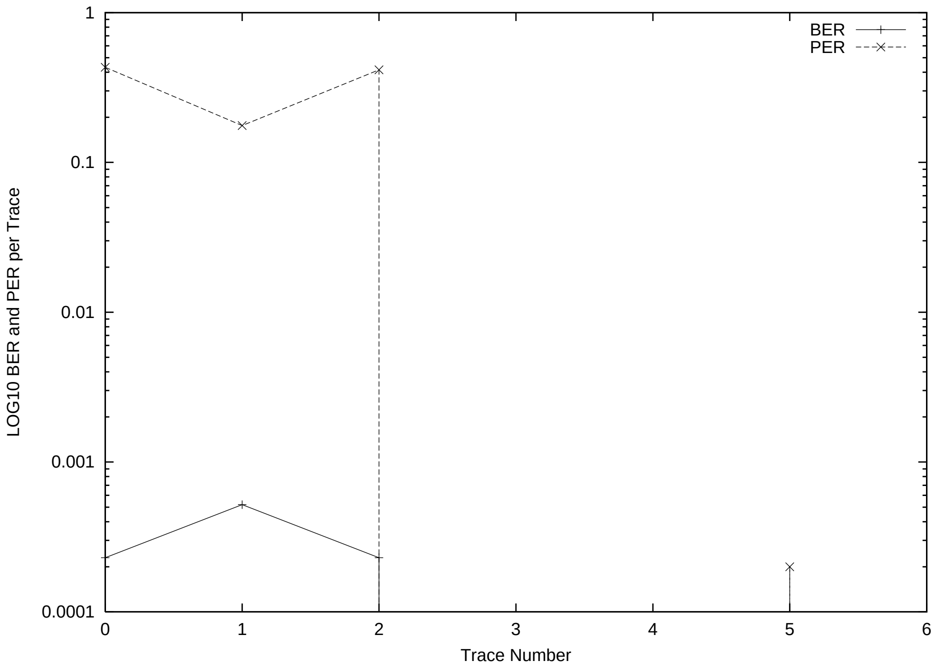


Figure 3.6: Log 10 Scaling of BER and PER per Trace vs. Tracenumber Second Sequence

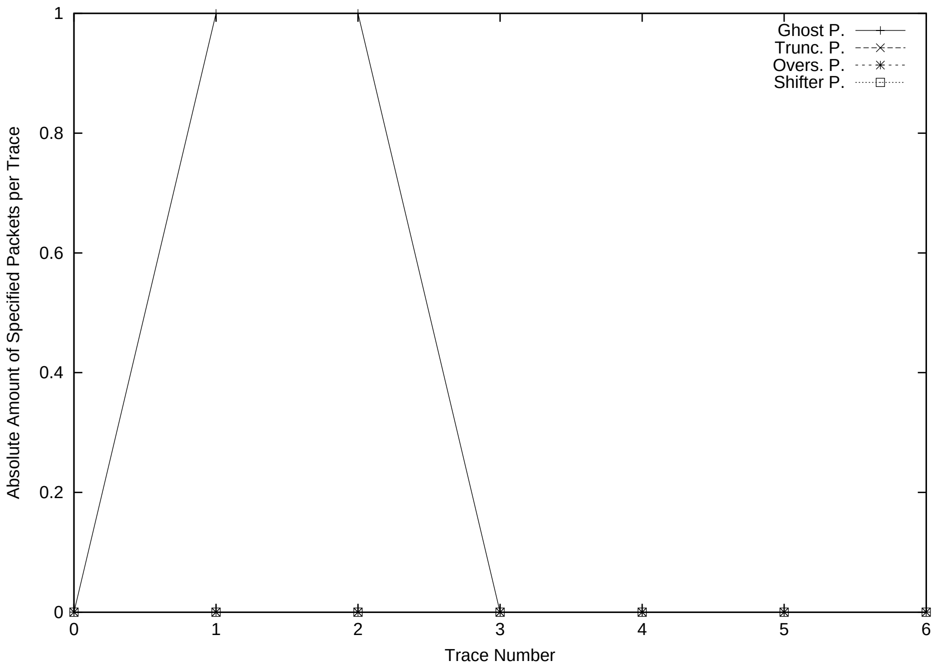
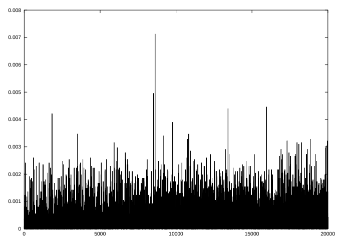
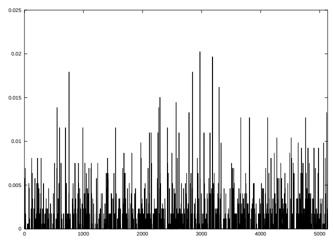


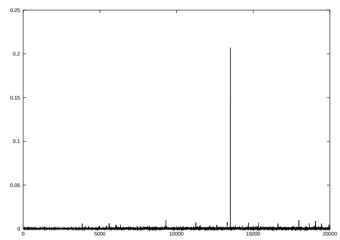
Figure 3.7: Number of Ghost, Truncated, Oversized and Shifter Packets vs. Tracenumber Second Sequence



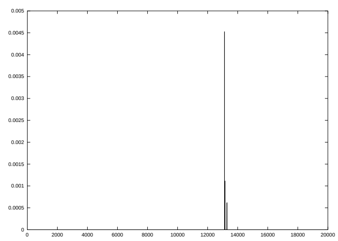
Trace 01



Trace 02

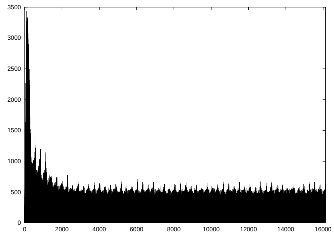


Trace 03

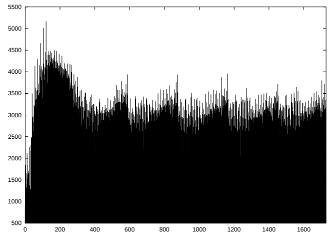


Trace 07

Table 3.5: BER per packet vs. packet number: Campaign One, Second Sequence of Measurement One



Trace 01



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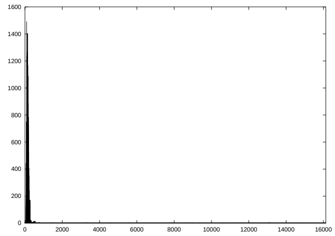

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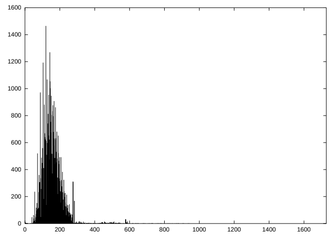
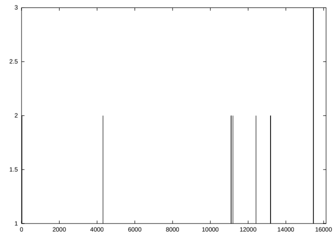
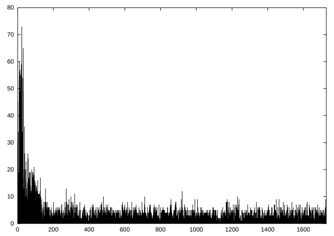


Trace 04

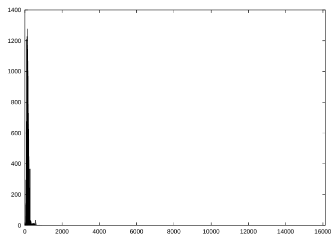


Trace 05

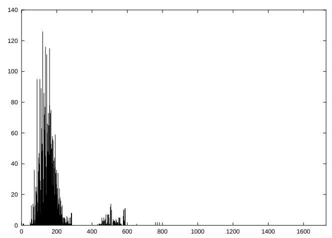


Trace 06

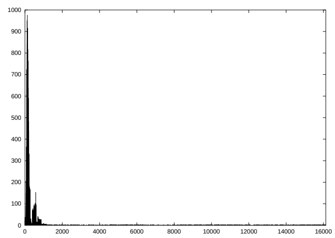
Table 3.6: Error position histograms: Campaign One, First Sequence of Measurement One



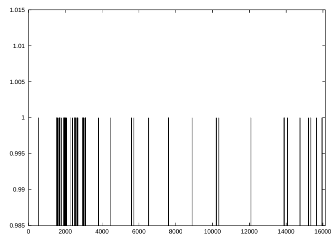
Trace 01



Trace 02



Trace 03



Trace 07

Table 3.7: Error position histograms: Campaign One, Second Sequence of Measurement One

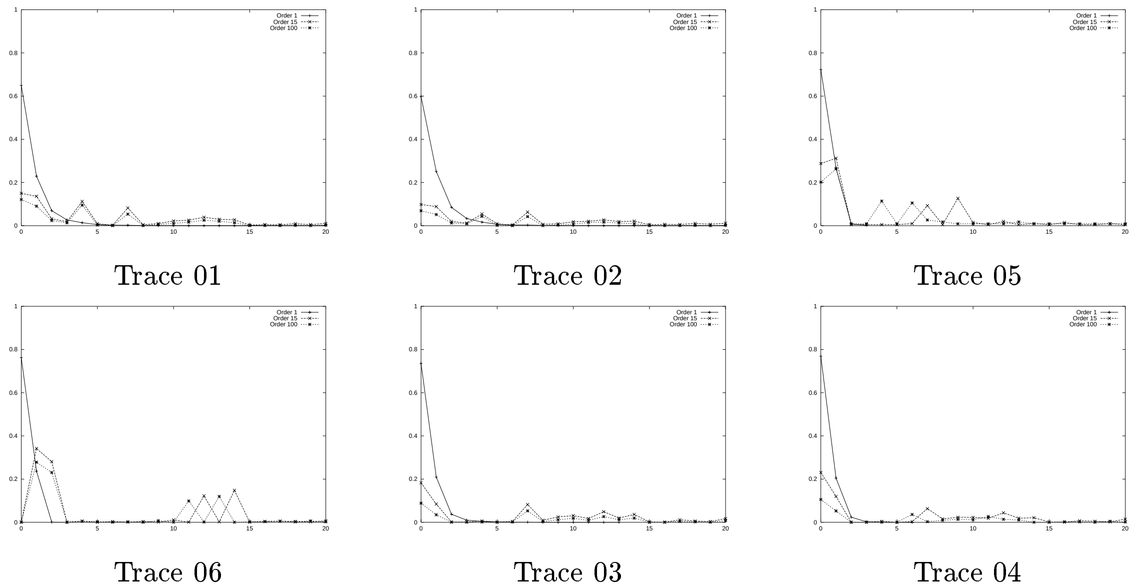


Table 3.8: Normalized Histogram Plots of error runlengths at Different burst orders k_0 of Campaign One, First Sequence of Measurement One

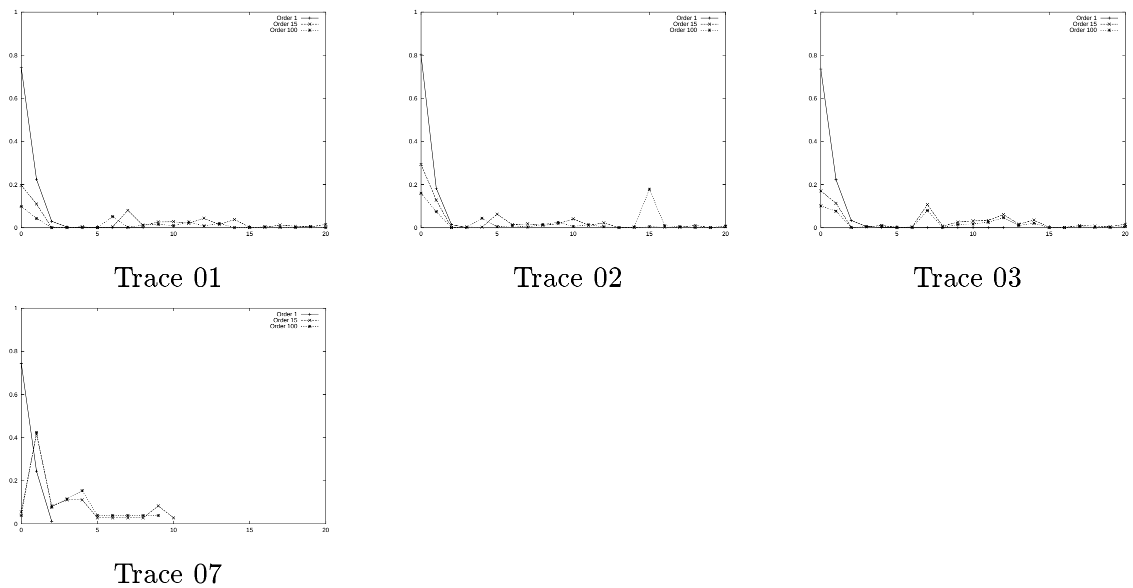
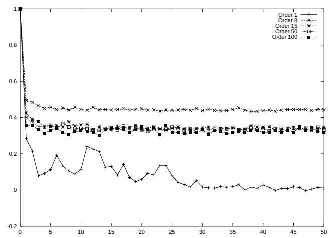
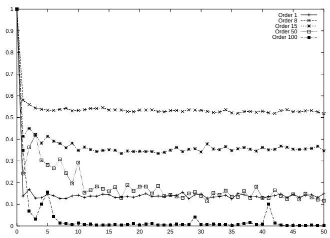


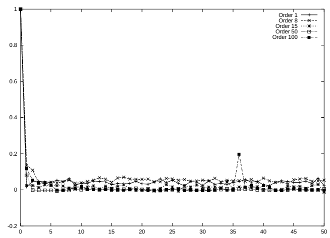
Table 3.9: Normalized Histogram Plots of error runlengths at different burst orders k_0 of Campaign One, Second Sequence of Measurement One



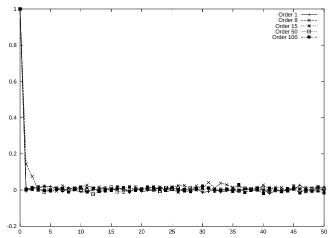
Trace 01



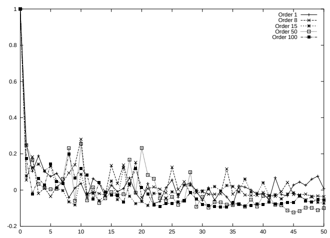
Trace 02



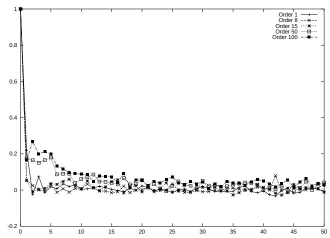
Trace 03



Trace 04

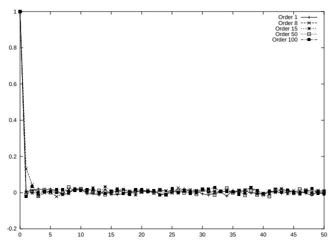


Trace 05

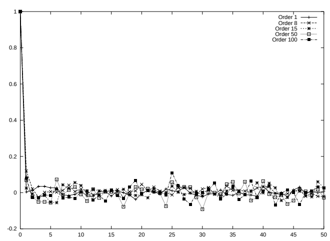


Trace 06

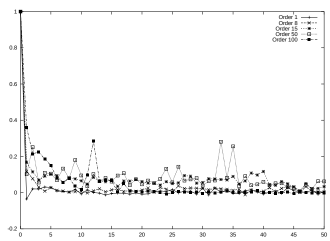
Table 3.10: Autocovariance of Error Runlengths at different burst orders k_0 of Campaign One, First Sequence of Measurement One



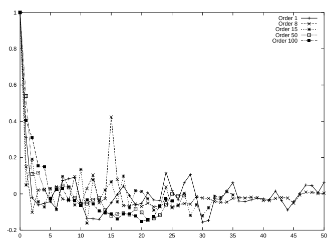
Trace 01



Trace 02



Trace 03



Trace 07

Table 3.11: Autocovariance of Error Runlengths at different burst orders k_0 of Campaign One, Second Sequence of Measurement One

Trace No.	**BER**	**PER**	**Packet Loss Rate**	**Packets Wrong**
Trace 01	0.01939	0.97687	0.00334	19472
Trace 02	0.15491	0.98996	0.1328	17170
Trace 03	0.00033	0.4748	0	9496
Trace 04	0.00177	0.4077	0	8154
Trace 05	0.00000	0.00090	0.00029	18
Trace 06	0.00024	0.05836	0.05765	1100
Trace 07	0.00000	0	0	0
Trace 08	0.00000	0	0	0

Table 3.12: Primary Measurement Results of Campaign One, First Sequence of Measurement One (Part 1)

Trace No.	**Packets Ghost**	**Packets Truncated**	**Packets Oversized**	**Packets Shifted**
Trace 01	92	0	0	0
Trace 02	8	3	2	0
Trace 03	1	0	0	0
Trace 04	0	0	0	0
Trace 05	0	0	0	0
Trace 06	0	0	0	0
Trace 07	0	0	0	0
Trace 08	0	0	0	0

Table 3.13: Primary Measurement Results of Campaign One, First Sequence of Measurement One (Part 2)

Trace No.	BER	PER	Packet Loss Rate	Packets Wrong
Trace 01	0.00023	0.43165	0	8633
Trace 02	0.00052	0.17624	0.74325	905
Trace 03	0.00023	0.4149	0	8298
Trace 05	0.00000	0	0	0
Trace 06	0.00000	0	0	0
Trace 07	0.00000	0.00020	0	4
Trace 08	0.00000	0	0	0

Table 3.14: Primary Measurement Results of Campaign One, Second Sequence of Measurement One (Part 1)

Trace No.	Packets Ghost	Packets Truncated	Packets Oversized	Packets Shifted
Trace 01	0	0	0	0
Trace 02	1	0	0	0
Trace 03	1	0	0	0
Trace 05	0	0	0	0
Trace 06	0	0	0	0
Trace 07	0	0	0	0
Trace 08	0	0	0	0

Table 3.15: Primary Measurement Results of Campaign One, Second Sequence of Measurement One (Part 2)

Parameter	**Value**
PreambleLength	128 bits
ScramblingEnabled	False
Gap Time	1000 μsec
SFD Threshold	152
Frequency	12
NumPackets	20000
NumChunks	28
CRCUsageEnabled	False
DiversityEnabled	False
PacketSize	1000 bytes

Table 3.18: Fixed Parameters for Campaign One, Measurement Two

3.2 Measurement Two

The second measurement intended to find out the behavior of IEEE 802.11 PHY when increasing the transmission distance. Therefore the distance between transmitter and receiver was incremented by 5 meters starting at a distance of 30 meters. At the distance of 50 meters the increments were reduced to 2 and 3 meters. The distance boundary is 60 meters, simply given by the restricted length of the Ethernet cable used for synchronization between transmitter and receiver station. Also, the measurement included a switching between 3 different modulation techniques and therefore three different transmission speeds. All together, 3 traces at 7 different distance points were recorded, summing up to 21 traces for this measurement. Since the influence of space diversity was evaluated in the first measurement of this campaign, space diversity was kept disabled. This applies also to the packet size.

3.2.1 Measurement Parameters

The Tables 3.18 and 3.19 below display the exact fixed and variable parameters used during this measurement. In Table 3.20 the mapping of trace numbers to the parameters used is given.

Parameter	**Value**
Rx-Tx-Distance	30, 40, 45, 50, 53, 55 and 57 meter
ModulationCode	1 MBit BPSK vs.2 MBit QPSK vs.11 MBit CCK

Table 3.19: Variable Parameters for Campaign One, Measurement Two

Trace No.	**Description**
Trace 01	Distance of 30 meters, 1 MBit BPSK
Trace 02	Distance of 30 meters, 2 MBit QPSK
Trace 03	Distance of 30 meters, 11 MBit CCK
Trace 04	Distance of 40 meters, 1 MBit BPSK
Trace 05	Distance of 40 meters, 2 MBit QPSK
Trace 06	Distance of 40 meters, 11 MBit CCK
Trace 07	Distance of 45 meters, 1 MBit BPSK
Trace 08	Distance of 45 meters, 2 MBit QPSK
Trace 09	Distance of 45 meters, 11 MBit CCK
Trace 10	Distance of 50 meters, 1 MBit BPSK
Trace 11	Distance of 50 meters, 2 MBit QPSK
Trace 12	Distance of 50 meters, 11 MBit CCK
Trace 13	Distance of 53 meters, 1 MBit BPSK
Trace 14	Distance of 53 meters, 2 MBit QPSK
Trace 15	Distance of 53 meters, 11 MBit CCK
Trace 16	Distance of 55 meters, 1 MBit BPSK
Trace 17	Distance of 55 meters, 2 MBit QPSK
Trace 18	Distance of 55 meters, 11 MBit CCK
Trace 19	Distance of 57 meters, 1 MBit BPSK
Trace 20	Distance of 57 meters, 2 MBit QPSK
Trace 21	Distance of 57 meters, 11 MBit CCK

Table 3.20: Trace Key of Campaign One, Measurement Two

3.2.2 Occurences during the Measurement

During this measurement, several events happened. First of all it was planned to record traces also at a distance of 60 meter, which was not possible due to a too short ethernet cable connecting the sending and receiving unit. Second it turned out to be difficult to keep the power unit running because of cold winds. This led several times to power shortages, resulting in rebooting of the units.

Also, the sending unit had to be rebooted several times due to an unknown error, maybe due to imperfect power supply, since under laboratory conditions the computers worked just fine. This occurred at the distance points of 53, 45, 40 and 30 meters. Beside this, the measurements related to the distance points of 20 and 25 were skipped due to the lack of time. During the whole measurement no cars passed.

3.2.3 Measurement Results

The bit error rates for the IEEE 802.11 PHY CCK modulation type has at all captured distances distinct high error rate values compared to the BPSK and QPSK modulation type, see Figures 3.8, 3.9 and Table 3.25. At most distances nearly all packets, which were transmitted using the CCK modulation type, were wrong at a packet size of 1000 bytes, because of the relatively high bit error rate.

Comparing the two lower modulation types to each other the difference in bit error rates are mostly very small. This means that using QPSK results in twice the efficiency of transmission. And even at the distance of 57 meters data was transmitted using QPSK modulation at bit error rates which is on a similar level as in the traces at 30 or 40 meters distance as shown in table 3.25.

At some distances we had a strong loss of packets. For example at 53 meters distance more than 75 percent of the transmitted packets were lost at all three types of modulation. Furthermore listed in Table 3.25 as well at the distances of 40 and 45 meters we lost a high number of packets transmitted at the CCK modulation type. On one hand this may be a hint to the presence of destructive interference patters at the positions were the receiving unit was placed to capture the traces. But on the other hand we encountered several freezes during the traces at these distances as mentioned before. So in this case a malfunction of the used hard- or software may also be the reason for the dramatic packet loss at these traces.

Like in the first measurement of this campaign bit errors tend to occur in the beginning of the packets. This is shown in the error position histograms in Table 3.22.

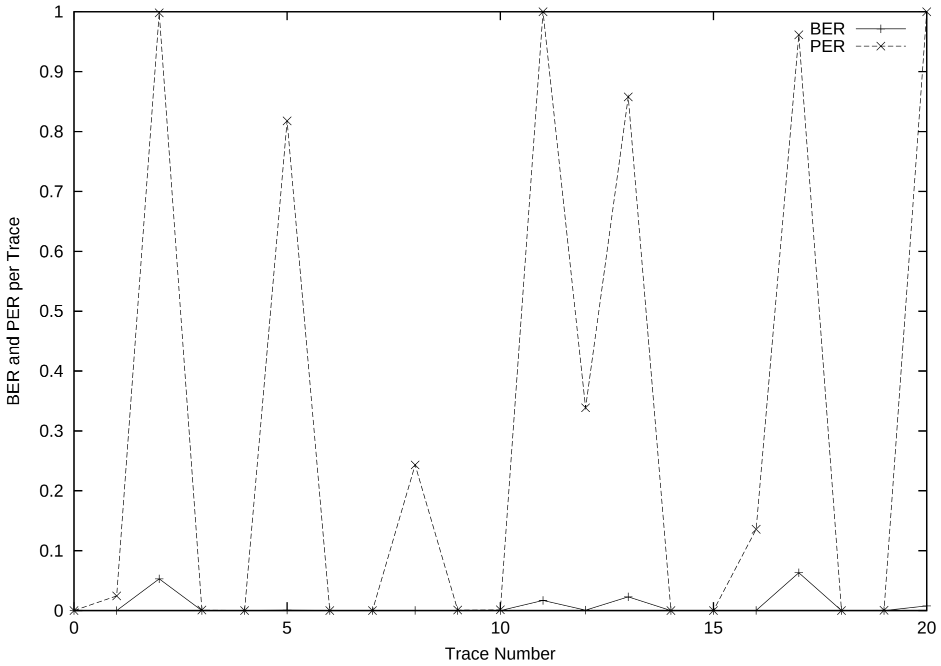


Figure 3.8: BER and PER per Trace vs.Tracenumber

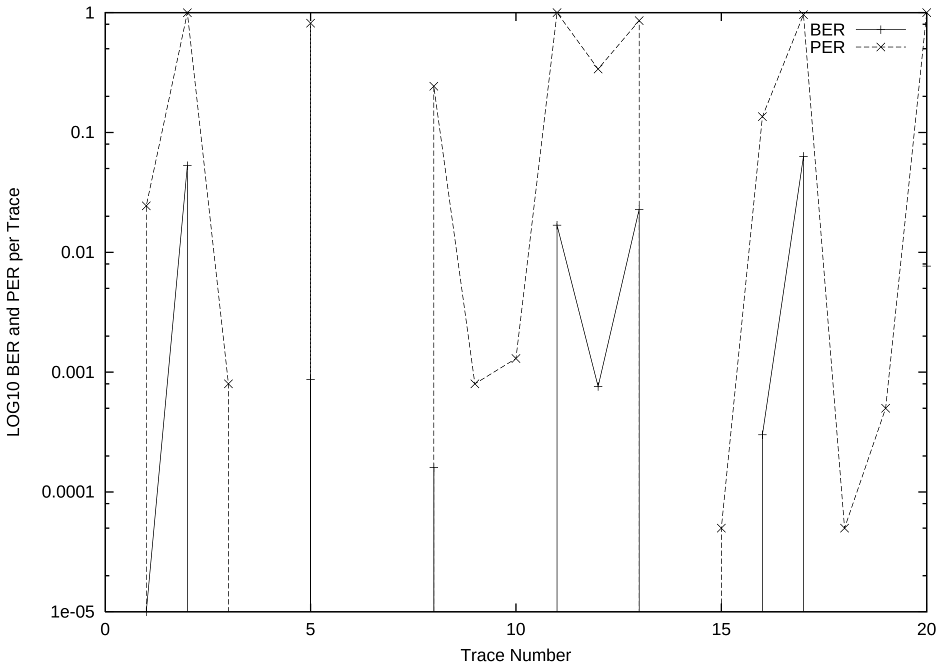


Figure 3.9: Log 10 Scaling of BER and PER per Trace vs. Tracenumber

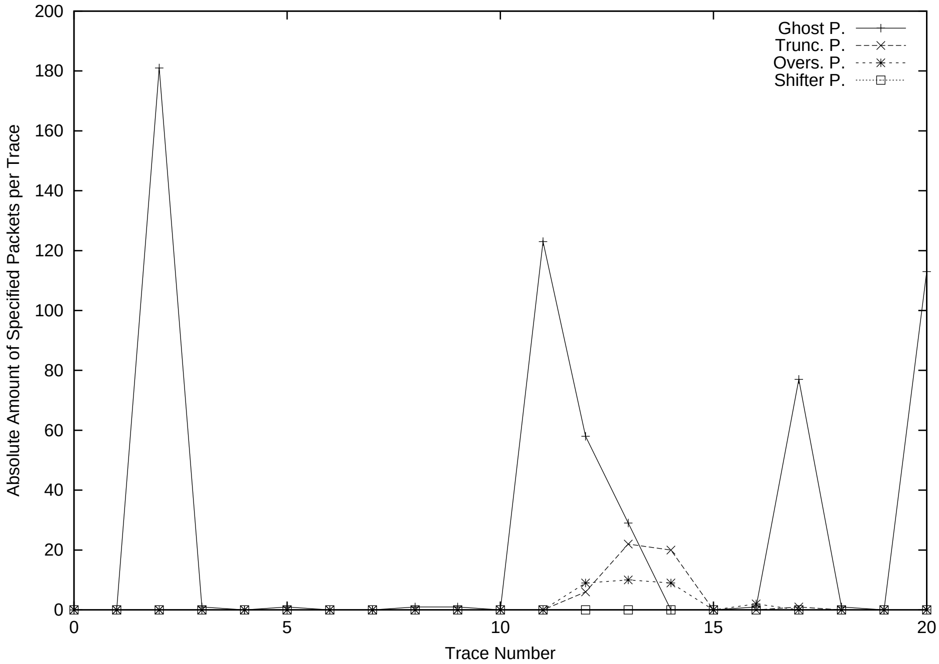


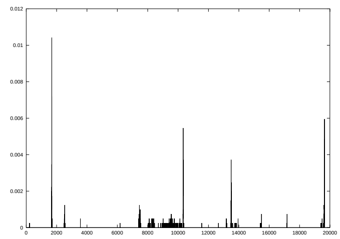
Figure 3.10: Number of Ghost, Truncated, Oversized and Shifter Packets vs. Tracenumber

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 01	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 01	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 01	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 01	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 01	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 02	1	1.26270	0.19369	81097.1	8260833	1.26270	0.19369
Trace 02	8	2.22785	3.82677	103412.	1051238	1.61039	0.38543
Trace 02	15	6.78702	39.3939	134011.	1358483	2.08735	0.22614
Trace 02	50	8.65998	149.063	140429.	1422722	2.18744	0.60392
Trace 02	100	12.5574	614.573	146955.	1487966	2.28923	0.95375
Trace 03	1	1.65808	2.29902	29.6992	33652.8	1.65808	2.29902
Trace 03	8	9.11934	794.914	73.6913	85751.4	4.37879	199.587
Trace 03	15	24.0273	7400.84	123.417	147038.	7.79649	1578.43
Trace 03	50	90.4564	805665.	246.363	308886.	17.8101	134268.
Trace 03	100	231.885	1139098	402.176	529510.	33.5274	1236415
Trace 04	1	2.09090	9.84022	1609575	2239380	2.09090	9.84022
Trace 04	8	2.95402	18.7105	1829062	2544199	2.37931	11.9135
Trace 04	15	7.02898	87.5643	2299389	3196932	3.00000	21.6811
Trace 04	50	19.8823	1030.33	3095321	4300142	4.05882	32.0945
Trace 04	100	58.8055	40134.4	4350151	6035766	5.75000	128.409
Trace 05	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 05	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 05	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 05	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 05	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 06	1	1.26297	0.77340	1437.45	1401186	1.26297	0.77340
Trace 06	8	3.72105	29.5564	2084.38	1899313	1.83333	2.68080
Trace 06	15	19.7087	534.236	4458.02	3018315	3.93361	14.0341
Trace 06	50	43.4396	2722.72	6676.79	3054643	5.86473	39.0799
Trace 06	100	63.6704	4061.63	7880.81	2669575	6.93714	46.9541
Trace 07	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 07	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 07	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 07	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 07	100	nan	0.00000	1612719	0.00000	0.00000	0.00000

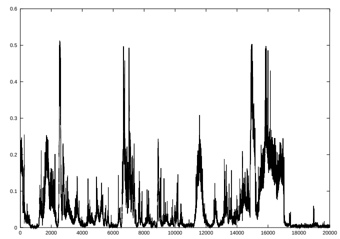
Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 08	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 08	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 08	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 08	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 08	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 09	1	1.23528	0.24097	7501.32	3822346	1.23528	0.24097
Trace 09	8	4.35935	31.3651	11780.2	5500192	1.94037	1.96686
Trace 09	15	16.8946	328.292	21839.9	8005605	3.59909	7.45783
Trace 09	50	32.9853	1475.29	29755.9	8557736	4.90116	19.0019
Trace 09	100	42.2604	2070.53	32532.6	8456576	5.35851	20.9215
Trace 10	1	2.45283	11.7383	1491161	5927960	2.45283	11.7383
Trace 10	8	2.75000	14.4875	1579745	6269503	2.60000	12.8000
Trace 10	15	5.80722	102.348	1899453	7492160	3.13253	37.3197
Trace 10	50	10.9041	448.305	2156132	8462383	3.56164	42.7667
Trace 10	100	24.7777	2344.90	2493016	9720302	4.12698	49.6346
Trace 11	1	1.13043	0.11342	3431316	3836829	1.13043	0.11342
Trace 11	8	3.33333	1.11111	5759708	5146065	1.92592	0.06858
Trace 11	15	3.92307	4.76331	5973030	5211672	2.00000	0.00000
Trace 11	50	3.92307	4.76331	5973030	5211672	2.00000	0.00000
Trace 11	100	3.92307	4.76331	5973030	5211672	2.00000	0.00000
Trace 12	1	1.33941	0.68040	78.2208	29092.1	1.33941	0.68040
Trace 12	8	4.67598	36.3134	133.851	43380.3	2.33214	3.74310
Trace 12	15	12.3500	333.717	199.163	53873.2	3.56088	13.3300
Trace 12	50	27.0494	3169.67	258.222	59134.4	4.80264	60.6038
Trace 12	100	61.8782	12337.4	323.186	63465.0	6.48266	115.655
Trace 13	1	2.56873	18.7799	3378.38	4764597	2.56873	18.7799
Trace 13	8	3.04179	24.7587	3653.36	5142818	2.77805	21.1849
Trace 13	15	6.20455	99.4843	4402.17	6167850	3.34951	40.7436
Trace 13	50	11.6163	672.340	5075.52	7083768	3.86537	71.8276
Trace 13	100	22.6626	6309.78	5732.06	7976490	4.37278	120.060
Trace 14	1	1.69439	7.12030	72.3919	1870666	1.69439	7.12030
Trace 14	8	4.20181	45.7062	110.455	2890973	2.62226	17.1244
Trace 14	15	12.7685	286.914	162.963	4423004	4.01909	43.9328
Trace 14	50	44.5875	6659.71	263.740	7736656	7.05170	265.899
Trace 14	100	138.017	95843.0	420.970	1397118	12.7844	2257.71
Trace 15	1	nan	0.00000	0.00000	0.00000	0.00000	0.00000
Trace 15	8	nan	0.00000	0.00000	0.00000	0.00000	0.00000
Trace 15	15	nan	0.00000	0.00000	0.00000	0.00000	0.00000
Trace 15	50	nan	0.00000	0.00000	0.00000	0.00000	0.00000
Trace 15	100	nan	0.00000	0.00000	0.00000	0.00000	0.00000
Trace 16	1	1.93367	0.93947	818596.	1282568	1.93367	0.93947
Trace 16	8	10.5857	433.899	2271311	3557724	5.41428	84.5569
Trace 16	15	29.9722	3512.63	4358453	6824303	10.5277	440.582
Trace 16	50	203.222	133509.	1612620	2518867	42.1111	8545.87
Trace 16	100	750.333	923950.	4031540	6256340	126.333	29444.2

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 17	1	1.48508	4.84693	4850.47	8887269	1.48508	4.84693
Trace 17	8	2.77519	21.6833	6390.64	1170102	1.95690	10.3476
Trace 17	15	8.61023	105.272	8794.70	1609066	2.69457	21.1951
Trace 17	50	15.2794	994.233	10279.2	1880131	3.15105	46.5912
Trace 17	100	31.0728	9702.53	12134.7	2219681	3.72388	254.654
Trace 18	1	1.56144	1.48119	23.1803	8762.12	1.56144	1.48119
Trace 18	8	8.62610	700.347	55.3808	20970.9	4.03946	172.647
Trace 18	15	22.7163	5884.94	89.8711	34128.7	7.10536	1173.98
Trace 18	50	86.3368	410732.	167.125	65975.6	15.9959	49476.4
Trace 18	100	244.041	1302100	264.983	113225.	32.1237	1170556
Trace 19	1	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 19	8	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 19	15	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 19	50	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 19	100	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 20	1	1.53846	0.24852	1151942	5983121	1.53846	0.24852
Trace 20	8	1.83333	0.63888	1240553	6362628	1.66666	0.22222
Trace 20	15	4.60000	22.4400	1466108	7271397	2.00000	0.00000
Trace 20	50	4.60000	22.4400	1466108	7271397	2.00000	0.00000
Trace 20	100	4.60000	22.4400	1466108	7271397	2.00000	0.00000
Trace 21	1	1.34275	0.63306	173.291	229901.	1.34275	0.63306
Trace 21	8	4.93599	42.1792	300.959	364715.	2.35201	3.88635
Trace 21	15	13.4054	446.704	465.433	496013.	3.68177	16.7369
Trace 21	50	26.3387	3331.01	601.226	572235.	4.82532	63.6200
Trace 21	100	45.5092	8184.43	704.383	618504.	5.76590	93.2556

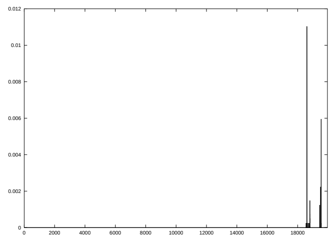
Table 3.27: Further Statistical Measurement Results of Campaign One, Measurement Two



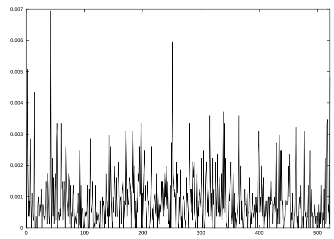
Trace 02



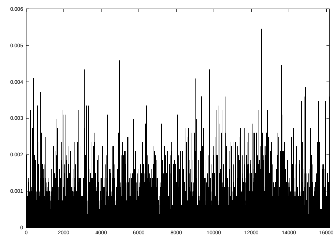
Trace 03



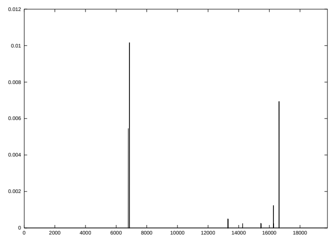
Trace 04



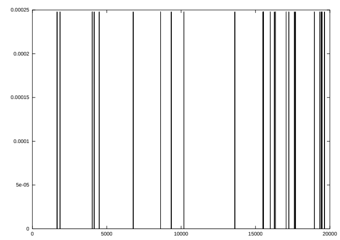
Trace 06



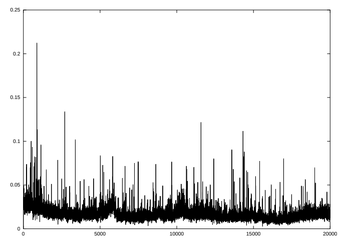
Trace 09



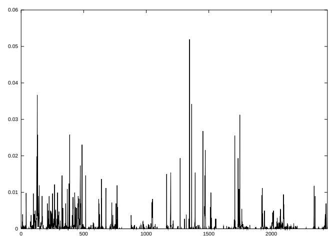
Trace 10



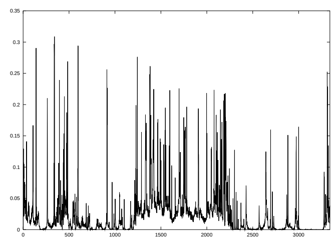
Trace 11



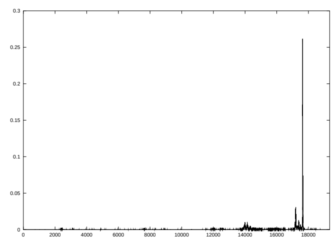
Trace 12



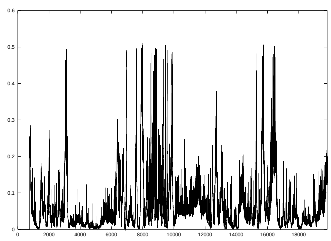
Trace 13



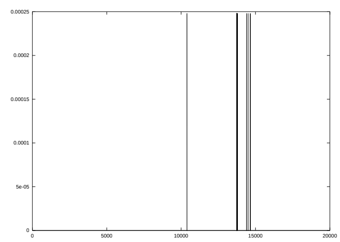
Trace 14



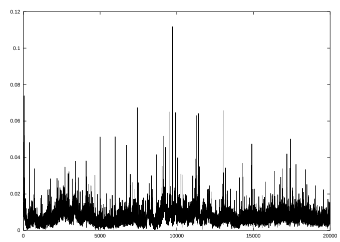
Trace 17



Trace 18

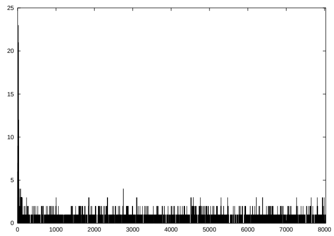


Trace 20

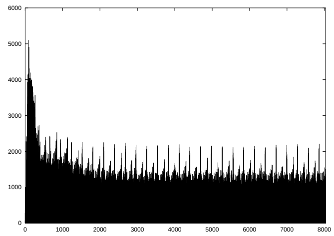


Trace 21

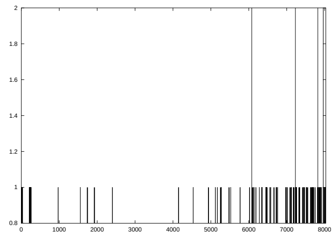
Table 3.21: BER per packet vs. packet number: Campaign One, Measurement Two



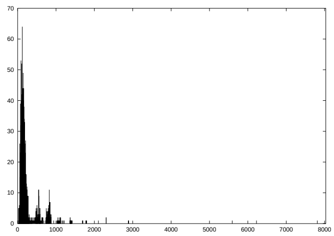
Trace 02



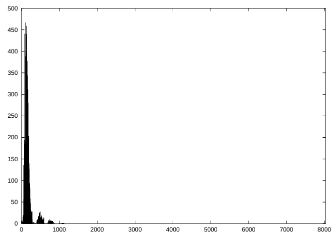
Trace 03



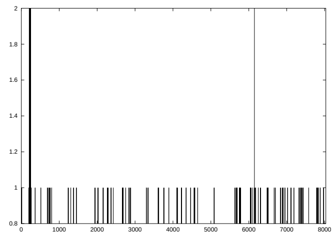
Trace 04



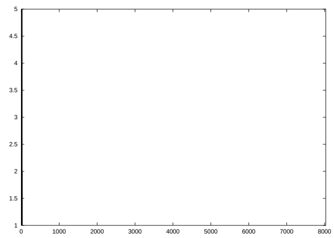
Trace 06



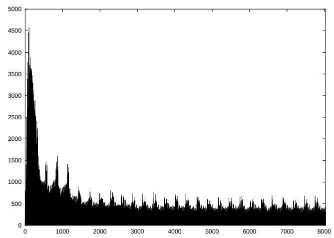
Trace 09



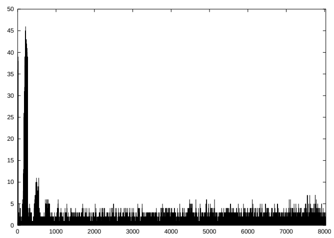
Trace 10



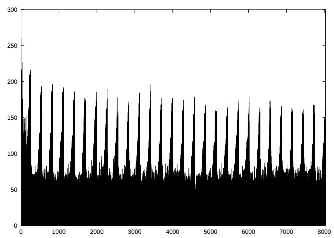
Trace 11



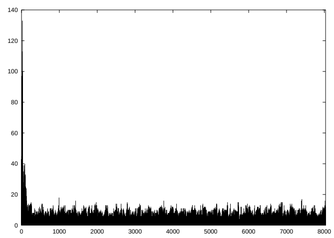
Trace 12



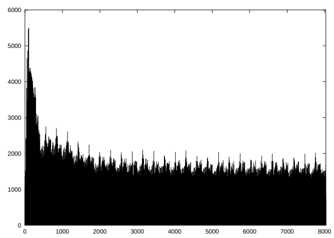
Trace 13



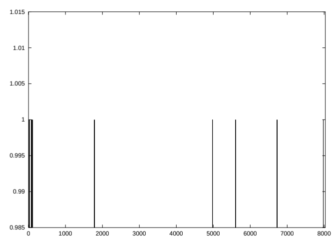
Trace 14



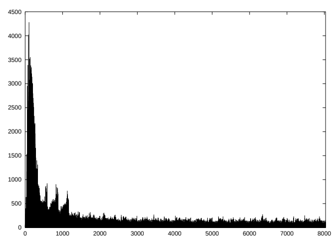
Trace 17



Trace 18

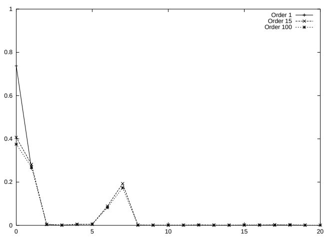


Trace 20

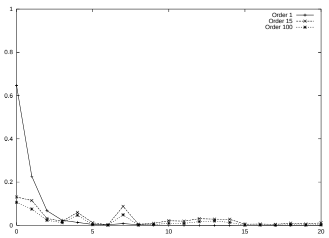


Trace 21

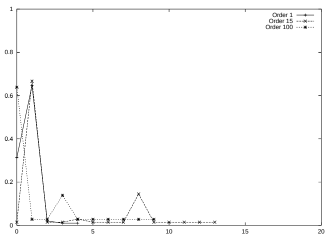
Table 3.22: Error position histograms: Campaign One, Measurement Two



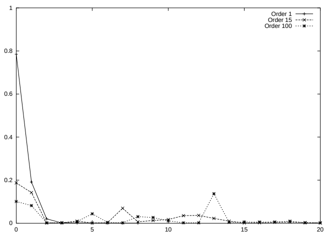
Trace 02



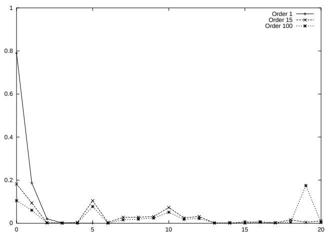
Trace 03



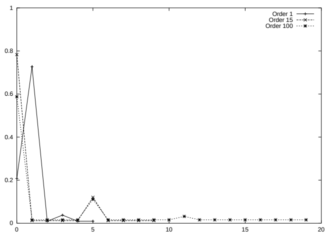
Trace 04



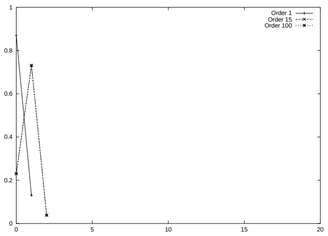
Trace 06



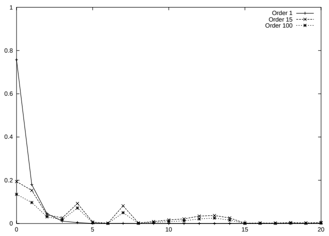
Trace 09



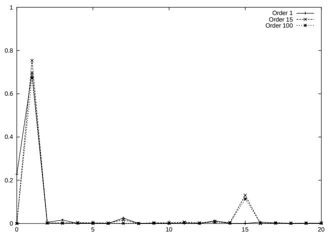
Trace 10



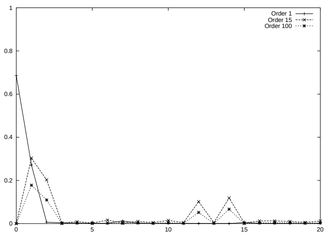
Trace 11



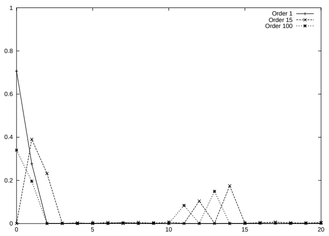
Trace 12



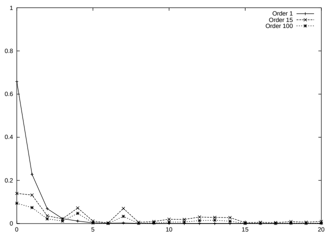
Trace 13



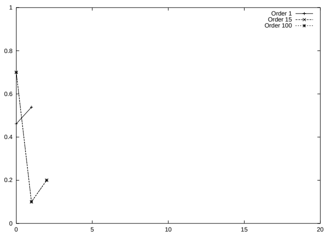
Trace 14



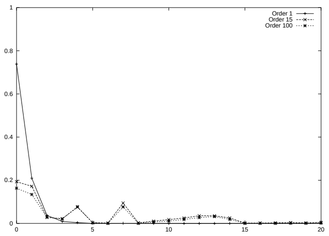
Trace 17



Trace 18

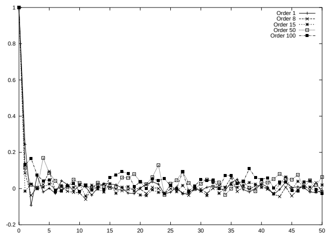


Trace 20

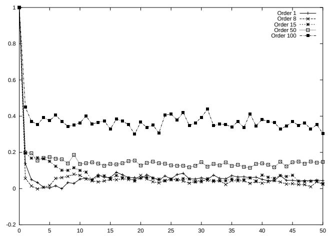


Trace 21

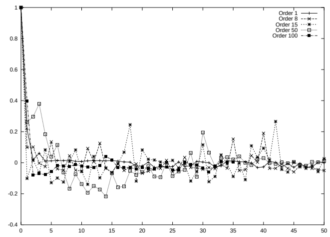
Table 3.23: Normalized Histogram Plots of error runlengths at different burst orders k_0 of Campaign One, Measurement Two



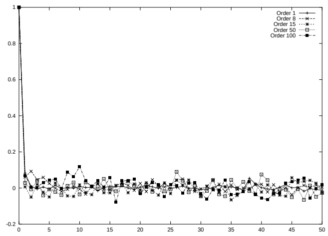
Trace 02



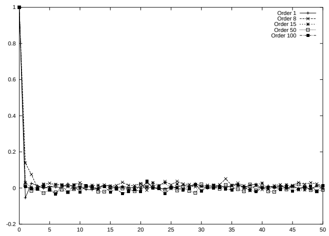
Trace 03



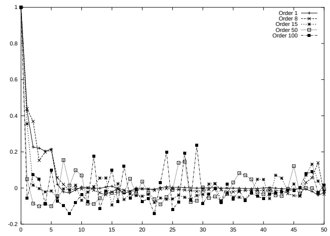
Trace 04



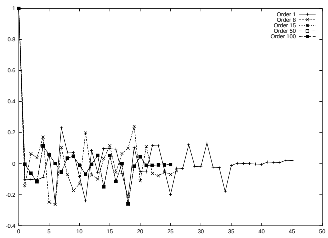
Trace 06



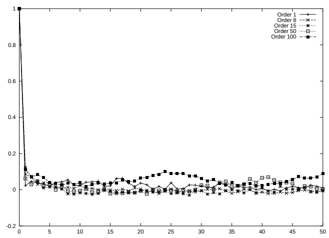
Trace 09



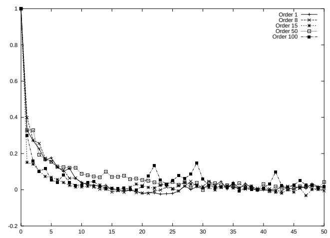
Trace 10



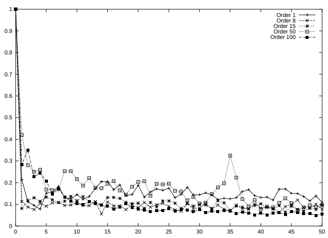
Trace 11



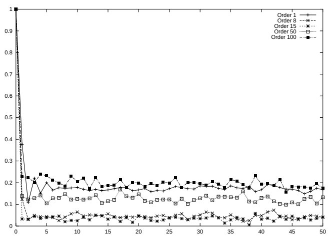
Trace 12



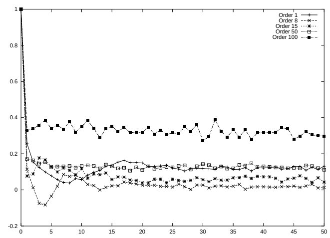
Trace 13



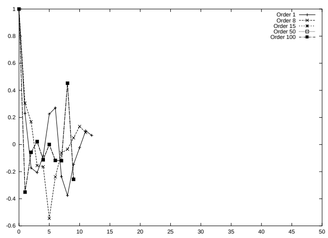
Trace 14



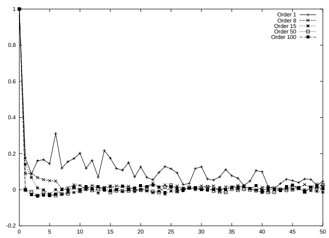
Trace 17



Trace 18



Trace 20



Trace 21

Table 3.24: Autocovariance of error runlengths for different burst orders k_0 of Campaign One, Measurement Two

Trace No.	BER	PER	Packet Loss Rate	Packets Wrong
Trace 01	0.00000	0	0	0
Trace 02	0.00001	0.02445	0.00029	489
Trace 03	0.05287	0.99814	0.00080	19947
Trace 04	0.00000	0.00080	0.00190	16
Trace 05	0.00000	0	0	0
Trace 06	0.00087	0.81765	0.97395	426
Trace 07	0.00000	0	0	0
Trace 08	0.00000	0	0	0
Trace 09	0.00016	0.24319	0.1922	3929
Trace 10	0.00000	0.00080	0.01060	16
Trace 11	0.00000	0.0013	0	26
Trace 12	0.01683	0.99995	0	19999
Trace 13	0.00076	0.33864	0.8776	829
Trace 14	0.02287	0.85778	0.833	2865
Trace 15	0	0	0.78155	0
Trace 16	0.00000	0.00005	0.00005	1
Trace 17	0.00030	0.13566	0.0329	2624
Trace 18	0.06311	0.96155	0.00895	19059
Trace 19	0.00000	0.00005	0	1
Trace 20	0.00000	0.0005	0	10
Trace 21	0.00768	0.99995	0	19999

Table 3.25: Primary Measurement Results of Campaign One, Measurement Two (Part 1)

Trace No.	**Packets Ghost**	**Packets Truncated**	**Packets Oversized**	**Packets Shifted**
Trace 01	0	0	0	0
Trace 02	0	0	0	0
Trace 03	181	0	0	0
Trace 04	1	0	0	0
Trace 05	0	0	0	0
Trace 06	1	0	0	0
Trace 07	0	0	0	0
Trace 08	0	0	0	0
Trace 09	1	0	0	0
Trace 10	1	0	0	0
Trace 11	0	0	0	0
Trace 12	123	0	0	0
Trace 13	58	6	9	0
Trace 14	29	22	10	0
Trace 15	0	20	9	0
Trace 16	0	0	0	0
Trace 17	1	0	2	0
Trace 18	77	1	0	0
Trace 19	1	0	0	0
Trace 20	0	0	0	0
Trace 21	113	0	0	0

Table 3.26: Primary Measurement Results of Campaign One, Measurement Two (Part 2)

Parameter	**Value**
PreambleLength	128 bits
ScramblingEnabled	False
Gap Time	1000 μsec
SFD Threshold	152
Frequency	12
NumPackets	20000
NumChunks	28
CRCUsageEnabled	False
DiversityEnabled	False
PacketSize	500 bytes
Rx-Tx-Distance	$\approx$ 20 meter
ModulationCode	1 MBit BPSK

Table 3.28: Fixed Parameters for Campaign One, Measurement Three

3.3 Measurement Three

The third measurement intended to show long term effects in the area. The expectation here was that only little or no errors occur due to the idle environment.

3.3.1 Measurement Parameters

Table 3.28 holds the parameters used during this measurement. Here no variable parameters were used, since the only variable parameter was the time passing by while recording traces. To keep the focus only on the long term aspect during this measurement, space diversity was disabled and the packetsize was set to 500 bytes. A special description of the traces is not necessary. The trace numbers are given in their order.

3.3.2 Occurences during the Measurement

During measurement three, a couple of cars passed. Originally it was planned to record at least 20 traces, which was not possible due to time constraints. Also, the sending unit had again problems and had to be rebooted after working for ten minutes. So we decided to start over the whole measurement. Then the measurement went fine, till it was interrupted by the project students (after recording 14 traces).

At trace 12 and 13 cars passed the setup for a short time. During trace 14 the project students took one of their cars and disturbed the setup a little bit more intense by passing the equipment several times. During trace 15, the setup was forced to stop. This explains that trace 15 is not complete. It is listed in Tables 3.33, 3.34 and 3.35 as trace, but cannot be interpreted since the units were not able to complete transmission and computing jobs related to the trace.

3.3.3 Measurement Results

In this measurement the bit error rate level decreased during the first traces to a lower level. Beginning with the 11th trace bit error rates increased again. So only plots of the first and the 12th, 13th and 14th trace were shown.

As mentioned before nothing changed during the whole campaign, except for the passing cars. The bit error rate stayed continuously low. This is shown in Figures 3.11 and 3.12 and listed in Table 3.33.

The cars, which passed our setup during the last traces, obviously caused an increase in bit error rates in the last three traces.

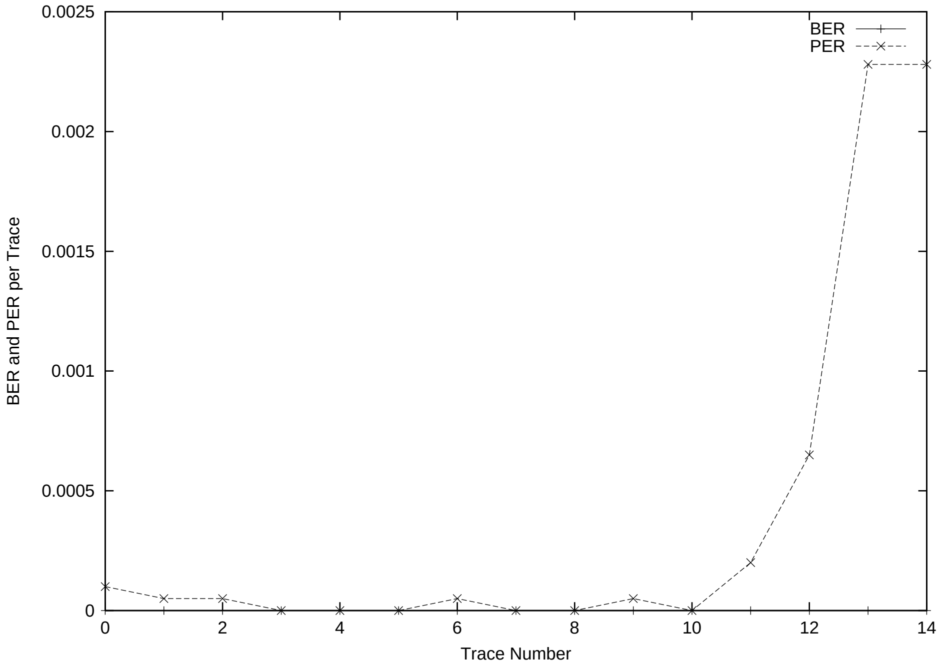


Figure 3.11: BER and PER per Trace vs.Tracenumber

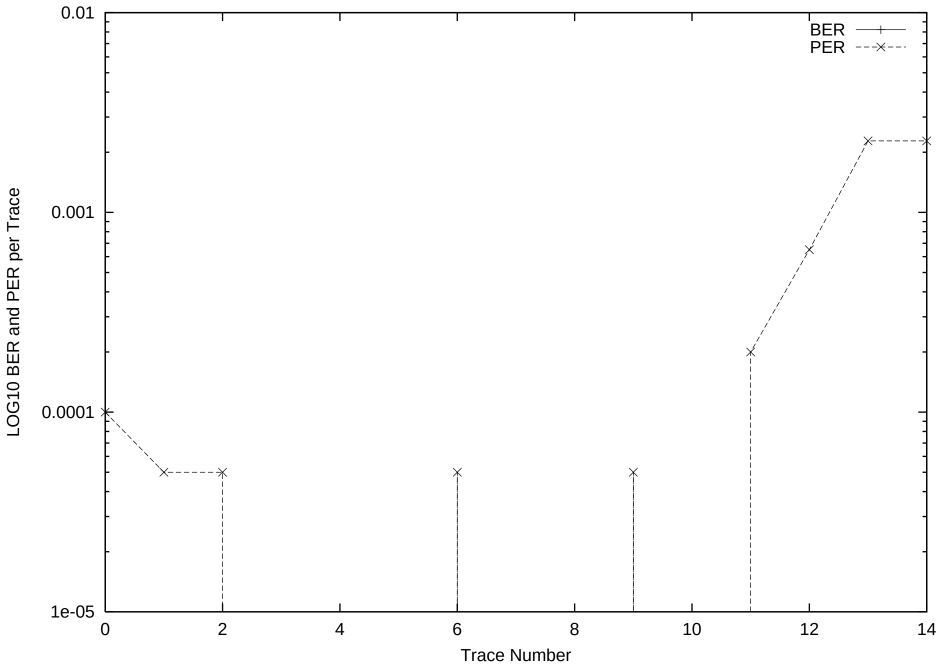


Figure 3.12: Log 10 Scaling of BER and PER per Trace vs. Tracenumber

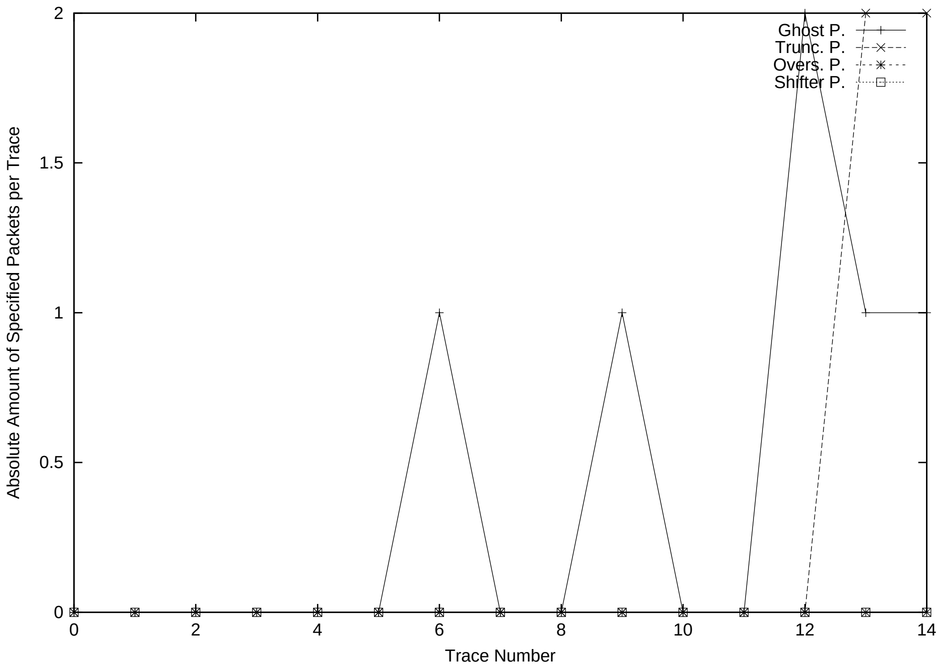
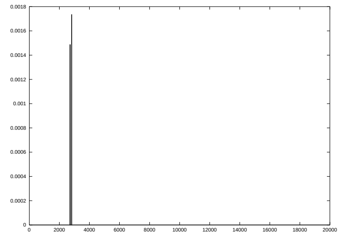
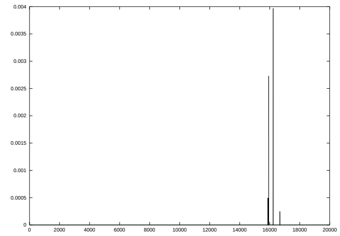


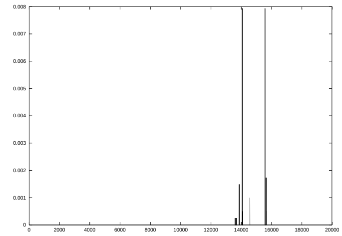
Figure 3.13: Number of Ghost, Truncated, Oversized and Shifter Packets vs. Tracenumber



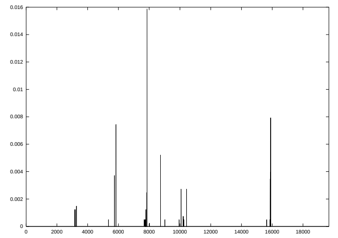
Trace 01



Trace 12



Trace 13



Trace 14

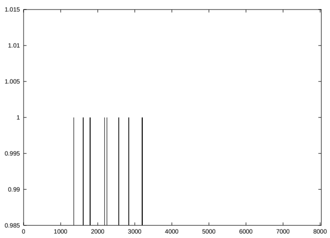
Table 3.29: BER per packet vs. packet number: Campaign One, Measurement Three

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 01	1	1.62500	0.23437	8957758	5242203	1.62500	0.23437
Trace 01	8	1.62500	0.23437	8957758	5242203	1.62500	0.23437
Trace 01	15	1.62500	0.23437	8957758	5242203	1.62500	0.23437
Trace 01	50	1.62500	0.23437	8957758	5242203	1.62500	0.23437
Trace 01	100	10.8571	488.693	1007747	5862132	1.85714	0.12244
Trace 02	1	1.00000	0.00000	8047871	6444224	1.00000	0.00000
Trace 02	8	1.00000	0.00000	8047871	6444224	1.00000	0.00000
Trace 02	15	1.00000	0.00000	8047871	6444224	1.00000	0.00000
Trace 02	50	1.00000	0.00000	8047871	6444224	1.00000	0.00000
Trace 02	100	52.2000	2293.76	1341307	1073604	1.80000	0.56000
Trace 03	1	1.00000	0.00000	2687596	1388063	1.00000	0.00000
Trace 03	8	1.00000	0.00000	2687596	1388063	1.00000	0.00000
Trace 03	15	16.0000	0.00000	4031394	1692651	2.00000	0.00000
Trace 03	50	16.0000	0.00000	4031394	1692651	2.00000	0.00000
Trace 03	100	16.0000	0.00000	4031394	1692651	2.00000	0.00000

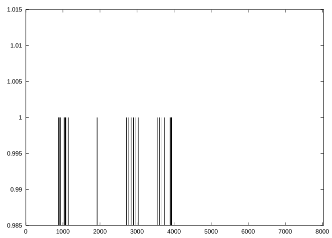
Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 04	1	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 04	8	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 04	15	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 04	50	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 04	100	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 05	1	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 05	8	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 05	15	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 05	50	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 05	100	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 06	1	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 06	8	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 06	15	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 06	50	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 06	100	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 07	1	nan	0.00000	8063193	0.00000	0.00000	0.00000
Trace 07	8	nan	0.00000	8063193	0.00000	0.00000	0.00000
Trace 07	15	nan	0.00000	8063193	0.00000	0.00000	0.00000
Trace 07	50	nan	0.00000	8063193	0.00000	0.00000	0.00000
Trace 07	100	nan	0.00000	8063193	0.00000	0.00000	0.00000
Trace 08	1	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 08	8	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 08	15	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 08	50	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 08	100	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 09	1	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 09	8	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 09	15	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 09	50	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 09	100	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 10	1	nan	0.00000	8063193	0.00000	0.00000	0.00000
Trace 10	8	nan	0.00000	8063193	0.00000	0.00000	0.00000
Trace 10	15	nan	0.00000	8063193	0.00000	0.00000	0.00000
Trace 10	50	nan	0.00000	8063193	0.00000	0.00000	0.00000
Trace 10	100	nan	0.00000	8063193	0.00000	0.00000	0.00000
Trace 11	1	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 11	8	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 11	15	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 11	50	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 11	100	nan	0.00000	8063596	0.00000	0.00000	0.00000
Trace 12	1	1.30434	0.21172	3357982	1744905	1.30434	0.21172
Trace 12	8	1.80952	3.01133	3663253	1899371	1.42857	0.43537
Trace 12	15	2.30000	11.6100	3837693	1987310	1.50000	0.65000
Trace 12	50	12.2666	520.462	5036964	2585313	2.00000	3.46666
Trace 12	100	98.2857	11817.6	1007386	4960063	4.28571	3.63265

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 13	1	2.08510	2.80126	1678323	6796331	2.08510	2.80126
Trace 13	8	2.58139	7.45267	1830898	7399963	2.27907	3.92212
Trace 13	15	5.71428	111.518	2237762	8997736	2.80000	16.6742
Trace 13	50	10.5483	647.150	2517478	1008604	3.16129	21.0385
Trace 13	100	39.4782	3023.03	3356614	1330033	4.26087	26.4536
Trace 14	1	1.76585	6.00371	385212.	4690116	1.76585	6.00371
Trace 14	8	2.01538	8.33309	404865.	4922637	1.85641	6.58451
Trace 14	15	4.17751	60.2288	466784.	5650892	2.14201	18.2875
Trace 14	50	6.74050	197.483	499075.	6028092	2.29113	20.2063
Trace 14	100	37.5855	7471.07	708481.	8430846	3.26126	31.9407
Trace 15	1	nan	0.00000	0.00000	0.00000	0.00000	0.00000
Trace 15	8	nan	0.00000	0.00000	0.00000	0.00000	0.00000
Trace 15	15	nan	0.00000	0.00000	0.00000	0.00000	0.00000
Trace 15	50	nan	0.00000	0.00000	0.00000	0.00000	0.00000
Trace 15	100	nan	0.00000	0.00000	0.00000	0.00000	0.00000

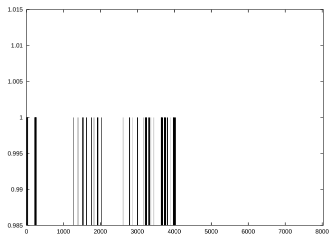
Table 3.35: Further Statistical Measurement Results of Campaign One, Measurement Three



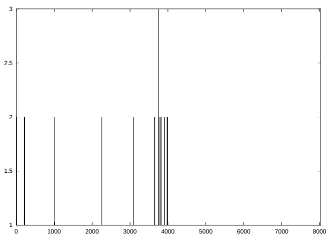
Trace 01



Trace 12

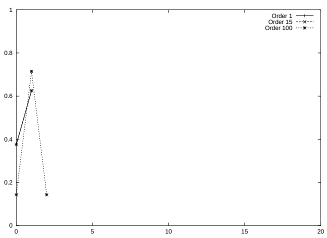


Trace 13

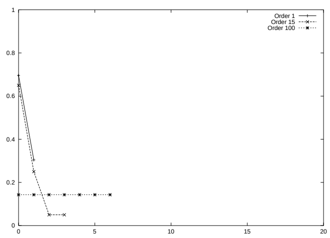


Trace 14

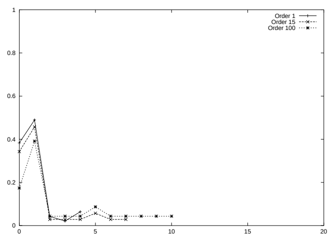
Table 3.30: Error position histograms: Campaign One, Measurement Three



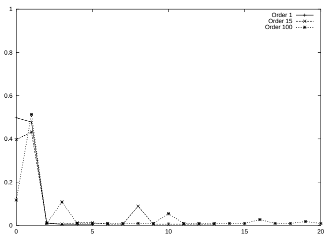
Trace 01



Trace 12

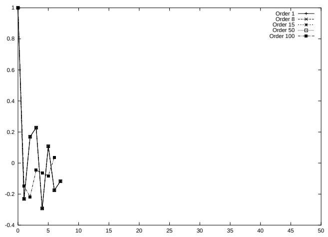


Trace 13

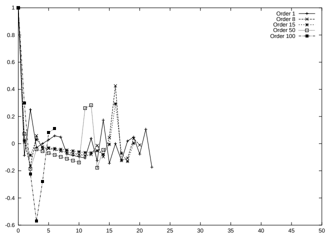


Trace 14

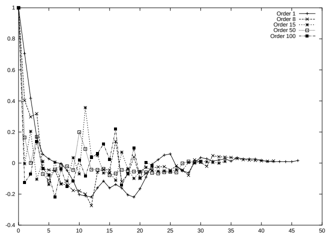
Table 3.31: Normalized Histogram Plots of error runlengths at different burst orders k_0 of Campaign One, Measurement Three



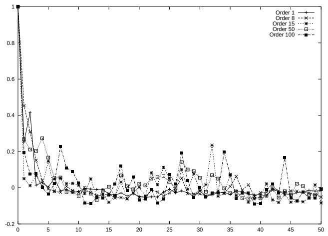
Trace 01



Trace 12



Trace 13



Trace 14

Table 3.32: Autocovariance of error runlengths at different burst orders k_0 of Campaign One, Measurement Three

Trace No.	**BER**	**PER**	**Packet Loss Rate**	**Packets Wrong**
Trace 01	0.00000	0.00010	0.00019	2
Trace 02	0.00000	0.00005	0.00195	1
Trace 03	0.00000	0.00005	0.0001	1
Trace 04	0.00000	0	0	0
Trace 05	0.00000	0	0	0
Trace 06	0.00000	0	0	0
Trace 07	0.00000	0.00005	0	1
Trace 08	0.00000	0	0	0
Trace 09	0.00000	0	0	0
Trace 10	0.00000	0.00005	0	1
Trace 11	0.00000	0	0	0
Trace 12	0.00000	0.00020	0.00055	4
Trace 13	0.00000	0.00065	0.00085	13
Trace 14	0.00000	0.00228	0.01575	45
Trace 15	0	0.00228	0.01575	45

Table 3.33: Primary Measurement Results of Campaign One, Measurement Three (Part 1)

Trace No.	**Packets Ghost**	**Packets Truncated**	**Packets Oversized**	**Packets Shifted**
Trace 01	0	0	0	0
Trace 02	0	0	0	0
Trace 03	0	0	0	0
Trace 04	0	0	0	0
Trace 05	0	0	0	0
Trace 06	0	0	0	0
Trace 07	1	0	0	0
Trace 08	0	0	0	0
Trace 09	0	0	0	0
Trace 10	1	0	0	0
Trace 11	0	0	0	0
Trace 12	0	0	0	0
Trace 13	2	0	0	0
Trace 14	1	2	0	0
Trace 15	1	2	0	0

Table 3.34: Primary Measurement Results of Campaign One, Measurement Three (Part 2)

Chapter 4

Campaign 2: Sportsgym, Berlin, December 2000

The second campaign was performed in the sports gym of the Technical University Berlin, which is located near the Grunewald forest. Like in campaign one no offices nor any industrial buildings were in the adjacency.

Since this campaign happened inside a building, the weather conditions were not important. The sports gym covers three basketball courts in size. The walls are made of stone and the ceiling is a combination of wood and glass. The height of the ceiling is about 15 meters.

The two computers were placed in 20 meters distance to each other. In the first and second measurement of this campaign one computer was near an entry door. After the traces were triggered the project students left the sports gym through this door during the first seconds and so any further interference by moving objects was prevented. During the most transmissions no moving objects were in the sports gym. Recording traces began at 03:00 PM and the last trace was transmitted at 09:00 PM.

In this campaign the goal was to investigate the behavior of errors in a basic interference environment. Since the sports gym has plain walls and a plain floor with no items like tables, chairs or shelves in there, relative simple interference patterns should have occurred. Like in campaign one no other RF-traffic was observed.

In contrast to campaign one, the scenario for campaign two was chosen to expose all measurement measurements to a strong RF reflection environment. For a mobile host the presence of RF reflections produce fading effects, introducing difficult transmission conditions depending on the velocity of the mobile. Fading effects are expected to cause bursty errors. Therefore the aim of the whole campaign was to observe some aspects of the fundamental phenomenon of RF reflections as a condition of fading in mobile transmission. Again the campaign was divided into three different measurements.

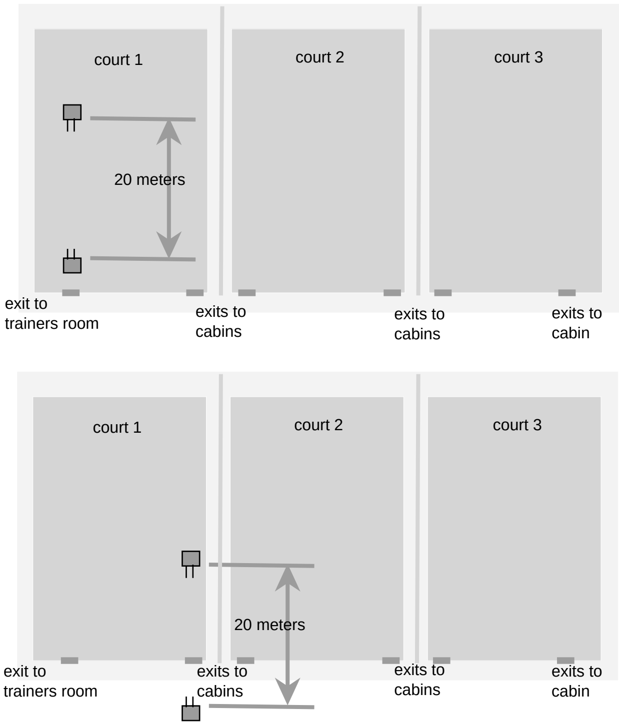


Figure 4.1: Measurement Setup of Campaign Two

4.1 Measurement One

Measurement one was designed to investigate, whether the interference patterns can be made visible. It also intended to demonstrate the ability of diversity to compensate such variable RF patterns. Since the wavelength of the used frequency band (2.4 GHz ISM band) is around 12.5 cm, the receiver was moved 12 times towards the transmitter always using an increment

Parameter	**Value**
PreambleLength	128 bits
ScramblingEnabled	False
Gap Time	1000 μsec
SFD Threshold	152
Frequency	12
NumPackets	20000
NumChunks	28
CRCUsageEnabled	False
ModulationCode	2 MBit QPSK
PacketSize	1000 bytes

Table 4.1: Fixed Parameters for Campaign Two, Measurement One

Parameter	**Value**
Diversity	True vs. False
Rx-Tx-Distance	≈ 20 meter, Position was changed 12 times by 1 centimeter

Table 4.2: Variable Parameters for Campaign Two, Measurement One

of 1 cm. For each distance one trace was observed with space diversity enabled and one without space diversity enabled. By this, the total amount of traces summed to twentyfour. Like in the first measurement of the first campaign the packet size was set to 1000 bytes and the base distance was set to 20 meters. These parameters were kept similar to compare the results among the different measurements. Regarding the other parameters, most of them were left unchanged when comparing this setup to the setups from [3]. The modulation was chosen to 2 MBit QPSK, since higher modulation types appeared to be to unstable in general from campaign one.

Also, the whole measurement was repeated once to produce more data.

4.1.1 Measurement Parameters

The Tables 4.1 and 4.2 display the set of fixed and variable parameters used during this measurement. Furthermore, Table 4.3 gives the mapping from trace numbers to the parameters used.

Trace No.	**Description**
Trace 01	Position One, Diversity deactivated
Trace 02	Position One, Diversity activated
Trace 03	Position Two, Diversity deactivated
Trace 04	Position Two, Diversity activated
Trace 05	Position Three, Diversity deactivated
Trace 06	Position Three, Diversity activated
Trace 07	Position Four, Diversity deactivated
Trace 08	Position Four, Diversity activated
Trace 09	Position Five, Diversity deactivated
Trace 10	Position Five, Diversity activated
Trace 11	Position Six, Diversity deactivated
Trace 12	Position Six, Diversity activated
Trace 13	Position Seven, Diversity deactivated
Trace 14	Position Seven, Diversity activated
Trace 15	Position Eight, Diversity deactivated
Trace 16	Position Eight, Diversity activated
Trace 17	Position Nine, Diversity deactivated
Trace 18	Position Nine, Diversity activated
Trace 19	Position Ten, Diversity deactivated
Trace 20	Position Ten, Diversity activated
Trace 21	Position Eleven, Diversity deactivated
Trace 22	Position Eleven, Diversity activated
Trace 23	Position Twelve, Diversity deactivated
Trace 24	Position Twelve, Diversity activated

Table 4.3: Trace Key of Campaign Two, Measurement One

4.1.2 Occurences during the Measurement

During both sequences only one thing occurred. While recording trace 15 in the second sequence, people entered the empty gym in a distance of 15 meter and activated a removable wall dividing the gym into two parts. The wall consisted of a metal structure with a plastic foil on top. After this these people were playing badminton in the separated part of the hall till measurement two.

4.1.3 Measurement Results

In this measurement we intended to show an interference pattern, as mentioned above. The results displayed in Figures 4.2 and 4.3 indeed suggest, that the measurement setup was surrounded by simple interference patterns; the curves for the measurement and its repetition show the same behaviour. If we consider the viewgraphs of the logarithmic scaling of the bit error rates and packet error rates, it can be observed, that likely we encountered two areas where interference was destructive, while three areas had constructive interference.

For the first measurement we observed the bad areas around trace 6 and trace 17. For the second measurement the bad areas were around trace 5 and trace 16. Between these bad areas, both bit error rate and packet error rate decrease almost to zero, which demarks the good areas with constructive interference.

Interesting about these traces is the correlation between destructive interference areas and areas where bit shifter packets in traces occur more often than else, see Figure 4.4. For both measurements, according to the bad areas bit shifter packets can be observed. This is not valid for the other types of packet errors as there are truncated, ghost and oversized packets. For these packet error types we only observe occasionally a correlation between packet error and bit error rates of traces and the absolute values for these packet error types per trace. It can be observed for trace number 15 of the second measurement sequence. Interestingly, this was the trace where people entered the gym hall and obviously disturbed the measurement environment. For this trace number we also observe a relative high loss of packets overall, where throughout the whole measurement the normal value is 20000 packets that were received per trace. Only one other trace has a similar loss rate, in fact even higher, which is trace number 23 of the first sequence. But in spite of trace 15 of the second sequence, trace 23 has no other remarkable features like trace 15. All values are normal according to the other traces of the first sequence.

A very surprising fact of both sequences here is the impact of space diversity. Remember in the viewgraphs that every second trace value represents the same measurement point but this time the trace was recorded by using space diversity. Therefore in comparing the bit error rate and packet error rate values of each even and odd trace does not show any significant impact on the values induced by space diversity. Also in comparing other trace statistics, there is no significant general difference. Sometimes it also occurs, that bit error statistics get even worse, when using space diversity. This can be observed for the first and second trace of the first sequence. In other cases there is a small gain as result of using space diversity, but nothing significant.

A possible explanation is due to the position of the receiver and transmitter stations antenna pairs relative to each other. Every receiver diversity system needs in the ideal case multiple uncorrelated copies of the same information sequence [1]. For space diversity this can be achieved in general by placing the antennas apart by half the wave length λ, which is for a 2.4 GHz system $\lambda \approx 12.5$ cm. Therefore the antennas have to be ≈ 6 cm apart to achieve decorrelated signals. But this is also dependent on the interference pattern encountered. In this case the antennas had the same distance radius to the transmitter, since the hard case of the computer was positioned with its back side towards the transmitter. As we can see from the bit error rates viewgraphs in Figures 4.2 and 4.3, our interference pattern was aligned in direction of the line of sight between transmitter and receiver. Now if the antennas never have a different distance towards the transmitter, they will likely encounter the same signal to noise ratio (SNR), if we consider the interference pattern in orthogonal direction of the line of sight to be without significant effect. This could be the case here, since the main reflection objects were probably the floor and the wall behind the receiving terminal. If this was really the case, it would explain that space diversity was not able to improve the statistics of our traces.

When observing the single trace statistics, several things are characteristic. First of all one can observe the typical plots for bit shifter traces. Especially traces 5 - 10 and traces 21 and 22 of the first measurement sequence have these characteristic behavior (see Figure 4.4. It can be observed by viewing at the biterror position histograms, where complete black areas are a strong hint for many shifted packets.

Interesting is for traces 17 and 18 the amount of regular bit error patterns throughout all bit positions. If one also takes the packet error statistics into account, the error patterns differ clearly from the other ones of that sequence. For these two traces, the errors tend to be very frequently (almost in every packet, which can be seen from the packet error rate), but they are not very severe, meaning that the absolute amount of wrong bits per packet is not very high (see Tables 4.4, 4.5 and 4.6). The histogram of burst lengths for several burst orders k_0 (see Tables 4.10 and 4.11) show a wide distribution of error burst lengths, with a few strongly preferred burst orders, which tend to be small. This pattern will be encountered in measurement three again. Important here is that bit shifter packets for this trace type do not occur at all.

Trace 19 and 20 of the first measurement sequence have also an interesting behavior. Here only one single burst type occurs very frequently. The error type always occurs at the beginning of the packets of these traces. Also, no bit shifter occur at these traces. The second measurement sequence shows quite similar results. Here we also encounter multiple bit shifter traces, namely several traces from trace number 3 to trace number 8 and another set of traces from trace number 19 to trace number 22. In between we observe again traces with frequent but not that severe bit errors, beginning from trace number 15. This could be influenced though by the environment disturbance described above.

Still traces 15 to 18 show small bit error rates for almost every packet. Observing trace 15 shows that the disturbance began at the middle of the trace since up to the middle of the trace almost no errors occurred at all. Also the histograms over the length of bursts show for all traces a lot of short bursts, while longer bursts are seldom (which is not completely true for trace 18).

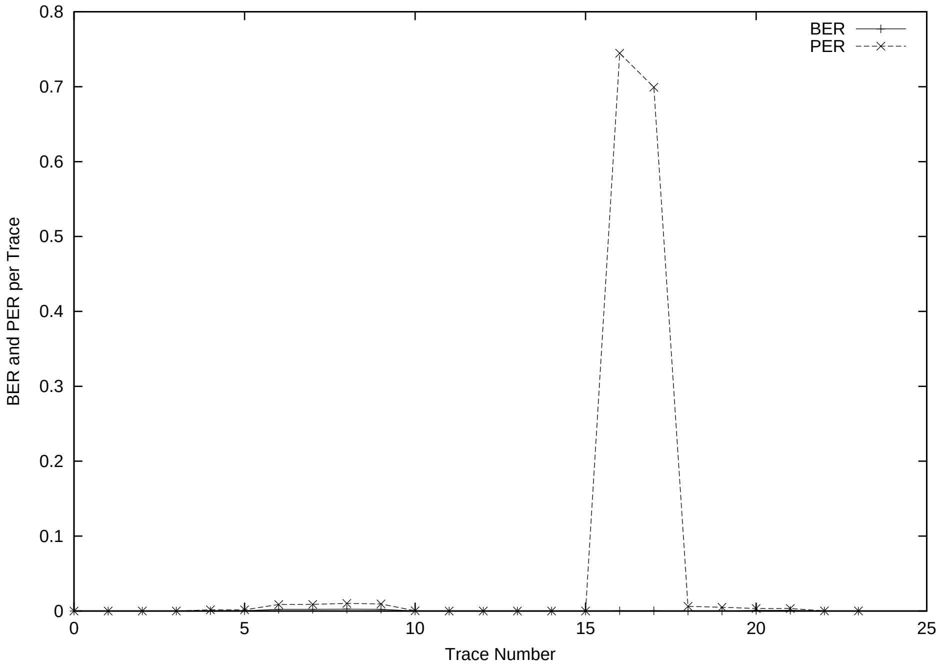


Figure 4.2: BER and PER per Trace vs.Tracenumber First Sequence

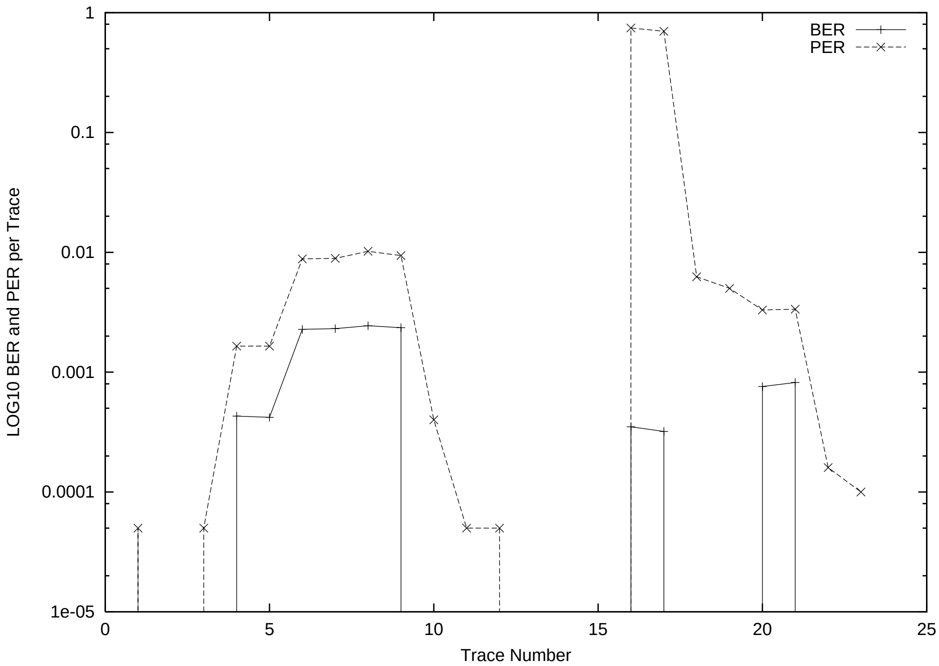


Figure 4.3: Log 10 Scaling of BER and PER per Trace vs. Tracenumber First Sequence

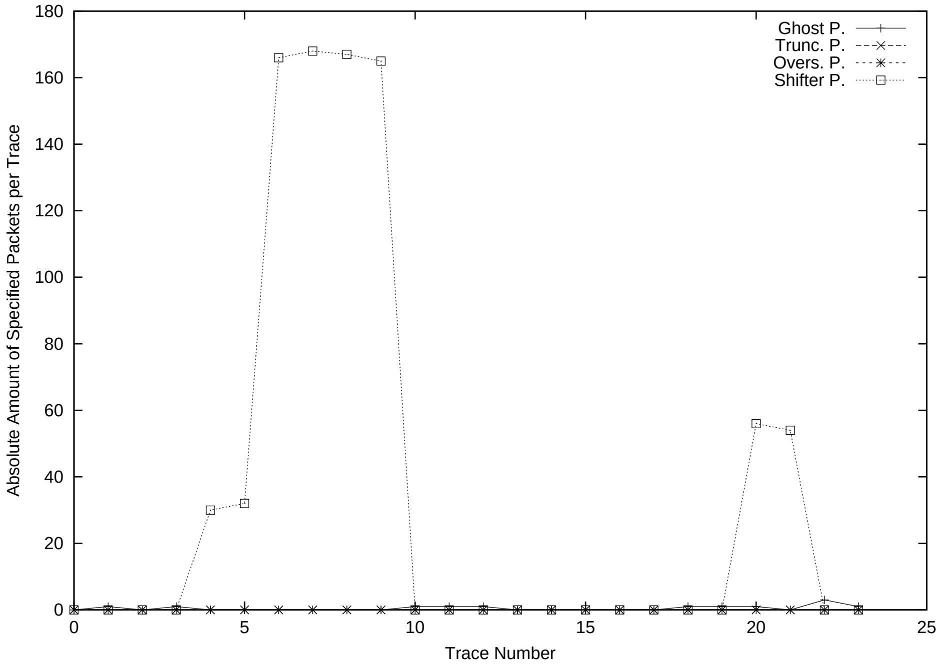


Figure 4.4: Number of Ghost, Truncated, Oversized and Shifter Packets vs. Tracenumber

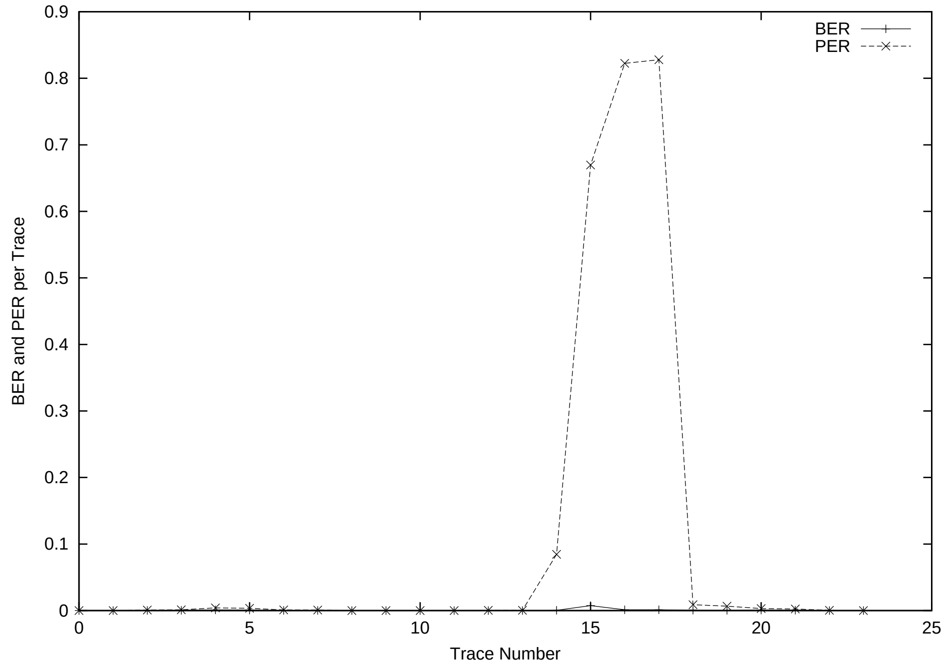


Figure 4.5: BER and PER per Trace vs.Tracenumber First Sequence

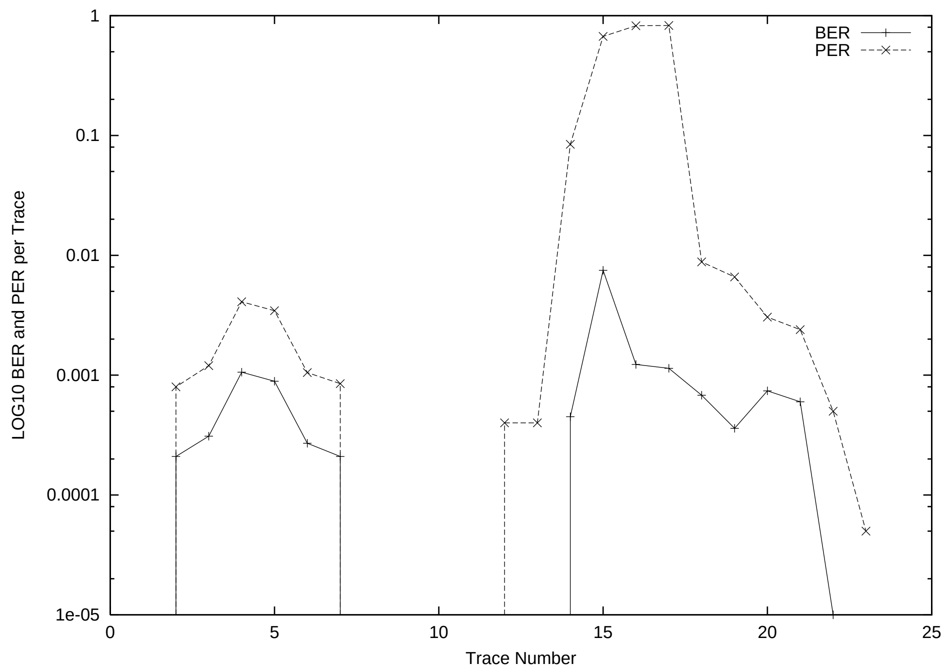


Figure 4.6: Log 10 Scaling of BER and PER per Trace vs. Tracenumber First Sequence

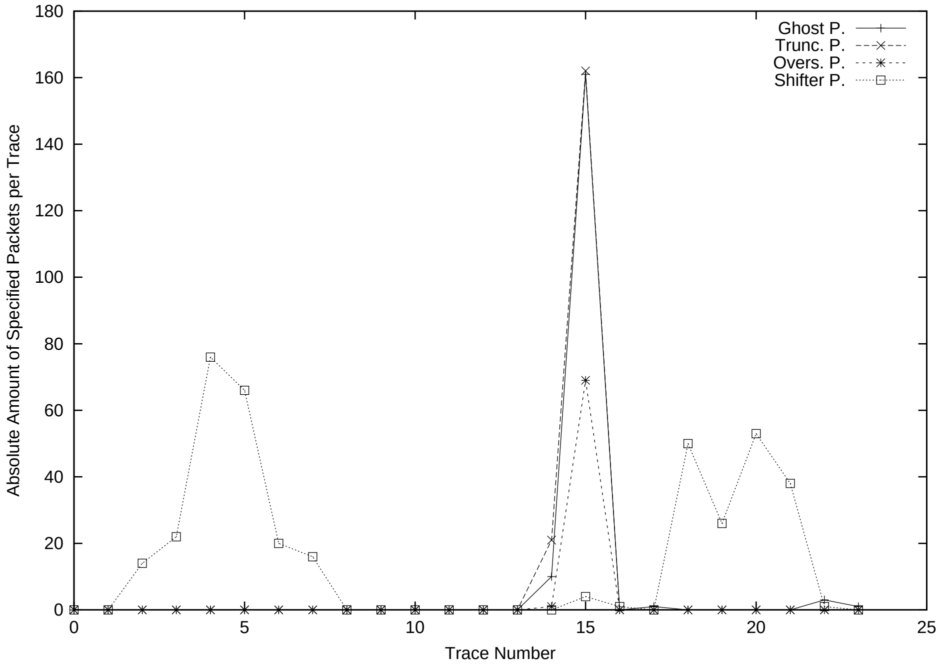
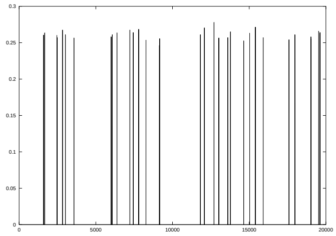
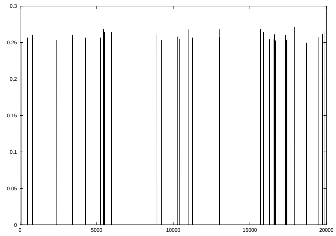


Figure 4.7: Number of Ghost, Truncated, Oversized and Shifter Packets vs. Tracenumber



Trace 05



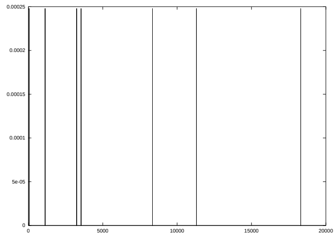
Trace 06

Trace 07

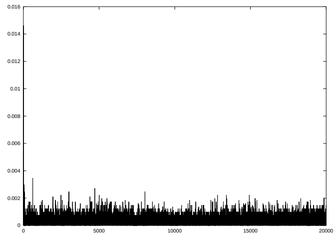
Trace 08

Trace 09

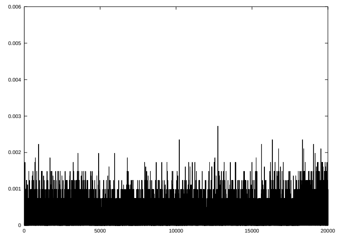
Trace 10



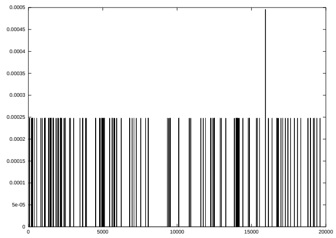
Trace 11



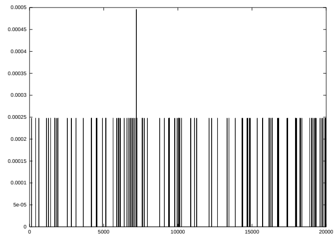
Trace 17



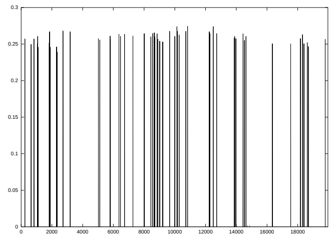
Trace 18



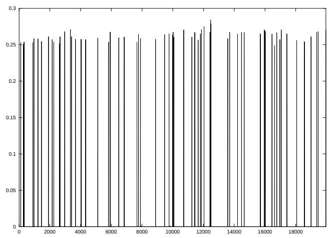
Trace 19



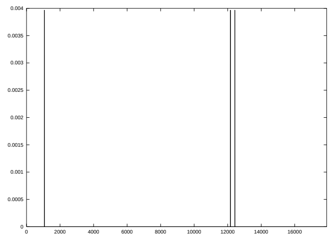
Trace 20



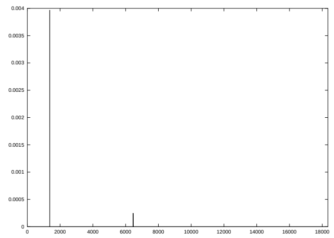
Trace 21



Trace 22

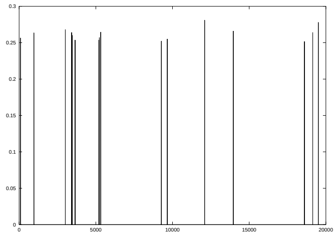


Trace 23

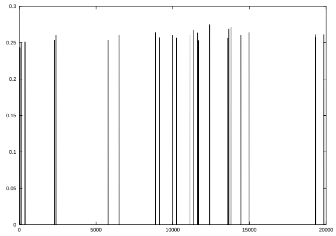


Trace 24

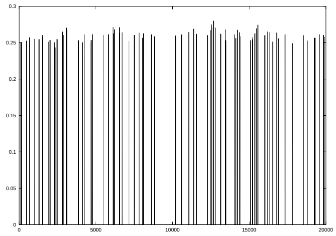
Table 4.4: BER per packet vs. packet number: Campaign Two, First Sequence of Measurement One



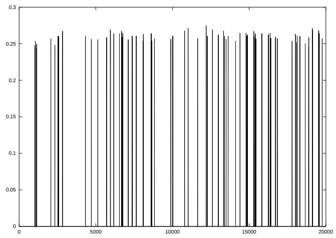
Trace 03



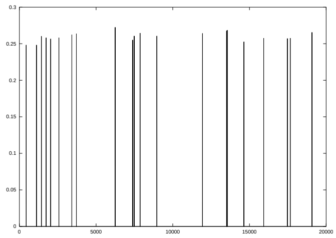
Trace 04



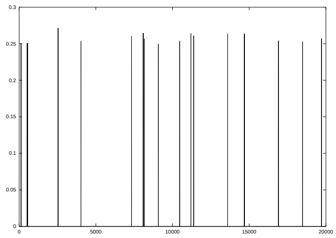
Trace 05



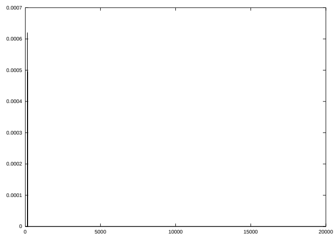
Trace 06



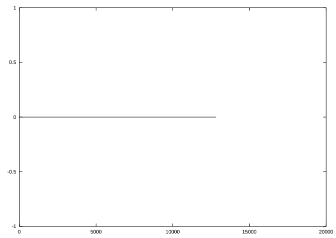
Trace 07



Trace 08



Trace 13



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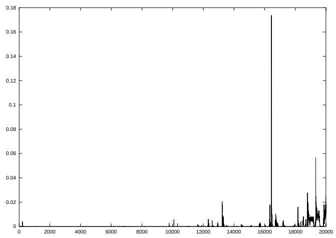
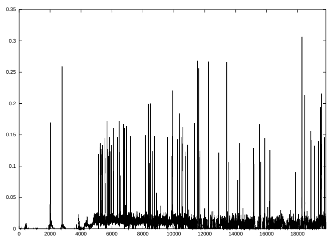
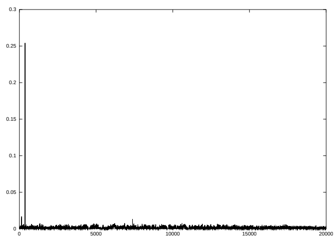


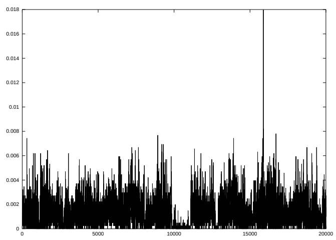
Trace 15



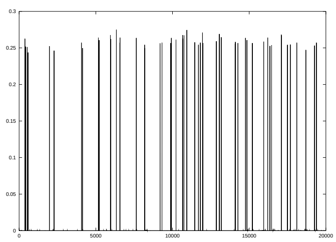
Trace 16



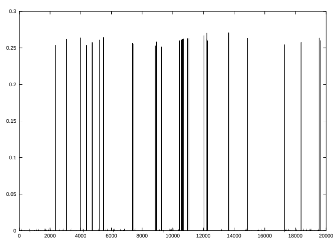
Trace 17



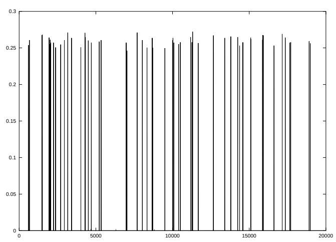
Trace 18



Trace 19

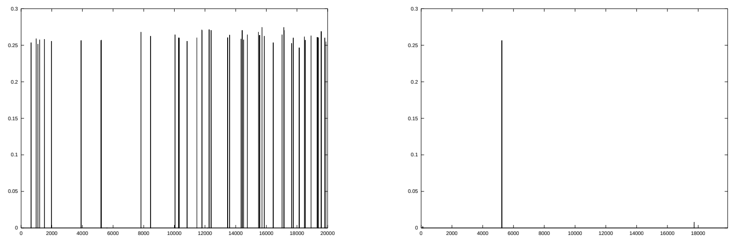


Trace 20



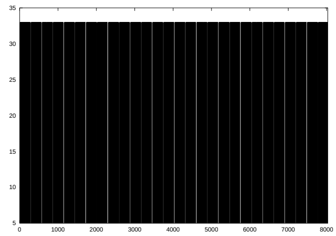
Trace 21

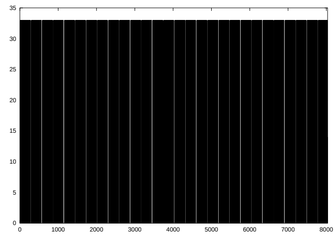
Table 4.5: BER per packet vs. packet number: Campaign Two, Second Sequence of Measurement One

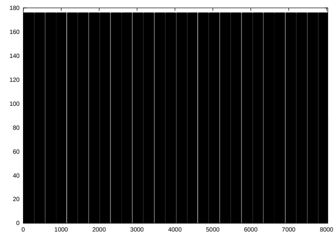


Trace 22 Trace 23

Table 4.6: BER per packet vs. packet number: Campaign Two, Second Sequence of Measurement One


Trace 05


Trace 06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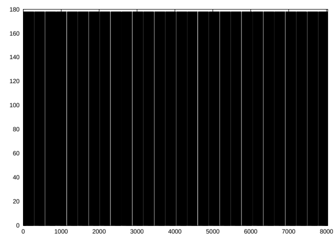
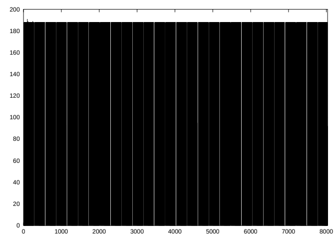
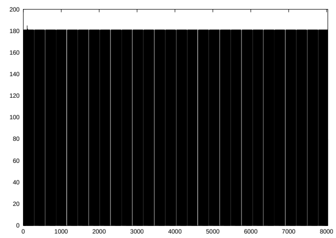

Trace 08


Trace 09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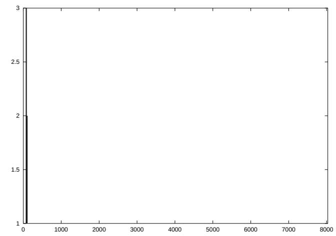
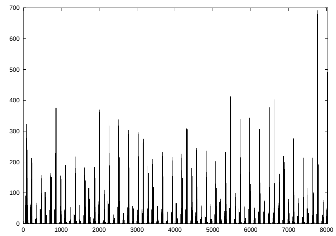
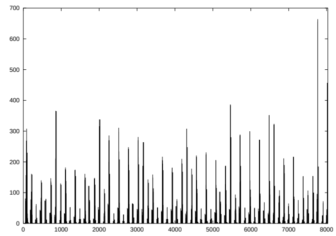
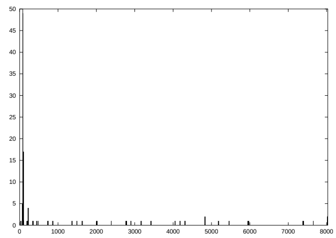

Trace 11


Trace 17


Trace 18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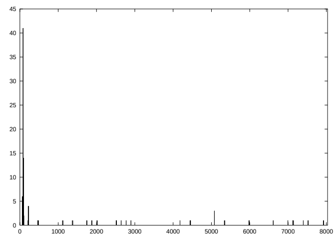
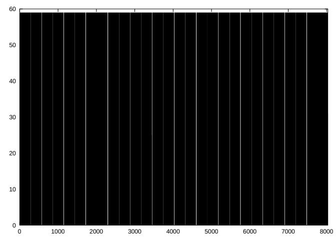
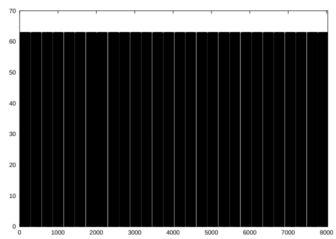
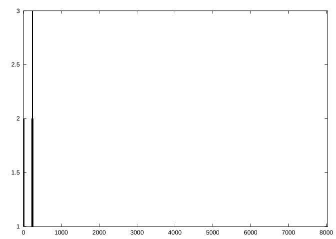

Trace 20


Trace 21


Trace 22


Trace 23

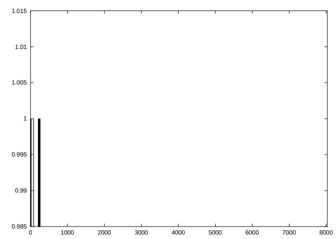
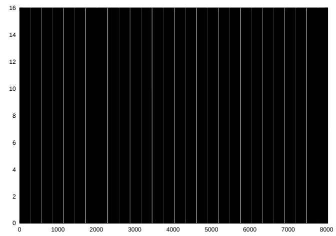
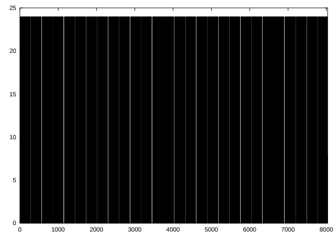

Trace 24

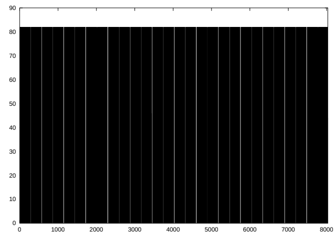
Table 4.7: Error position histograms: Campaign Two, First Sequence of Measurement One



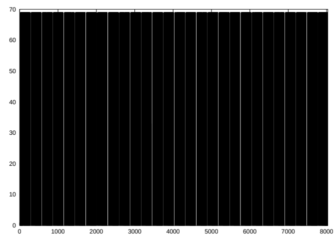
Trace 03



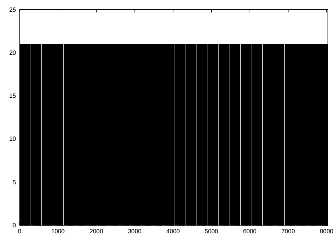
Trace 04



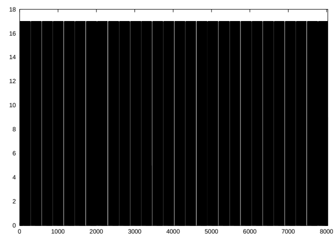
Trace 05



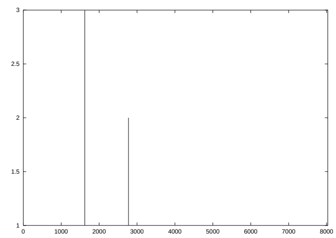
Trace 06



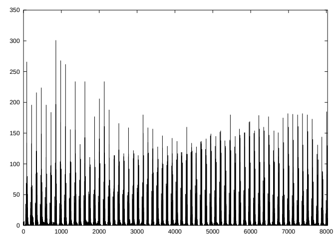
Trace 07



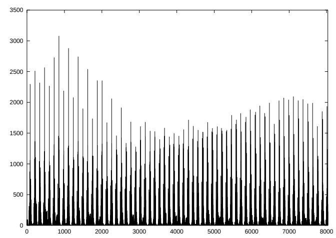
Trace 08



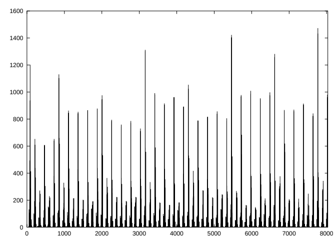
Trace 13



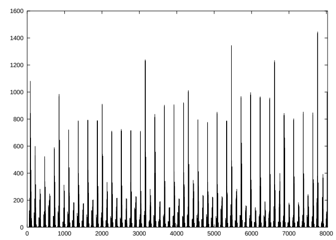
Trace 15



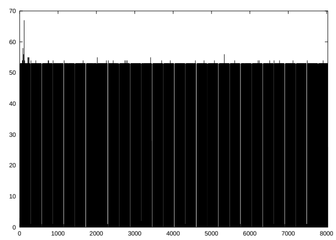
Trace 16



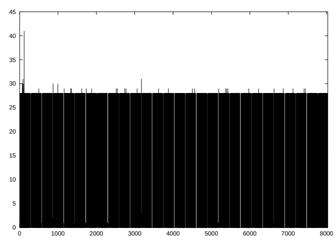
Trace 17



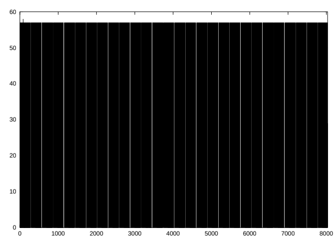
Trace 18



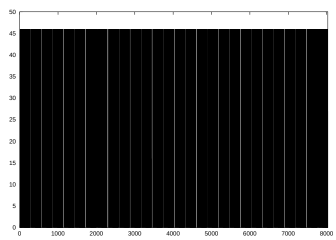
Trace 19



Trace 20

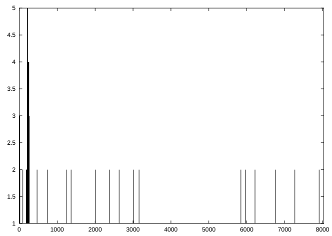


Trace 21



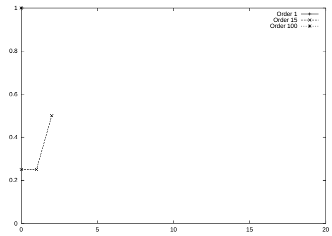
Trace 22

Table 4.8: Error position histograms: Campaign Two, Second Sequence of Measurement One

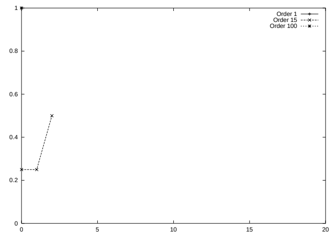


Trace 23

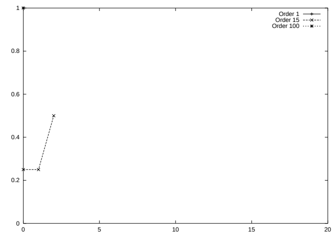
Table 4.9: Error position histograms: Campaign Two, Second Sequence of Measurement One



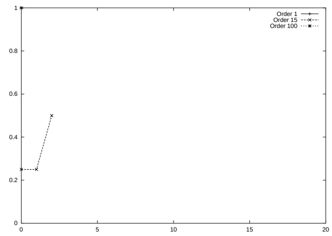
Trace 05



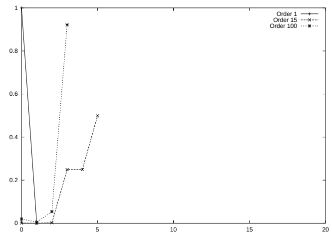
Trace 06



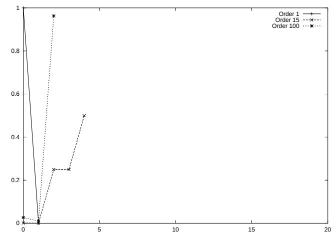
Trace 07



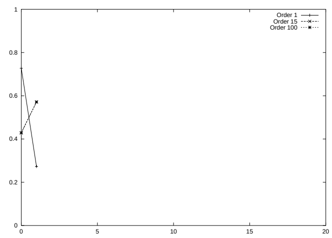
Trace 08



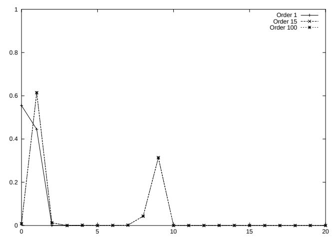
Trace 09



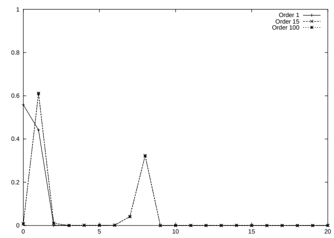
Trace 10



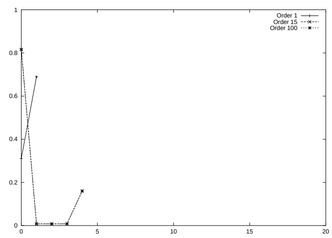
Trace 11



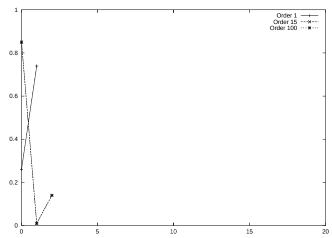
Trace 17



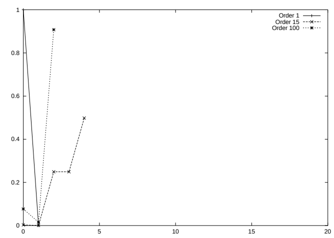
Trace 18



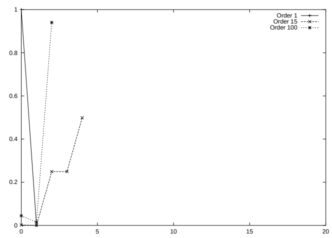
Trace 19



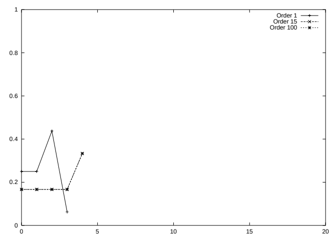
Trace 20



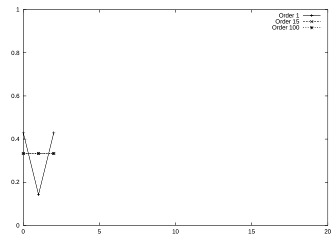
Trace 21



Trace 22

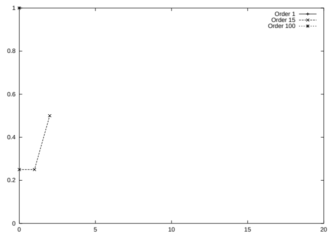


Trace 23

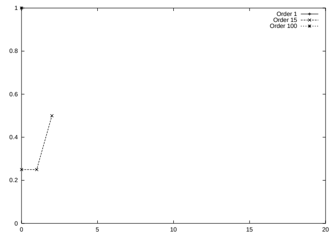


Trace 24

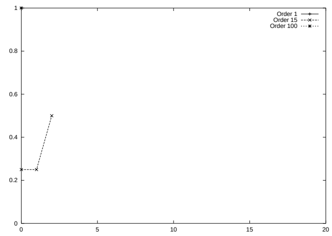
Table 4.10: Normalized Histogram Plots of error runlengths at different burst orders k_0 of Campaign Two, First Sequence of Measurement One



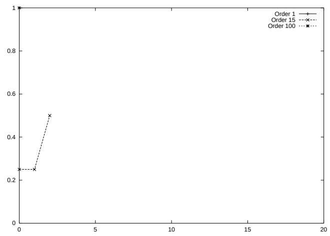
Trace 03



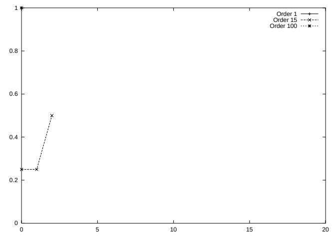
Trace 04



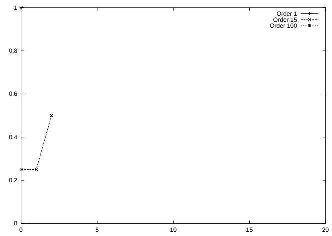
Trace 05



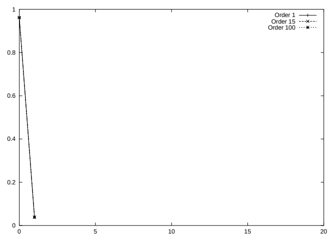
Trace 06



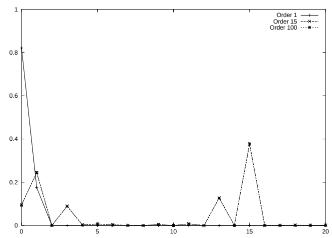
Trace 07



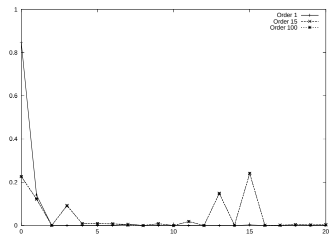
Trace 08



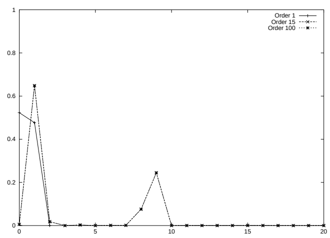
Trace 13



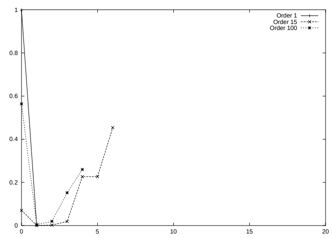
Trace 15



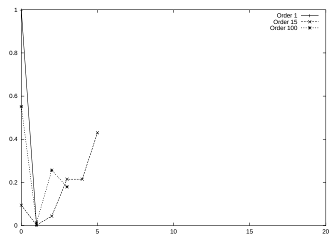
Trace 16



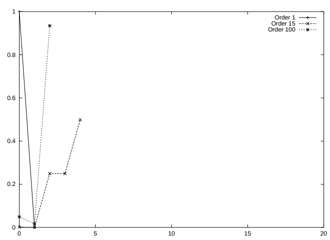
Trace 17



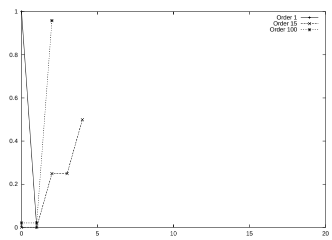
Trace 19



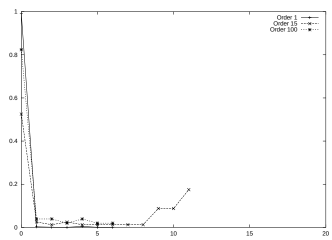
Trace 20



Trace 21

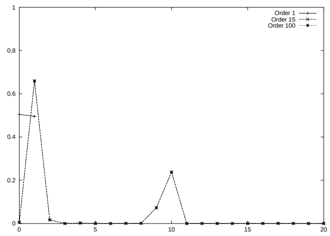


Trace 22



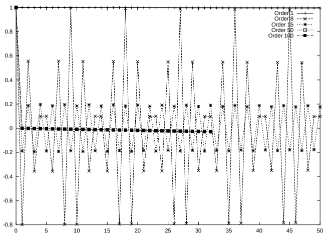
Trace 23

Table 4.11: Normalized Histogram Plots of error runlengths at different burst orders k_0 of Campaign Two, Second Sequence of Measurement One

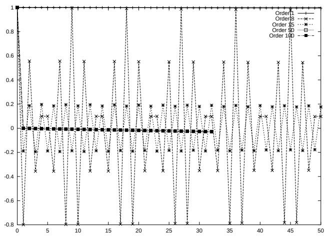


Trace 18

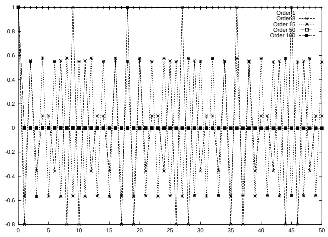
Table 4.12: Normalized Histogram Plots of error runlengths at different burst orders k_0 of Campaign Two, Second Sequence of Measurement One



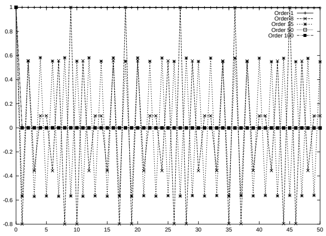
Trace 05



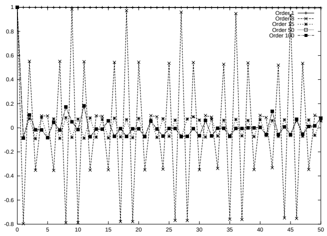
Trace 06



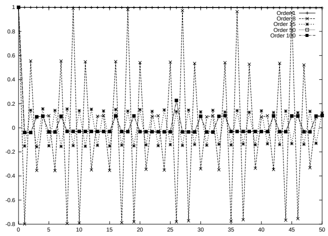
Trace 07



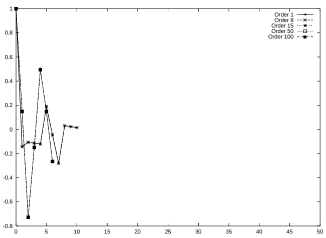
Trace 08



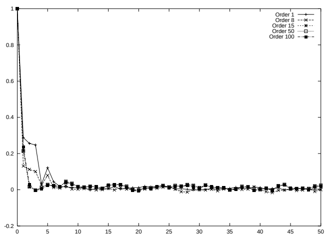
Trace 09



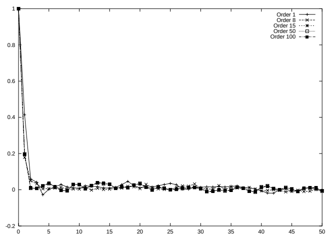
Trace 10



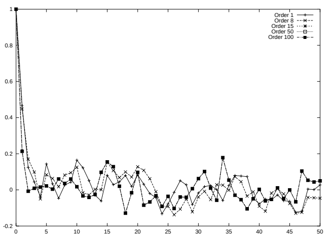
Trace 11



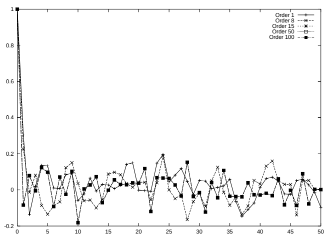
Trace 17



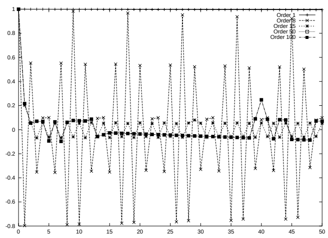
Trace 18



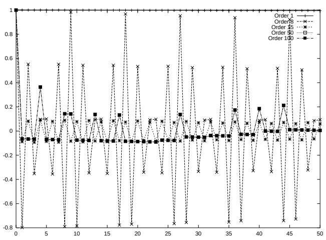
Trace 19



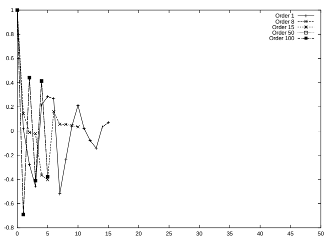
Trace 20



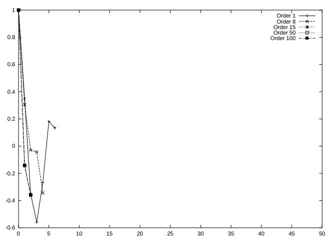
Trace 21



Trace 22

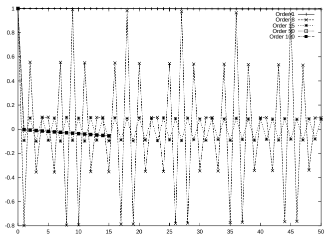


Trace 23

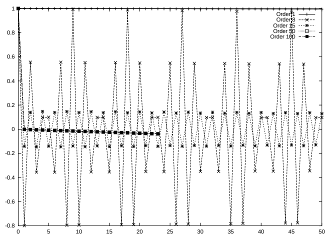


Trace 24

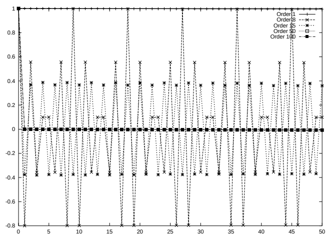
Table 4.13: Autocovariance of error runlengths at different burst orders k_0 of Campaign Two, First Sequence of Measurement One



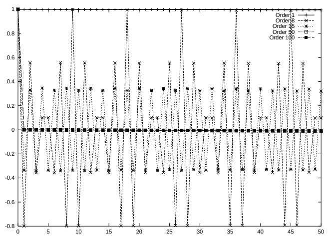
Trace 03



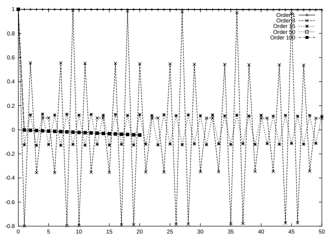
Trace 04



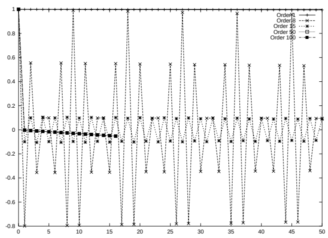
Trace 05



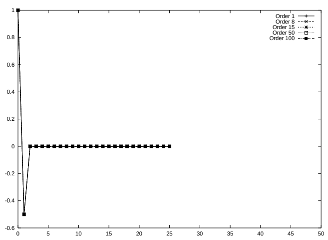
Trace 06



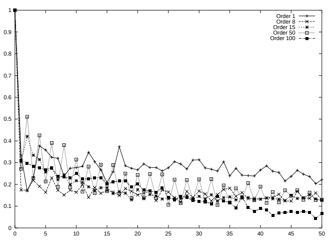
Trace 07



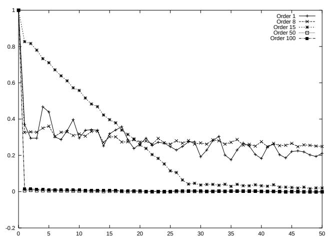
Trace 08



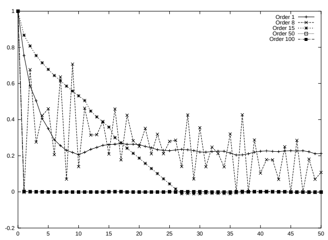
Trace 13



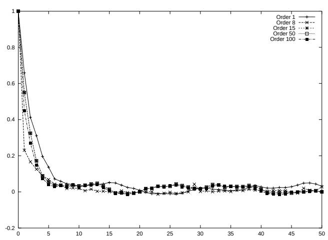
Trace 15



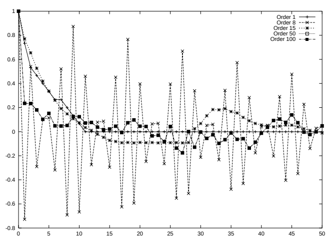
Trace 16



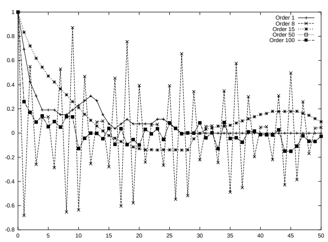
Trace 17



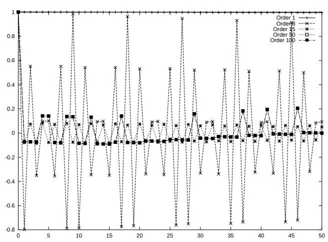
Trace 18



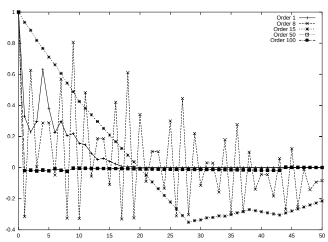
Trace 19



Trace 20



Trace 21



Trace 23

Table 4.14: Autocovariance of error runlengths at different burst orders k_0 of Campaign Two, Second Sequence of Measurement One

Trace No.	BER	PER	Packet Loss Rate	Packets Wrong
Trace 01	0.00000	0	0	0
Trace 02	0.00000	0.00005	0	1
Trace 03	0.00000	0	0	0
Trace 04	0.00000	0.00005	0	1
Trace 05	0.00043	0.00165	0	33
Trace 06	0.00042	0.00165	0	33
Trace 07	0.00228	0.0088	0	176
Trace 08	0.00231	0.0089	0	178
Trace 09	0.00244	0.0102	0	204
Trace 10	0.00235	0.0094	0	188
Trace 11	0.00000	0.0004	0	8
Trace 12	0.00000	0.00005	0	1
Trace 13	0.00000	0.00005	0	1
Trace 14	0.00000	0	0	0
Trace 15	0.00000	0	0	0
Trace 16	0.00000	0	0	0
Trace 17	0.00035	0.7447	0	14894
Trace 18	0.00032	0.69925	0	13985
Trace 19	0.00000	0.00625	0	125
Trace 20	0.00000	0.005	0	100
Trace 21	0.00076	0.00330	0.00180	66
Trace 22	0.00082	0.00335	0.00190	67
Trace 23	0.00000	0.00016	0.1048	3
Trace 24	0.00000	0.00010	0.08275	2

Table 4.15: Primary Measurement Results of Campaign Two, First Sequence of Measurement One (Part 1)

Trace No.	Packets Ghost	Packets Truncated	Packets Oversized	Packets Shifted
Trace 01	0	0	0	0
Trace 02	1	0	0	0
Trace 03	0	0	0	0
Trace 04	1	0	0	0
Trace 05	0	0	0	30
Trace 06	0	0	0	32
Trace 07	0	0	0	166
Trace 08	0	0	0	168
Trace 09	0	0	0	167
Trace 10	0	0	0	165
Trace 11	1	0	0	0
Trace 12	1	0	0	0
Trace 13	1	0	0	0
Trace 14	0	0	0	0
Trace 15	0	0	0	0
Trace 16	0	0	0	0
Trace 17	0	0	0	0
Trace 18	0	0	0	0
Trace 19	1	0	0	0
Trace 20	1	0	0	0
Trace 21	1	0	0	56
Trace 22	0	0	0	54
Trace 23	3	0	0	0
Trace 24	1	0	0	0

Table 4.16: Primary Measurement Results of Campaign Two, First Sequence of Measurement One (Part 2)

Trace No.	**BER**	**PER**	**Packet Loss Rate**	**Packets Wrong**
Trace 01	0.00000	0	0	0
Trace 02	0.00000	0	0	0
Trace 03	0.00021	0.0008	0	16
Trace 04	0.00031	0.0012	0	24
Trace 05	0.00106	0.0041	0	82
Trace 06	0.00089	0.00345	0	69
Trace 07	0.00027	0.00105	0	21
Trace 08	0.00021	0.00085	0	17
Trace 09	0.00000	0	0	0
Trace 10	0.00000	0	0	0
Trace 11	0.00000	0	0	0
Trace 12	0.00000	0	0	0
Trace 13	0.00000	0.0004	0	8
Trace 14	0.00000	0.0004	0	8
Trace 15	0.00045	0.08445	0.00070	1688
Trace 16	0.00749	0.66972	0.00870	13278
Trace 17	0.00123	0.8224	0	16448
Trace 18	0.00114	0.82795	0	16559
Trace 19	0.00068	0.0088	0	176
Trace 20	0.00036	0.00660	0.00005	132
Trace 21	0.00074	0.00305	0	61
Trace 22	0.00060	0.00240	0.00005	48
Trace 23	0.00001	0.00050	0.00424	10
Trace 24	0.00000	0.00005	0.00460	1

Table 4.17: Primary Measurement Results of Campaign Two, Second Sequence of Measurement One (Part 1)

Trace No.	Packets Ghost	Packets Truncated	Packets Oversized	Packets Shifted
Trace 01	0	0	0	0
Trace 02	0	0	0	0
Trace 03	0	0	0	14
Trace 04	0	0	0	22
Trace 05	0	0	0	76
Trace 06	0	0	0	66
Trace 07	0	0	0	20
Trace 08	0	0	0	16
Trace 09	0	0	0	0
Trace 10	0	0	0	0
Trace 11	0	0	0	0
Trace 12	0	0	0	0
Trace 13	0	0	0	0
Trace 14	0	0	0	0
Trace 15	10	21	1	0
Trace 16	161	162	69	4
Trace 17	0	0	0	1
Trace 18	1	0	0	0
Trace 19	0	0	0	50
Trace 20	0	0	0	26
Trace 21	0	0	0	53
Trace 22	0	0	0	38
Trace 23	3	0	0	1
Trace 24	1	0	0	0

Table 4.18: Primary Measurement Results of Campaign Two, Second Sequence of Measurement One (Part 2)

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 01	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 01	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 01	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 01	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 01	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 02	1	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 02	8	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 02	15	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 02	50	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 02	100	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 03	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 03	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 03	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 03	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 03	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 04	1	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 04	8	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 04	15	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 04	50	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 04	100	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 05	1	1.00000	0.00000	2318.82	2357363	1.00000	0.00000
Trace 05	8	114.333	16063.1	77420.3	7824428	33.4381	1317.46
Trace 05	15	268.500	20.7500	174079.	1743652	75.2359	4.68459
Trace 05	50	8039.00	0.00000	4735489	2656729	2106.60	2502.90
Trace 05	100	8039.00	0.00000	4735489	2656729	2106.60	2502.90
Trace 06	1	1.00000	0.00000	2334.68	2674944	1.00000	0.00000
Trace 06	8	114.333	16063.1	77420.3	8825644	33.2111	1298.84
Trace 06	15	268.500	20.7500	174079.	1968926	74.7251	4.09326
Trace 06	50	8039.00	0.00000	4735489	3287495	2092.30	2048.99
Trace 06	100	8039.00	0.00000	4735489	3287495	2092.30	2048.99
Trace 07	1	1.00000	0.00000	436.628	7705055	1.00000	0.00000
Trace 07	8	114.333	16063.1	14429.0	2540603	33.2352	1301.34
Trace 07	15	268.500	20.7500	32450.5	5657880	74.7792	5.34898
Trace 07	50	8039.00	0.00000	903147.	7933881	2093.81	3008.14
Trace 07	100	8039.00	0.00000	903147.	7933881	2093.81	3008.14
Trace 08	1	1.00000	0.00000	430.165	7471689	1.00000	0.00000
Trace 08	8	114.333	16063.1	14265.6	2472399	33.3543	1310.67
Trace 08	15	268.500	20.7500	32082.9	5505741	75.0473	4.69599
Trace 08	50	8039.00	0.00000	892966.	7685654	2101.32	2485.65
Trace 08	100	8039.00	0.00000	892966.	7685654	2101.32	2485.65
Trace 09	1	1.00001	0.00001	407.588	6486419	1.00001	0.00001
Trace 09	8	114.076	16055.5	13470.1	2139103	33.2497	1307.81
Trace 09	15	267.721	219.962	30270.4	4758487	74.7553	21.4795
Trace 09	50	7409.41	4657483	779319.	6450137	1934.84	320759.
Trace 09	100	7409.41	4657483	779319.	6450137	1934.84	320759.

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 10	1	1.00001	0.00001	423.377	7459678	1.00001	0.00001
Trace 10	8	114.244	16060.4	14016.3	2465018	33.3003	1308.10
Trace 10	15	268.137	115.688	31503.3	5487927	74.8815	12.0283
Trace 10	50	7739.89	2313218	845591.	7894162	2021.40	160115.
Trace 10	100	7739.89	2313218	845591.	7894162	2021.40	160115.
Trace 11	1	1.27272	0.19834	1343865	3320486	1.27272	0.19834
Trace 11	8	1.27272	0.19834	1343865	3320486	1.27272	0.19834
Trace 11	15	10.0000	48.0000	2015797	3669933	2.00000	0.00000
Trace 11	50	10.0000	48.0000	2015797	3669933	2.00000	0.00000
Trace 11	100	10.0000	48.0000	2015797	3669933	2.00000	0.00000
Trace 12	1	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 12	8	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 12	15	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 12	50	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 12	100	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 13	1	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 13	8	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 13	15	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 13	50	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 13	100	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 14	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 14	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 14	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 14	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 14	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 15	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 15	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 15	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 15	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 15	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 16	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 16	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 16	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 16	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 16	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 17	1	1.44733	0.31241	4076.63	3387601	1.44733	0.31241
Trace 17	8	1.55189	1.26280	4177.01	3429173	1.48300	0.36859
Trace 17	15	7.02926	44.5757	5672.76	3814722	2.01581	0.20018
Trace 17	50	7.03074	44.7105	5672.95	3814744	2.01588	0.20455
Trace 17	100	7.06560	48.4655	5674.92	3814991	2.01659	0.21574
Trace 18	1	1.44237	0.26193	4489.31	4121753	1.44237	0.26193
Trace 18	8	1.53592	1.13206	4587.61	4166996	1.47397	0.31369
Trace 18	15	7.12111	44.9080	6263.17	4646376	2.01395	0.11283
Trace 18	50	7.12111	44.9080	6263.17	4646376	2.01395	0.11283
Trace 18	100	7.13731	46.4777	6264.13	4646507	2.01427	0.11315

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 19	1	1.68918	0.21420	1082306	2049018	1.68918	0.21420
Trace 19	8	1.71428	0.24489	1089619	2054935	1.70068	0.20972
Trace 19	15	4.41600	27.2189	1279867	2171165	2.00000	0.00000
Trace 19	50	4.41600	27.2189	1279867	2171165	2.00000	0.00000
Trace 19	100	4.41600	27.2189	1279867	2171165	2.00000	0.00000
Trace 20	1	1.73913	0.19281	1390204	2379665	1.73913	0.19281
Trace 20	8	1.78947	0.34164	1402292	2383439	1.75438	0.18528
Trace 20	15	4.00000	23.6000	1596668	2403666	2.00000	0.00000
Trace 20	50	4.00000	23.6000	1596668	2403666	2.00000	0.00000
Trace 20	100	4.00000	23.6000	1596668	2403666	2.00000	0.00000
Trace 21	1	1.00004	0.00004	1304.01	7310067	1.00004	0.00004
Trace 21	8	114.121	16056.7	43100.2	2403274	33.1240	1296.90
Trace 21	15	267.542	273.004	96763.1	5345994	74.3992	25.1119
Trace 21	50	7297.30	5409392	2431806	7870708	1897.75	368730.
Trace 21	100	7297.30	5409392	2431806	7870708	1897.75	368730.
Trace 22	1	1.00002	0.00002	1205.81	4919219	1.00002	0.00002
Trace 22	8	114.191	16058.8	40380.3	1635211	33.5636	1330.88
Trace 22	15	267.903	177.495	90724.6	3629829	75.4423	17.6686
Trace 22	50	7559.35	3623387	2359691	4144487	1990.77	254083.
Trace 22	100	7559.35	3623387	2359691	4144487	1990.77	254083.
Trace 23	1	6.00000	13.0000	8490962	5505452	6.00000	13.0000
Trace 23	8	10.3636	10.7768	1202886	7543673	8.72727	5.28925
Trace 23	15	25.6666	144.555	2062090	1176302	16.0000	64.0000
Trace 23	50	25.6666	144.555	2062090	1176302	16.0000	64.0000
Trace 23	100	25.6666	144.555	2062090	1176302	16.0000	64.0000
Trace 24	1	4.85714	7.83673	1848977	1180061	4.85714	7.83673
Trace 24	8	8.00000	14.4000	2465303	1469755	6.80000	5.76000
Trace 24	15	18.6666	251.555	3697954	1841820	11.3333	86.2222
Trace 24	50	18.6666	251.555	3697954	1841820	11.3333	86.2222
Trace 24	100	18.6666	251.555	3697954	1841820	11.3333	86.2222

Table 4.19: Further Statistical Measurement Results of Campaign Two, First Sequence of Measurement One

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 01	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 01	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 01	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 01	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 01	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 02	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 02	8	nan	0.00000	1612719	0.00000	0.00000	0.00000

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 02	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 02	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 02	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 03	1	1.00000	0.00000	4771.34	1056271	1.00000	0.00000
Trace 03	8	114.333	16063.1	159719.	3516252	33.5238	1325.65
Trace 03	15	268.500	20.7500	358912.	7839917	75.4285	7.47704
Trace 03	50	8039.00	0.00000	9479018	1276651	2112.00	4590.00
Trace 03	100	8039.00	0.00000	9479018	1276651	2112.00	4590.00
Trace 04	1	1.00000	0.00000	3206.66	5811704	1.00000	0.00000
Trace 04	8	114.333	16063.1	106476.	1921465	33.2513	1302.70
Trace 04	15	268.500	20.7500	239363.	4291443	74.8154	5.48976
Trace 04	50	8039.00	0.00000	6443160	7852298	2094.83	3150.63
Trace 04	100	8039.00	0.00000	6443160	7852298	2094.83	3150.63
Trace 05	1	1.00000	0.00000	936.731	3421307	1.00000	0.00000
Trace 05	8	114.333	16063.1	31097.5	1129598	33.2907	1305.89
Trace 05	15	268.500	20.7500	69941.4	2514420	74.9041	5.50301
Trace 05	50	8039.00	0.00000	1935093	3387156	2097.31	3123.82
Trace 05	100	8039.00	0.00000	1935093	3387156	2097.31	3123.82
Trace 06	1	1.00000	0.00000	1112.61	5149320	1.00000	0.00000
Trace 06	8	114.333	16063.1	36976.7	1702205	33.3144	1307.48
Trace 06	15	268.500	20.7500	83162.5	3791536	74.9575	4.77045
Trace 06	50	8039.00	0.00000	2295960	5462217	2098.81	2504.61
Trace 06	100	8039.00	0.00000	2295960	5462217	2098.81	2504.61
Trace 07	1	1.00000	0.00000	3661.35	4498020	1.00000	0.00000
Trace 07	8	114.333	16063.1	121692.	1482722	33.2834	1304.83
Trace 07	15	268.500	20.7500	273538.	3294519	74.8877	4.45678
Trace 07	50	8039.00	0.00000	7322869	3816721	2096.85	2372.78
Trace 07	100	8039.00	0.00000	7322869	3816721	2096.85	2372.78
Trace 08	1	1.00000	0.00000	4565.66	6661841	1.00000	0.00000
Trace 08	8	114.333	16063.1	150326.	2174672	32.9729	1279.97
Trace 08	15	268.500	20.7500	337828.	4829537	74.1890	4.64492
Trace 08	50	8039.00	0.00000	8951959	5357779	2077.29	2481.38
Trace 08	100	8039.00	0.00000	8951959	5357779	2077.29	2481.38
Trace 09	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 09	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 09	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 09	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 09	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 10	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 10	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 10	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 10	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 10	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 11	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 11	8	nan	0.00000	1612719	0.00000	0.00000	0.00000

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 11	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 11	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 11	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 12	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 12	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 12	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 12	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 12	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 13	1	1.03846	0.03698	5973033	9482221	1.03846	0.03698
Trace 13	8	1.03846	0.03698	5973033	9482221	1.03846	0.03698
Trace 13	15	1.03846	0.03698	5973033	9482221	1.03846	0.03698
Trace 13	50	1.03846	0.03698	5973033	9482221	1.03846	0.03698
Trace 13	100	1.03846	0.03698	5973033	9482221	1.03846	0.03698
Trace 14	1	nan	0.00000	1035046	0.00000	0.00000	0.00000
Trace 14	8	nan	0.00000	1035046	0.00000	0.00000	0.00000
Trace 14	15	nan	0.00000	1035046	0.00000	0.00000	0.00000
Trace 14	50	nan	0.00000	1035046	0.00000	0.00000	0.00000
Trace 14	100	nan	0.00000	1035046	0.00000	0.00000	0.00000
Trace 15	1	1.21911	0.95293	2654.77	2028933	1.21911	0.95293
Trace 15	8	2.17494	16.0839	3262.94	2494065	1.49871	2.33835
Trace 15	15	10.1162	61.4681	4954.87	3791710	2.27898	4.39845
Trace 15	50	10.2143	70.8898	4969.21	3802733	2.28561	5.11747
Trace 15	100	11.3268	249.120	5023.88	3845309	2.31121	5.92245
Trace 16	1	1.32846	3.93650	175.816	7632567	1.32846	3.93650
Trace 16	8	3.66093	59.5707	266.930	1165650	2.02925	10.5132
Trace 16	15	10.7116	125.918	381.155	1687655	2.93873	19.4931
Trace 16	50	11.1934	970.123	385.937	1710311	2.97821	77.4361
Trace 16	100	14.4243	1541.02	395.887	1767046	3.07706	83.3249
Trace 17	1	1.47680	0.24947	1194.70	2698379	1.47680	0.24947
Trace 17	8	1.64984	15.0825	1245.07	2806122	1.53919	1.37439
Trace 17	15	6.52607	62.0545	1642.20	3646290	2.03551	1.63542
Trace 17	50	6.53340	700.800	1642.66	3647259	2.03609	43.0069
Trace 17	100	6.59177	707.985	1643.55	3649211	2.03726	43.0362
Trace 18	1	1.49543	0.24997	1302.24	2982796	1.49543	0.24997
Trace 18	8	1.60729	1.11726	1337.23	3058436	1.53569	0.30508
Trace 18	15	6.31992	40.1398	1750.88	3942271	2.01557	0.07911
Trace 18	50	6.32157	40.1612	1750.99	3942509	2.01570	0.07916
Trace 18	100	6.37707	46.6042	1751.89	3944509	2.01680	0.08508
Trace 19	1	1.00103	0.00103	1453.13	3908252	1.00103	0.00103
Trace 19	8	108.387	15850.2	45629.5	1209468	31.4950	1276.61
Trace 19	15	244.184	5832.48	98332.9	2555717	67.9021	446.825
Trace 19	50	2092.42	1241176	784610.	1507246	544.215	838395.
Trace 19	100	2092.42	1241176	784610.	1507246	544.215	838395.
Trace 20	1	1.00145	0.00145	2731.77	1046983	1.00145	0.00145
Trace 20	8	104.415	15671.7	83236.1	3127502	30.5563	1276.43

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 20	15	231.736	8301.94	176399.	6467715	64.7982	646.827
Trace 20	50	1448.28	9502001	1025719	2904393	378.820	649383.
Trace 20	100	1448.28	9502001	1025719	2904393	378.820	649383.
Trace 21	1	1.00002	0.00002	1347.06	6556037	1.00002	0.00002
Trace 21	8	114.176	16058.4	44720.9	2161647	33.2686	1306.77
Trace 21	15	267.841	193.912	100464.	4802270	74.7712	17.7026
Trace 21	50	7512.18	3954932	2593769	6023094	1961.21	271535.
Trace 21	100	7512.18	3954932	2593769	6023094	1961.21	271535.
Trace 22	1	1.00001	0.00001	1659.59	1286556	1.00001	0.00001
Trace 22	8	114.216	16059.6	55455.7	4276907	33.4753	1322.95
Trace 22	15	268.096	125.820	124646.	9531765	75.2806	13.1879
Trace 22	50	7704.37	2575400	3283552	1502815	2023.16	180088.
Trace 22	100	7704.37	2575400	3283552	1502815	2023.16	180088.
Trace 23	1	1.07360	1.41089	75239.3	5702088	1.07360	1.41089
Trace 23	8	61.4545	11424.8	1316030	9887057	18.9256	894.366
Trace 23	15	97.4875	15865.6	1982165	1482048	28.6250	1169.13
Trace 23	50	164.078	1240653	3087592	2289981	44.9019	82154.9
Trace 23	100	164.078	1240653	3087592	2289981	44.9019	82154.9
Trace 24	1	14.0000	132.000	3210444	2181843	14.0000	132.000
Trace 24	8	20.0000	74.6666	4013055	2479667	18.6666	99.5555
Trace 24	15	34.0000	484.000	5350740	2645861	28.0000	400.000
Trace 24	50	34.0000	484.000	5350740	2645861	28.0000	400.000
Trace 24	100	34.0000	484.000	5350740	2645861	28.0000	400.000

Table 4.20: Further Statistical Measurement Results of Campaign Two, Second Sequence of Measurement One

Parameter	Value
PreambleLength	128 bits
ScramblingEnabled	False
Gap Time	1000 μsec
SFD Threshold	152
Frequency	12
NumPackets	20000
NumChunks	28
CRCUsageEnabled	False
ModulationCode	2 MBit QPSK
Rx-Tx-Distance	≈ 20 meter
PacketSize	1000 bytes

Table 4.21: Fixed Parameters for Campaign Two, Measurement Two

4.2 Measurement Two

Measurement two intended to find out the change of transmission quality in the case that a direct line of sight is not given. In order to observe a change, two cases were designed, differing only in the condition of a given line of sight/non line of sight. In both cases possible reflection paths did not had to pass any obstacle. The non line of sight case was created by simply turning the front of the computer by 180 degrees. By this the prior line of sight was interrupted by the metal case of the computer, destroying all direct line of sight paths. The other parameters were kept to the same settings as in the other measurements for easy comparison among the measurements.

In each case five traces were recorded. In addition, diversity was switched on and off for each case. Therefore the total amount of traces was twenty.

4.2.1 Measurement Parameters

In Tables 4.21 and 4.22 the fixed and variable parameters used during this measurement are displayed. In Table 4.23 the mapping of trace parameters to the trace numbers is given. The parameters chosen are quite similar to the first measurement of this campaign, in order to be comparable.

Parameter	**Value**
Diversity	True vs. False

Table 4.22: Variable Parameters for Campaign Two, Measurement Two

Trace No.	**Description**
Traces 01, 03, 05, 07 and 09	Direct LOS, no Diversity
Traces 02, 04, 06, 08, 10	Direct LOS, Diversity activated
Trace 11, 13, 15, 17, 19	No LOS, Paths are not physically interrupted, no Diversity
Trace 12, 14, 16, 18, 20	No LOS, Paths are not physically interrupted, Diversity activated

Table 4.23: Trace Key of Campaign Two, Measurement Two

4.2.2 Occurences during the Measurement

As mentioned above, during this measurement the wall was removed again and the people, playing badminton before, left the gym. This occurred during trace 09. After trace 09 the whole gym was empty again, for the rest of the measurement.

4.2.3 Measurement Results

When comparing line of sight and non line of sight trace results, one first observes something confusing. For the non line of sight setting, we do not encounter any errors in the traces. But for the line of sight setting, this is the case.

In general, error rates are low and also the results of all other trace statistics do not indicate any stronger transmission problems. For the first six traces we observed varying rates of ghost packets, truncated packets and oversized packets. Throughout the whole measurement, bit shifter packets do not occur with the intensity observed in measurement one. Also, for the first six traces the amount of lost packets is higher than for the remaining traces. It seems, as if space diversity in this measurement has a little effect, especially if one compares the first five traces with the second five ones.

Although during trace 09 the measurement environment was disturbed through the badminton players leaving the gym, no such dramatic effect as observed in measurement one can be noticed. Trace nine is almost a perfect trace, without any signs of disturbance.

Trace 07 is a trace consisting of errors only resulting from bit shifter packets, although the total amount of wrong packets is rather small. Beside these observations, nothing else is noticeable.

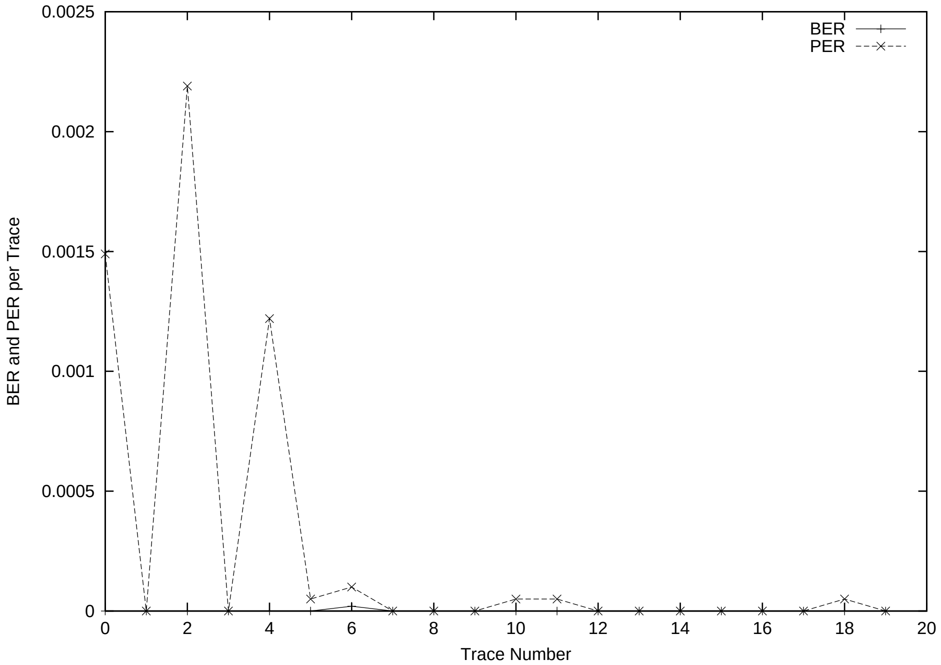


Figure 4.8: BER and PER per Trace vs.Tracenumber

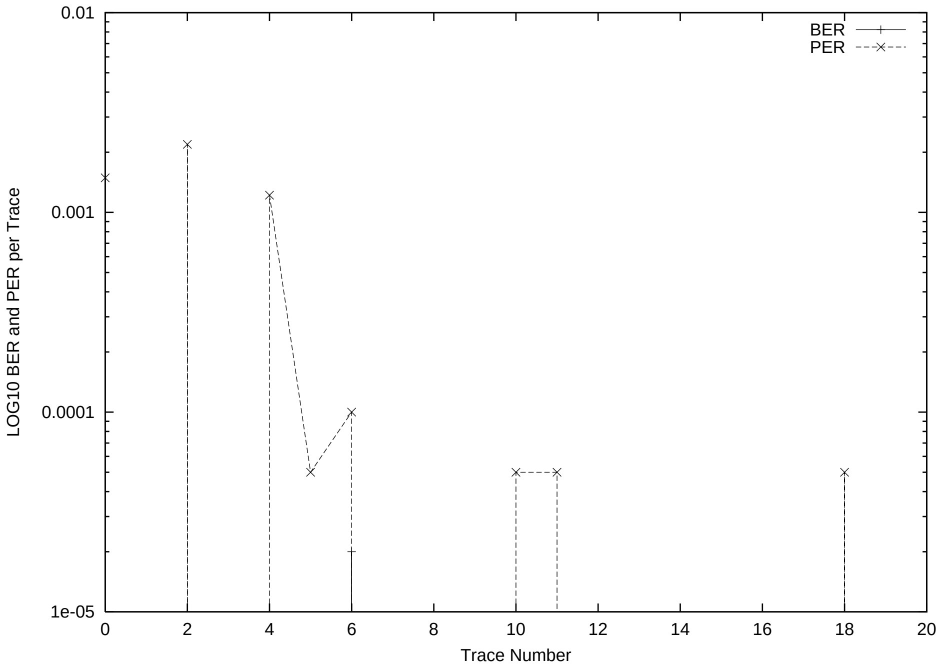


Figure 4.9: Log 10 Scaling of BER and PER per Trace vs. Tracenumber

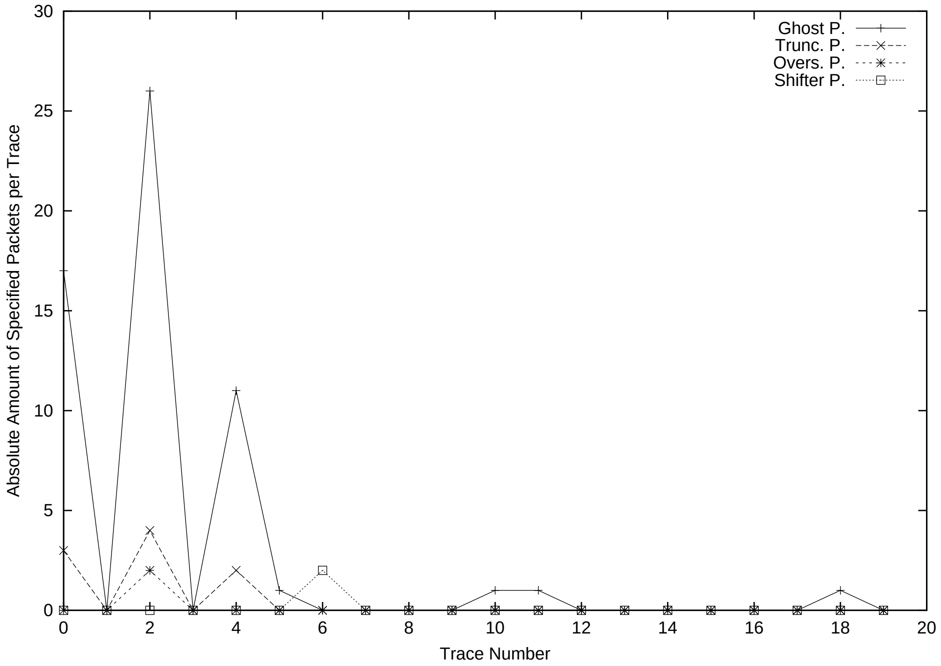
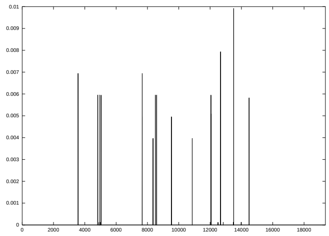
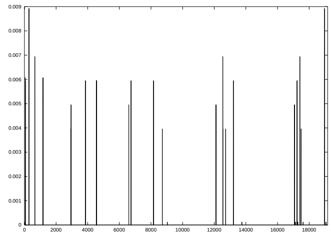


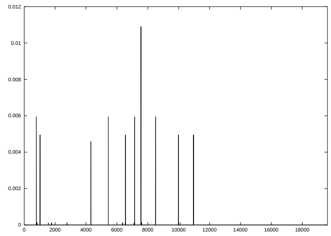
Figure 4.10: Number of Ghost, Truncated, Oversized and Shifter Packets vs. Tracenumber



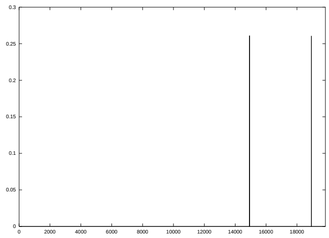
Trace 01



Trace 03

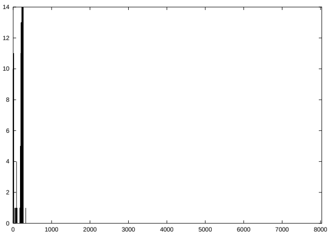


Trace 05

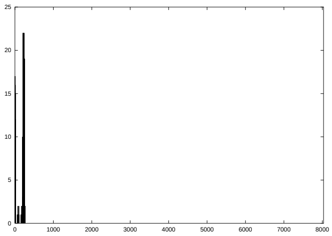


Trace 07

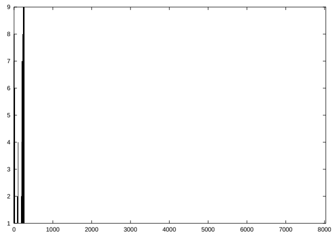
Table 4.24: BER per packet vs. packet number: Campaign Two, Measurement Two



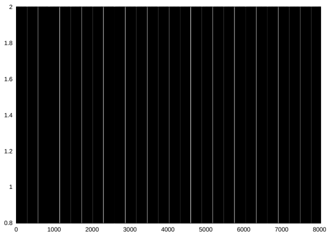
Trace 01



Trace 03

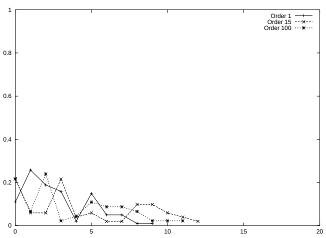


Trace 05

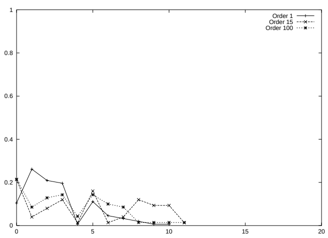


Trace 07

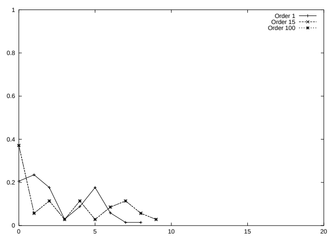
Table 4.25: Error position histograms: Campaign Two, Measurement Two



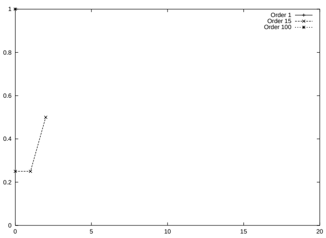
Trace 01



Trace 03

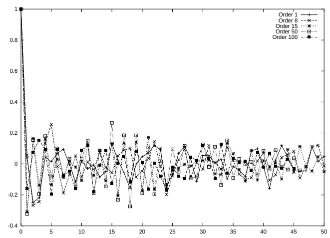


Trace 05

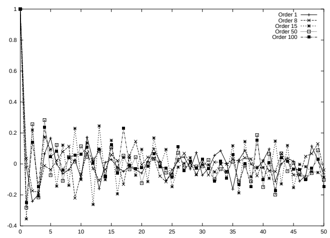


Trace 07

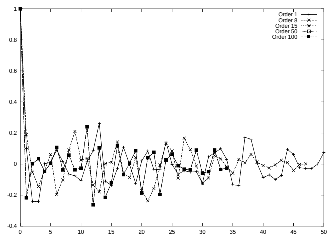
Table 4.26: Normalized Histogram Plots of error runlengths at different burst orders k_0 of Campaign Two, Measurement Two



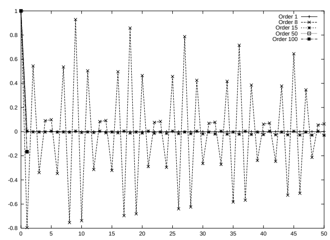
Trace 01



Trace 03



Trace 05



Trace 07

Table 4.27: Autocovariance of error runlengths at different burst orders k_0 of Campaign Two, Measurement Two

Trace No.	**BER**	**PER**	**Packet Loss Rate**	**Packets Wrong**
Trace 01	0.00000	0.00149	0.0319	29
Trace 02	0.00000	0	0	0
Trace 03	0.00000	0.00219	0.0415	42
Trace 04	0.00000	0	0	0
Trace 05	0.00000	0.00122	0.01855	24
Trace 06	0.00000	0.00005	0	1
Trace 07	0.00002	0.00010	0.00790	2
Trace 08	0.00000	0	0	0
Trace 09	0.00000	0	0.00029	0
Trace 10	0.00000	0	0	0
Trace 11	0.00000	0.00005	0	1
Trace 12	0.00000	0.00005	0	1
Trace 13	0.00000	0	0	0
Trace 14	0.00000	0	0	0
Trace 15	0.00000	0	0	0
Trace 16	0.00000	0	0	0
Trace 17	0.00000	0	0	0
Trace 18	0.00000	0	0	0
Trace 19	0.00000	0.00005	0	1
Trace 20	0.00000	0	0	0

Table 4.28: Primary Measurement Results of Campaign Two, Measurement Two (Part 1)

Trace No.	Packets Ghost	Packets Truncated	Packets Oversized	Packets Shifted
Trace 01	17	3	0	0
Trace 02	0	0	0	0
Trace 03	26	4	2	0
Trace 04	0	0	0	0
Trace 05	11	2	0	0
Trace 06	1	0	0	0
Trace 07	0	0	0	2
Trace 08	0	0	0	0
Trace 09	0	0	0	0
Trace 10	0	0	0	0
Trace 11	1	0	0	0
Trace 12	1	0	0	0
Trace 13	0	0	0	0
Trace 14	0	0	0	0
Trace 15	0	0	0	0
Trace 16	0	0	0	0
Trace 17	0	0	0	0
Trace 18	0	0	0	0
Trace 19	1	0	0	0
Trace 20	0	0	0	0

Table 4.29: Primary Measurement Results of Campaign Two, Measurement Two (Part 2)

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 01	1	9.03960	101.146	1529115	3027922	9.03960	101.146
Trace 01	8	13.9861	98.2914	2136571	4115913	12.6805	104.272
Trace 01	15	23.0392	432.508	2999414	5546824	17.9019	302.206
Trace 01	50	26.8723	593.473	3249363	5935949	19.4255	348.372
Trace 01	100	29.4782	798.075	3318497	6041552	19.8478	348.955
Trace 02	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 02	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 02	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 02	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 02	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 03	1	8.51634	101.177	1002123	1368460	8.51634	101.177
Trace 03	8	13.7289	104.496	1428951	1895208	12.1775	109.360
Trace 03	15	23.0000	370.266	2030612	2580028	17.3733	272.260
Trace 03	50	25.6478	516.566	2143422	2700862	18.3521	306.368
Trace 03	100	27.0285	567.570	2173610	2732790	18.6142	306.094
Trace 04	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 04	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 04	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 04	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 04	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 05	1	7.91176	96.7863	2292434	7676418	7.91176	96.7863
Trace 05	8	12.5833	108.951	3228120	1056658	11.2083	110.164
Trace 05	15	20.2285	474.862	4393828	1396448	15.3714	332.119
Trace 05	50	20.2285	474.862	4393828	1396448	15.3714	332.119
Trace 05	100	20.2285	474.862	4393828	1396448	15.3714	332.119
Trace 06	1	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 06	8	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 06	15	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 06	50	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 06	100	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 07	1	1.00000	0.00000	38012.2	3700240	1.00000	0.00000
Trace 07	8	114.333	16063.1	1259711	1220250	33.3968	1312.65
Trace 07	15	268.500	20.7500	2806715	2701369	75.1428	1.40816
Trace 07	50	8039.00	0.00000	5332724	3522653	2104.00	4.00000
Trace 07	100	8039.00	0.00000	5332724	3522653	2104.00	4.00000
Trace 08	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 08	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 08	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 08	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 08	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 09	1	nan	0.00000	1612235	0.00000	0.00000	0.00000
Trace 09	8	nan	0.00000	1612235	0.00000	0.00000	0.00000
Trace 09	15	nan	0.00000	1612235	0.00000	0.00000	0.00000
Trace 09	50	nan	0.00000	1612235	0.00000	0.00000	0.00000
Trace 09	100	nan	0.00000	1612235	0.00000	0.00000	0.00000

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 10	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 10	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 10	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 10	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 10	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 11	1	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 11	8	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 11	15	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 11	50	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 11	100	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 12	1	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 12	8	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 12	15	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 12	50	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 12	100	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 13	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 13	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 13	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 13	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 13	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 14	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 14	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 14	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 14	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 14	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 15	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 15	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 15	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 15	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 15	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 16	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 16	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 16	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 16	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 16	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 17	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 17	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 17	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 17	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 17	100	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 18	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 18	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 18	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 18	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 18	100	nan	0.00000	1612719	0.00000	0.00000	0.00000

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 19	1	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 19	8	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 19	15	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 19	50	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 19	100	nan	0.00000	1612638	0.00000	0.00000	0.00000
Trace 20	1	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 20	8	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 20	15	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 20	50	nan	0.00000	1612719	0.00000	0.00000	0.00000
Trace 20	100	nan	0.00000	1612719	0.00000	0.00000	0.00000

Table 4.30: Further Statistical Measurement Results of Campaign Two, Measurement Two

Parameter	**Value**
PreambleLength	128 bits
ScramblingEnabled	False
Gap Time	1000 μsec
SFD Threshold	152
Frequency	12
NumPackets	20000
NumChunks	28
CRCUsageEnabled	False
Rx-Tx-Distance	≈ 20 meter
ModulationCode	2 MBit QPSK
PacketSize	1000 bytes

Table 4.31: Fixed Parameters for Campaign Two, Measurement Three

Parameter	**Value**
Diversity	True vs. False

Table 4.32: Variable Parameters for Campaign Two, Measurement Three

4.3 Measurement Three

Measurement three repeated measurement two with a slight modification. For the non line of sight setting each path had to pass a wooden wall. While in measurement two there still were direct reflection paths, which where not interrupted, in measurement three each path had to pass an obstacle. The aim was to observe quality differences as compared with measurement two. The other parameters were set to the same settings like in the other measurements of this campaign.

Again in each case five traces were recorded, space diversity was switched on and off. This increased the total amount of traces to twenty.

4.3.1 Measurement Parameters

In Tables 4.31 and 4.32 the fixed and variable parameters used during this measurement are shown, while in Table 4.33 the mapping from trace numbers to parameters is displayed.

Trace No.	**Description**
Traces 01, 03, 05, 07 and 09	Direct LOS, no Diversity
Traces 02, 04, 06, 08, 10	Direct LOS, Diversity activated
Trace 11, 13, 15, 17, 19	No LOS, all Paths are physically interrupted, no Diversity
Trace 12, 14, 16, 18, 20	No LOS, all Paths are physically interrupted, Diversity activated

Table 4.33: Trace Key of Campaign Two, Measurement Three

4.3.2 Occurences during the Measurement

During this measurement nothing occurred beside the fact, that one of the project students entered the hall while traces were still recorded. This happened in trace 18.

4.3.3 Measurement Results

Measurement three provides us very interesting results.

As we can observe, the transmission quality differs between the line of sight and the non line of sight scenario (with wall in between). As we change the setting from a line of sight scenario to a non line of sight scenario, not only the error statistics change due to a weaker SNR, as we would think. Also the complete error pattern changes, leaving maybe a clear statement behind, when bit shifter packets occur.

As we can see from the bit error rate and packet error rate plots, for the line of sight setting we have relative low values, whereas especially for the non line of sight setting we have a very high packet error rate. The fact that the bit error rate only rises moderate gives a hint that the error distribution is different for the non line of sight scenario. If we consider the packet occurrence statistics for the line of sight scenario, we observe for all ten traces a high rate of bit shifter packets. All other types of packet errors per trace were quite small. In combination with the fact that for all traces all twenty thousand packets were processed correctly shows that bit shifting is an effect, that can occur without any other error pattern. In opposite to this setting, bit shifter packets in the non line of sight setting do not occur at all, although the overall packet error rate is higher.

By interrupting the line of sight through introducing a wooden wall as obstacle, one would suspect a lower SNR at the receiver and therefore a higher rate of lost packets. This is not the case. But the lower SNR has an effect on the bit error behavior of each packet. When observing the packet error statistics viewgraphs, it can be clearly seen that packet errors occur in the line of sight setting only rarely but then severe by damaging every fourth packet.

This is due to the bit shifter packets that occur in this setting.

For the non line of sight setting packet errors occur much more often but if they occur they are not that severe. Therefore, mostly shorter error burst length occur. The bit errors are distributed throughout the wrong packets quite similar with similar areas of concentration, but not that deterministically as with bit shifter packets. Whereas the traces of the line of sight setting have a strongly correlated error burst length sequence especially for the rank of eight, error burst length sequence patterns for the non line of sight setting are much more uncorrelated.

Interestingly, as in measurement one, space diversity has no impact on error behaviors for both cases. This is probably due to the same reason as in measurement one. The positioning of the receiver terminal had the same geometric properties as in measurement one.

Basically for this measurement it seems as if RF interference was present in the line of sight case whereas in the non line of sight case no significant interference pattern was present. Instead, the signal strength was attenuated by the wooden obstacle causing much more 'tiny' errors throughout the whole packets of a trace.

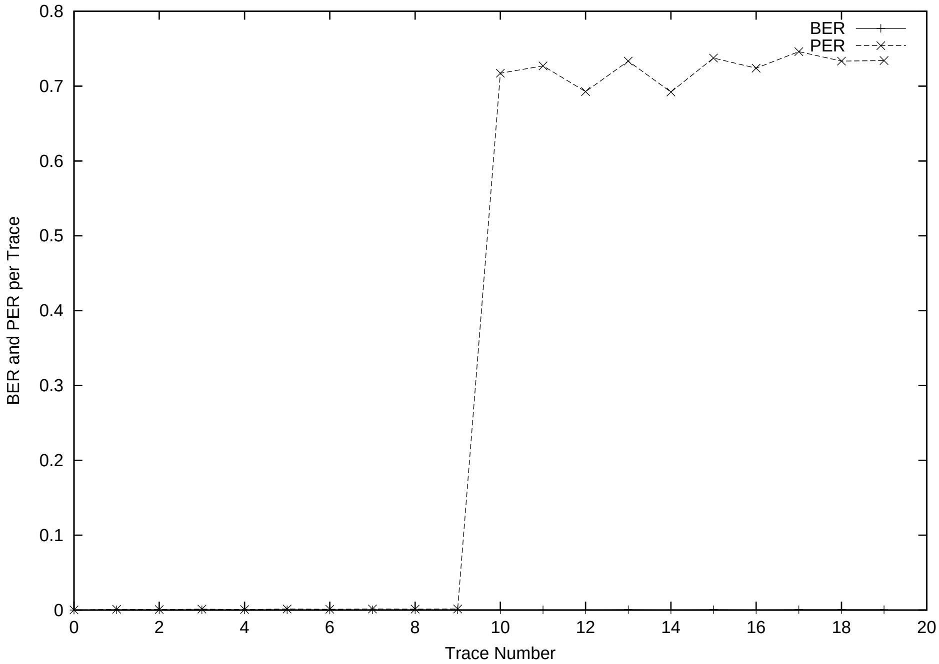


Figure 4.11: BER and PER per Trace vs.Tracenumber

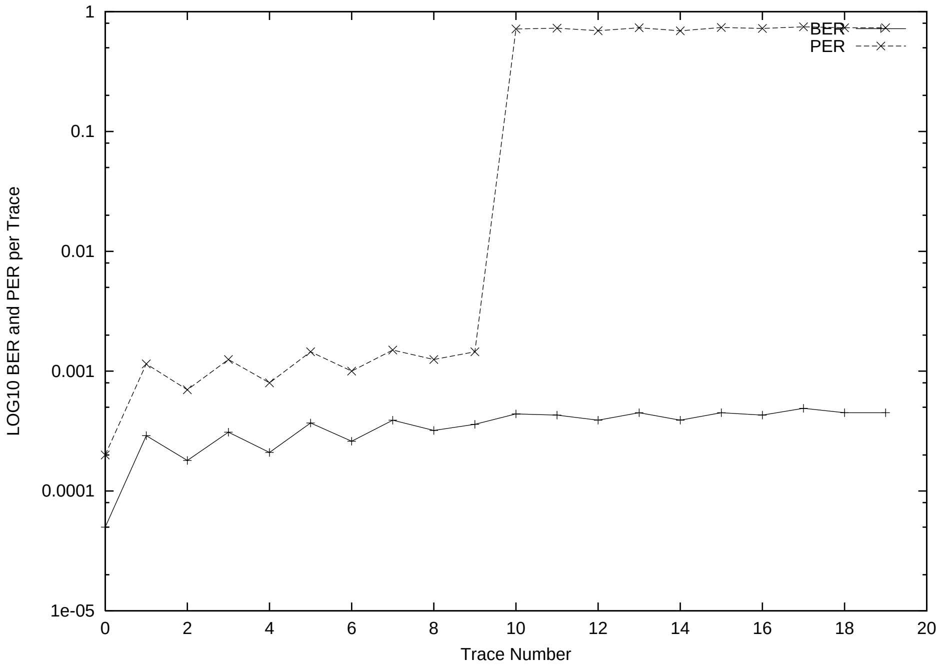


Figure 4.12: Log 10 Scaling of BER and PER per Trace vs. Tracenumber

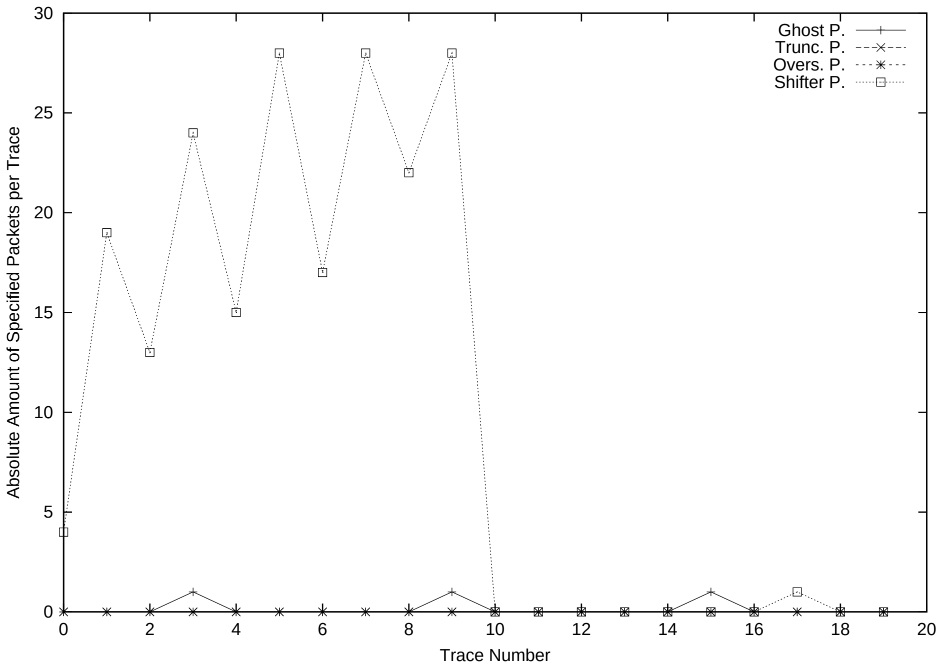
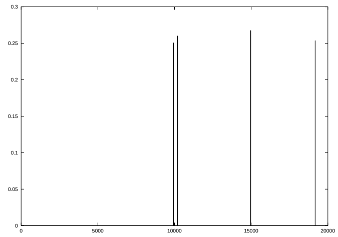
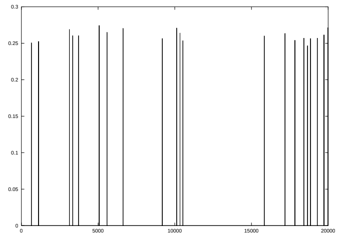


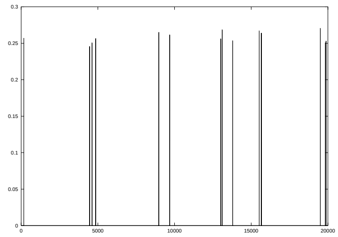
Figure 4.13: Number of Ghost, Truncated, Oversized and Shifter Packets vs. Tracenumber



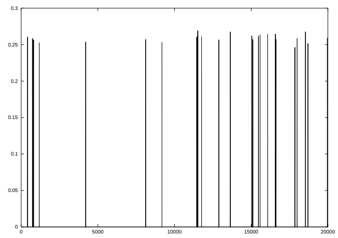
Trace 01



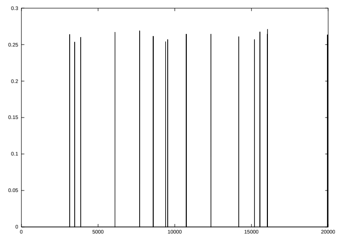
Trace 02



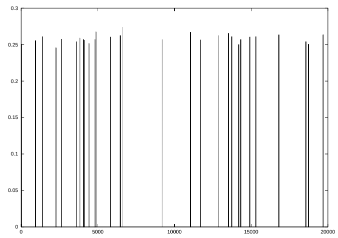
Trace 03



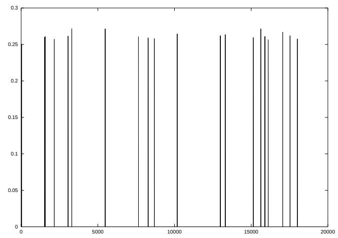
Trace 04



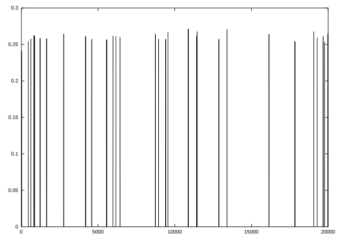
Trace 05



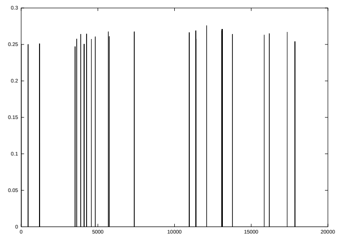
Trace 06



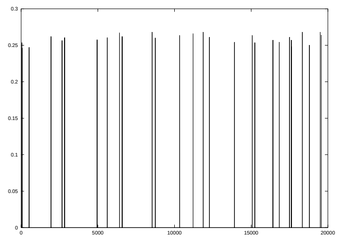
Trace 07



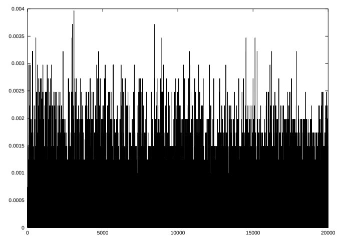
Trace 08



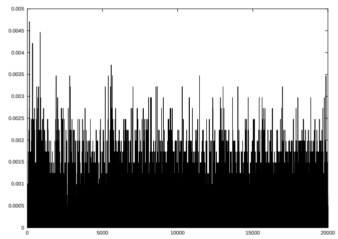
Trace 09



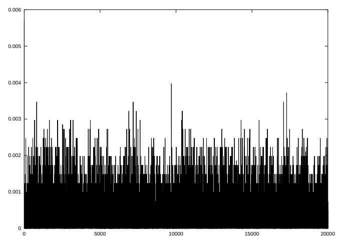
Trace 10



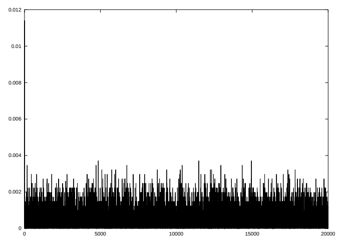
Trace 11



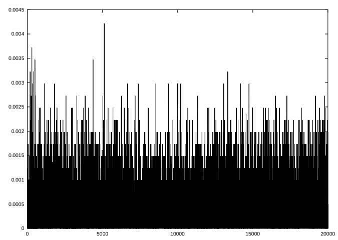
Trace 12



Trace 13

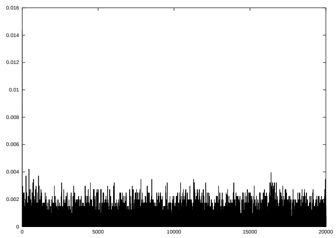


Trace 14

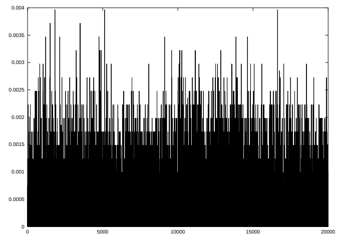


Trace 15

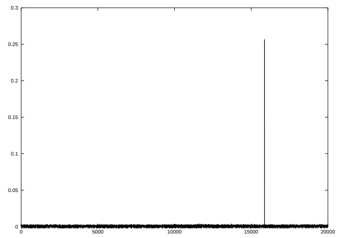
Table 4.34: BER per packet vs. packet number: Campaign Two, Measurement Three



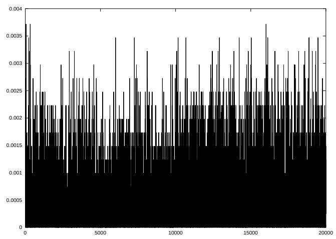
Trace 16



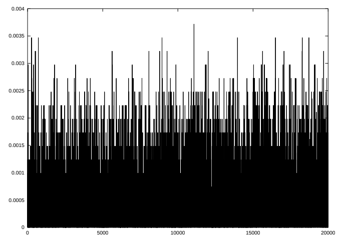
Trace 17



Trace 18

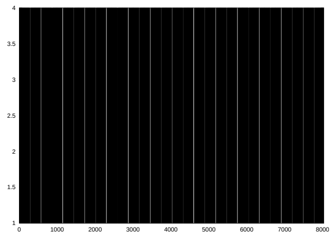


Trace 19

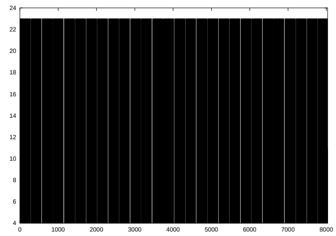


Trace 20

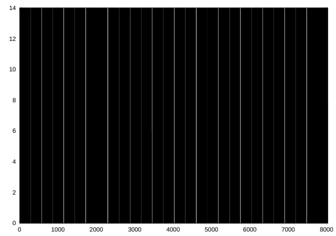
Table 4.35: BER per packet vs. packet number: Campaign Two, Measurement Three



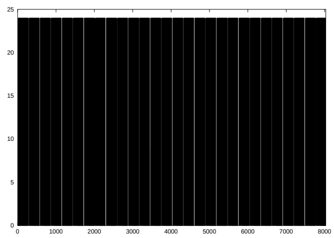
Trace 01



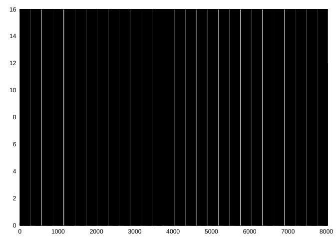
Trace 02



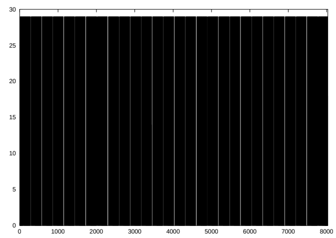
Trace 03



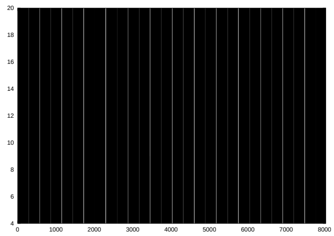
Trace 04



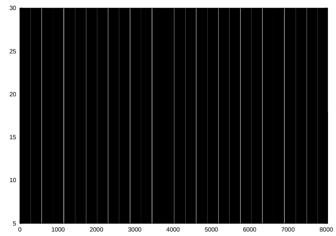
Trace 05



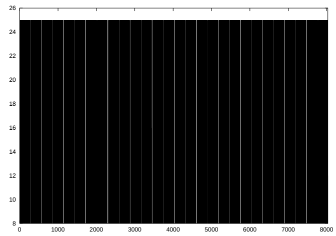
Trace 06



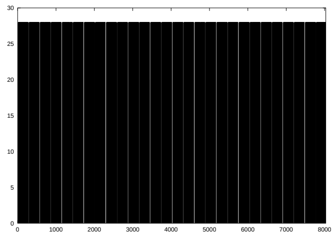
Trace 07



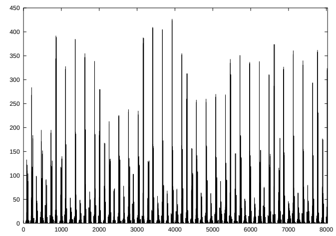
Trace 08



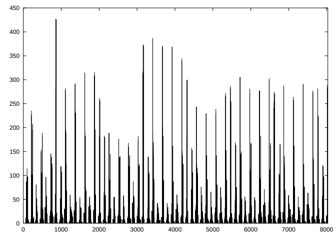
Trace 09



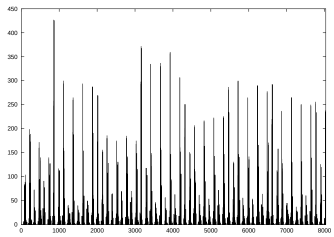
Trace 10



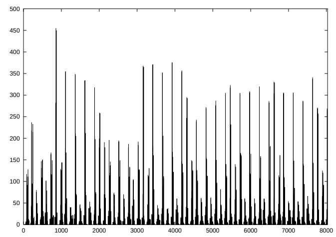
Trace 11



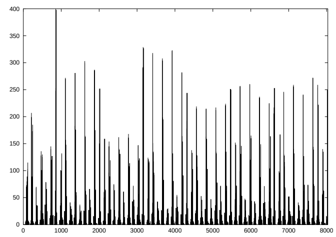
Trace 12



Trace 13

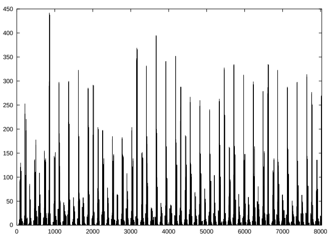


Trace 14

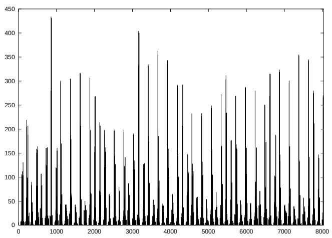


Trace 15

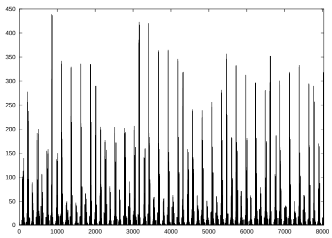
Table 4.36: Error position histograms: Campaign Two, Measurement Three



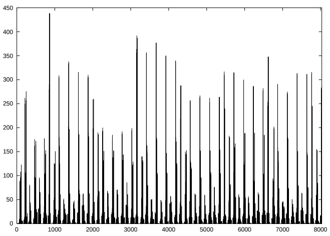
Trace 16



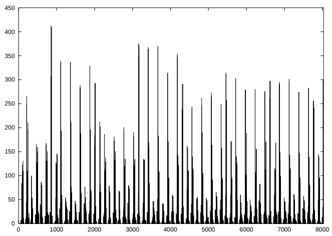
Trace 17



Trace 18

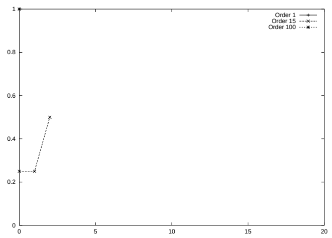


Trace 19

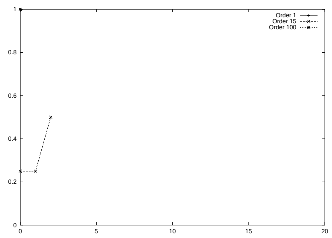


Trace 20

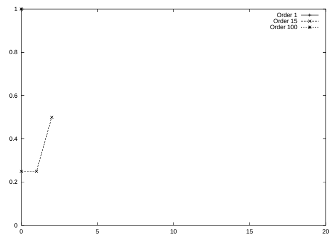
Table 4.37: Error position histograms: Campaign Two, Measurement Three



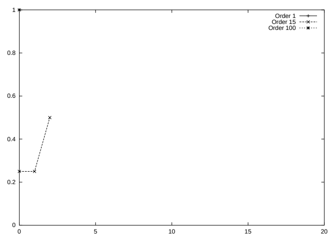
Trace 01



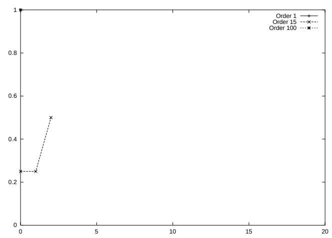
Trace 02



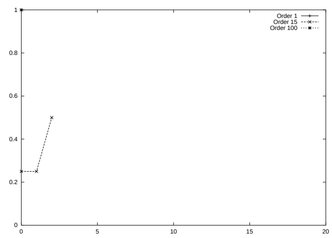
Trace 03



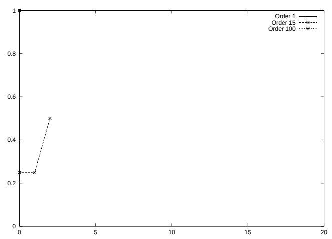
Trace 04



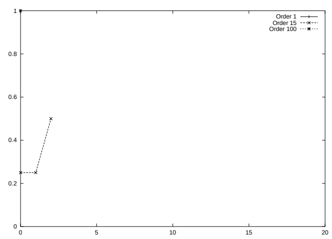
Trace 05



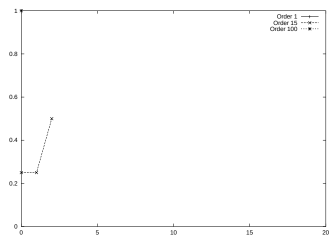
Trace 06



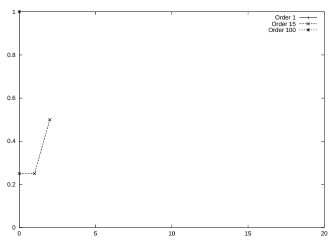
Trace 07



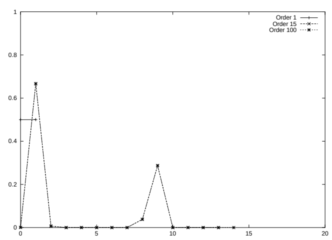
Trace 08



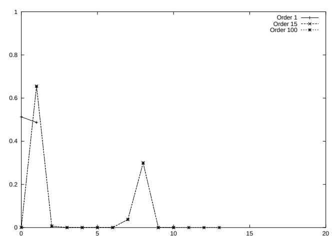
Trace 09



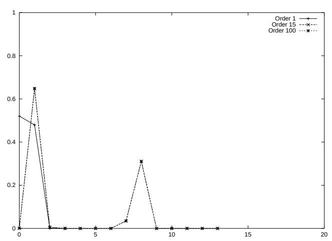
Trace 10



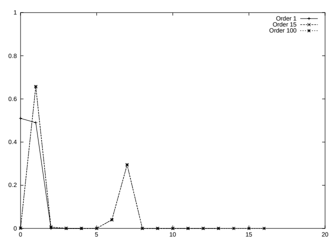
Trace 11



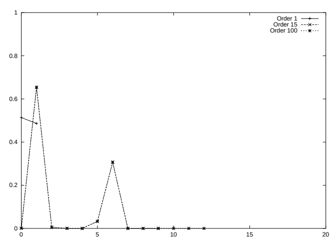
Trace 12



Trace 13

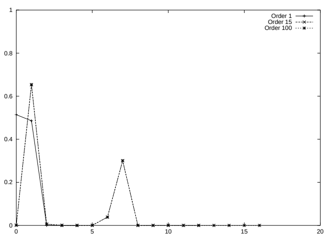


Trace 14

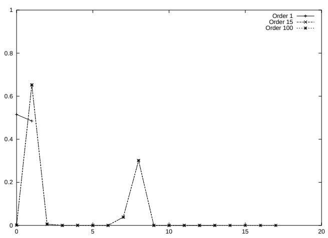


Trace 15

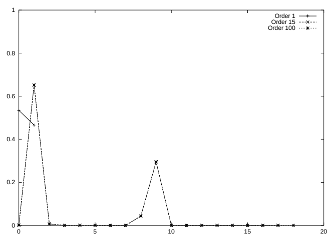
Table 4.38: Normalized Histogram Plots of error runlengths at different burst orders k_0 of Campaign Two, Measurement Three



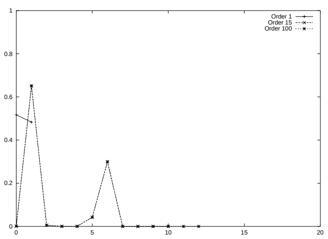
Trace 16



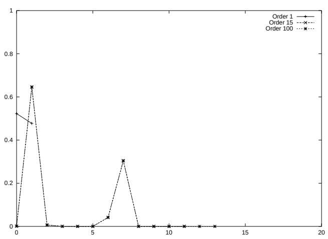
Trace 17



Trace 18

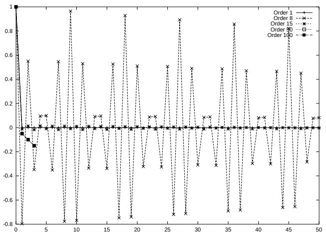


Trace 19

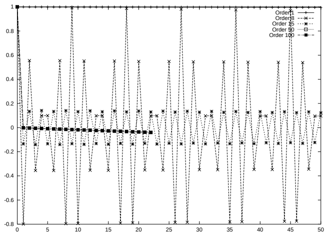


Trace 20

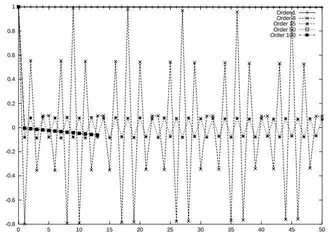
Table 4.39: Normalized Histogram Plots of error runlengths at different burst orders k_0 of Campaign Two, Measurement Three



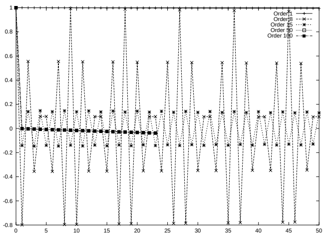
Trace 01



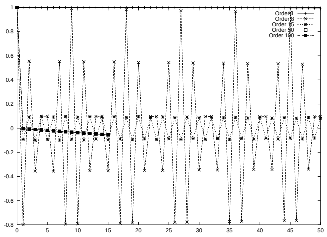
Trace 02



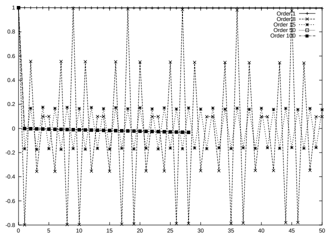
Trace 03



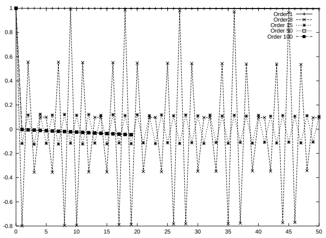
Trace 04



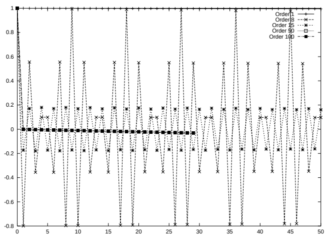
Trace 05



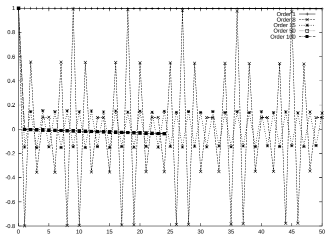
Trace 06



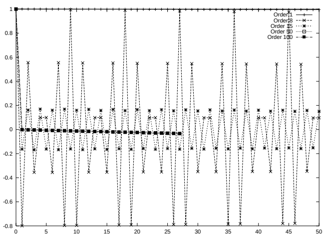
Trace 07



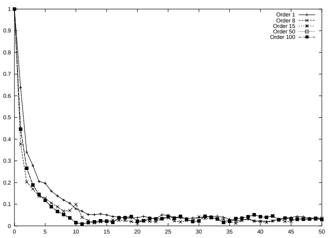
Trace 08



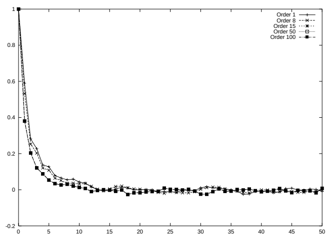
Trace 09



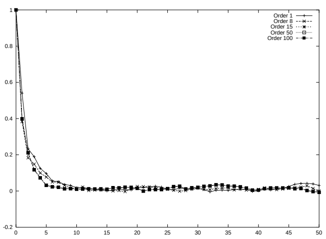
Trace 10



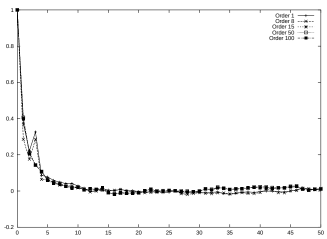
Trace 11



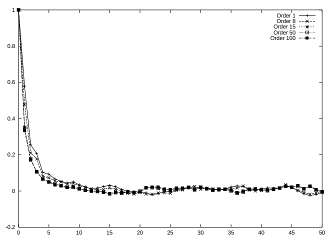
Trace 12



Trace 13

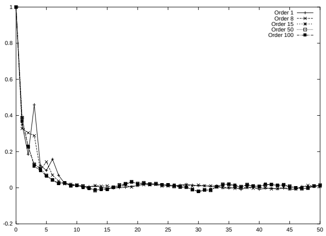


Trace 14

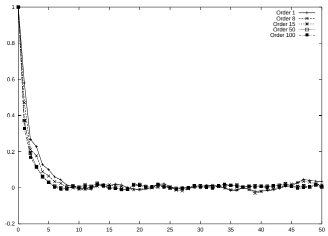


Trace 15

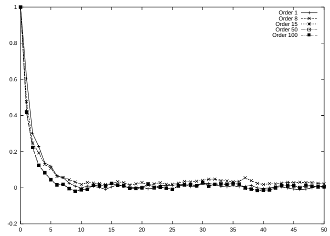
Table 4.40: Autocovariance of error runlengths at different burst orders k_0 of Campaign Two, Measurement Three



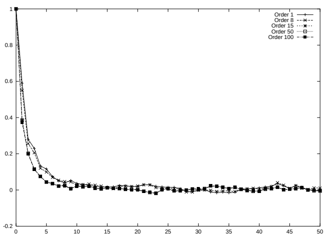
Trace 16



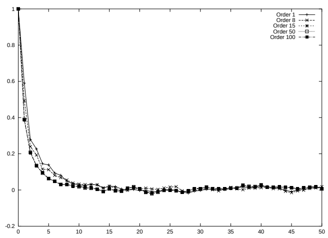
Trace 17



Trace 18



Trace 19



Trace 20

Table 4.41: Autocovariance of error runlengths at different burst orders k_0 of Campaign Two, Measurement Three

Trace No.	**BER**	**PER**	**Packet Loss Rate**	**Packets Wrong**
Trace 01	0.00005	0.0002	0	4
Trace 02	0.00029	0.00115	0	23
Trace 03	0.00018	0.0007	0	14
Trace 04	0.00031	0.00125	0	25
Trace 05	0.00021	0.0008	0	16
Trace 06	0.00037	0.00145	0	29
Trace 07	0.00026	0.001	0	20
Trace 08	0.00039	0.0015	0	30
Trace 09	0.00032	0.00125	0	25
Trace 10	0.00036	0.00145	0	29
Trace 11	0.00044	0.71715	0	14343
Trace 12	0.00043	0.72705	0	14541
Trace 13	0.00039	0.69265	0	13853
Trace 14	0.00045	0.7334	0	14668
Trace 15	0.00039	0.6921	0	13842
Trace 16	0.00045	0.73745	0	14749
Trace 17	0.00043	0.72395	0	14479
Trace 18	0.00049	0.746	0	14920
Trace 19	0.00045	0.73345	0	14669
Trace 20	0.00045	0.7342	0	14684

Table 4.42: Primary Measurement Results of Campaign Two, Measurement Three (Part 1)

Trace No.	**Packets Ghost**	**Packets Truncated**	**Packets Oversized**	**Packets Shifted**
Trace 01	0	0	0	4
Trace 02	0	0	0	19
Trace 03	0	0	0	13
Trace 04	1	0	0	24
Trace 05	0	0	0	15
Trace 06	0	0	0	28
Trace 07	0	0	0	17
Trace 08	0	0	0	28
Trace 09	0	0	0	22
Trace 10	1	0	0	28
Trace 11	0	0	0	0
Trace 12	0	0	0	0
Trace 13	0	0	0	0
Trace 14	0	0	0	0
Trace 15	0	0	0	0
Trace 16	1	0	0	0
Trace 17	0	0	0	0
Trace 18	0	0	0	1
Trace 19	0	0	0	0
Trace 20	0	0	0	0

Table 4.43: Primary Measurement Results of Campaign Two, Measurement Three (Part 2)

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 01	1	1.00000	0.00000	19371.0	1092595	1.00000	0.00000
Trace 01	8	114.333	16063.1	637324.	3569493	33.0317	1284.82
Trace 01	15	268.500	20.7500	1426919	7917686	74.3214	4.96811
Trace 01	50	8039.00	0.00000	3224795	9745587	2081.00	2731.00
Trace 01	100	8039.00	0.00000	3224795	9745587	2081.00	2731.00
Trace 02	1	1.00000	0.00000	3339.41	6302625	1.00000	0.00000
Trace 02	8	114.333	16063.1	111107.	2087936	33.3181	1308.31
Trace 02	15	268.500	20.7500	249765.	4663171	74.9658	5.96777
Trace 02	50	8039.00	0.00000	6711960	8530913	2099.04	3503.60
Trace 02	100	8039.00	0.00000	6711960	8530913	2099.04	3503.60
Trace 03	1	1.00000	0.00000	5521.06	1454318	1.00000	0.00000
Trace 03	8	114.333	16063.1	182526.	4783065	33.1111	1291.61
Trace 03	15	268.500	20.7500	410093.	1066833	74.5000	5.91326
Trace 03	50	8039.00	0.00000	1074395	1797565	2086.00	3485.71
Trace 03	100	8039.00	0.00000	1074395	1797565	2086.00	3485.71
Trace 04	1	1.00000	0.00000	3212.64	5063536	1.00000	0.00000
Trace 04	8	114.333	16063.1	106471.	1669476	33.1878	1296.89
Trace 04	15	268.500	20.7500	239351.	3724471	74.6726	3.92853
Trace 04	50	8039.00	0.00000	6442837	6265194	2090.83	1886.63
Trace 04	100	8039.00	0.00000	6442837	6265194	2090.83	1886.63
Trace 05	1	1.00000	0.00000	4758.39	8288286	1.00000	0.00000
Trace 05	8	114.333	16063.1	159719.	2761339	33.6150	1331.33
Trace 05	15	268.500	20.7500	358912.	6141363	75.6339	3.52670
Trace 05	50	8039.00	0.00000	9479018	8010562	2117.75	1592.93
Trace 05	100	8039.00	0.00000	9479018	8010562	2117.75	1592.93
Trace 06	1	1.00000	0.00000	2664.16	2561491	1.00000	0.00000
Trace 06	8	114.333	16063.1	88108.8	8408302	33.1198	1291.69
Trace 06	15	268.500	20.7500	198098.	1870053	74.5197	4.50330
Trace 06	50	8039.00	0.00000	5367960	2365303	2086.55	2293.76
Trace 06	100	8039.00	0.00000	5367960	2365303	2086.55	2293.76
Trace 07	1	1.00000	0.00000	3816.53	5030606	1.00000	0.00000
Trace 07	8	114.333	16063.1	127777.	1670758	33.5269	1324.23
Trace 07	15	268.500	20.7500	287204.	3713339	75.4357	3.69586
Trace 07	50	8039.00	0.00000	7671959	4448531	2112.20	1762.36
Trace 07	100	8039.00	0.00000	7671959	4448531	2112.20	1762.36
Trace 08	1	1.00000	0.00000	2558.34	2811172	1.00000	0.00000
Trace 08	8	114.333	16063.1	85169.6	9301964	33.3396	1309.36
Trace 08	15	268.500	20.7500	191493.	2072558	75.0142	4.41884
Trace 08	50	8039.00	0.00000	5194540	3117691	2100.40	2261.97
Trace 08	100	8039.00	0.00000	5194540	3117691	2100.40	2261.97
Trace 09	1	1.00000	0.00000	3054.83	4345679	1.00000	0.00000
Trace 09	8	114.333	16063.1	102215.	1445977	33.5073	1323.76
Trace 09	15	268.500	20.7500	229791.	3224093	75.3914	6.24106
Trace 09	50	8039.00	0.00000	6195037	5184163	2110.96	3775.07
Trace 09	100	8039.00	0.00000	6195037	5184163	2110.96	3775.07

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 10	1	1.00000	0.00000	2752.77	2609253	1.00000	0.00000
Trace 10	8	114.333	16063.1	91253.3	8581209	33.1972	1298.10
Trace 10	15	268.500	20.7500	205163.	1907373	74.6938	4.91649
Trace 10	50	8039.00	0.00000	5553061	2264873	2091.42	2685.95
Trace 10	100	8039.00	0.00000	5553061	2264873	2091.42	2685.95
Trace 11	1	1.50016	0.25000	3359.52	2812480	1.50016	0.25000
Trace 11	8	1.52616	0.37423	3381.91	2823674	1.51017	0.25468
Trace 11	15	6.49849	41.6950	4477.13	3253020	2.00125	0.00619
Trace 11	50	6.49849	41.6950	4477.13	3253020	2.00125	0.00619
Trace 11	100	6.50137	42.0204	4477.26	3253057	2.00130	0.00631
Trace 12	1	1.48731	0.24983	3452.98	2822859	1.48731	0.24983
Trace 12	8	1.50769	0.31103	3472.45	2832032	1.49571	0.25269
Trace 12	15	6.66280	42.4990	4639.06	3247694	2.00023	0.00409
Trace 12	50	6.66280	42.4990	4639.06	3247694	2.00023	0.00409
Trace 12	100	6.67475	43.9227	4639.59	3247830	2.00046	0.00455
Trace 13	1	1.48027	0.26223	3714.03	3347519	1.48027	0.26223
Trace 13	8	1.49984	0.37115	3732.85	3357473	1.48778	0.26805
Trace 13	15	6.78587	43.2165	5018.04	3874584	2.00193	0.03576
Trace 13	50	6.78668	43.2743	5018.20	3874627	2.00199	0.03963
Trace 13	100	6.78668	43.2743	5018.20	3874627	2.00199	0.03963
Trace 14	1	1.49138	0.29152	3303.12	2627727	1.49138	0.29152
Trace 14	8	1.51474	0.40575	3323.06	2636978	1.50039	0.29848
Trace 14	15	6.62759	42.3708	4430.86	3030401	2.00266	0.07486
Trace 14	50	6.62879	42.4848	4430.99	3030431	2.00272	0.07915
Trace 14	100	6.63937	43.4712	4431.46	3030557	2.00294	0.07949
Trace 15	1	1.48631	0.24981	3806.22	3400126	1.48631	0.24981
Trace 15	8	1.50434	0.32068	3824.54	3409499	1.49347	0.25337
Trace 15	15	6.70420	42.8283	5118.73	3906760	2.00069	0.00451
Trace 15	50	6.70435	42.8290	5118.73	3906760	2.00069	0.00451
Trace 15	100	6.71699	44.1819	5119.37	3906936	2.00095	0.00502
Trace 16	1	1.48789	0.30182	3249.14	2536871	1.48789	0.30182
Trace 16	8	1.51114	0.41480	3268.23	2545553	1.49664	0.30749
Trace 16	15	6.69170	42.7108	4371.55	2927747	2.00404	0.09482
Trace 16	50	6.69170	42.7108	4371.55	2927747	2.00404	0.09482
Trace 16	100	6.70672	44.4614	4372.25	2927924	2.00437	0.10200
Trace 17	1	1.48480	0.24976	3402.24	2809421	1.48480	0.24976
Trace 17	8	1.50740	0.36195	3422.30	2819140	1.49356	0.25590
Trace 17	15	6.69309	42.6518	4579.06	3247793	2.00045	0.00830
Trace 17	50	6.69309	42.6518	4579.06	3247793	2.00045	0.00830
Trace 17	100	6.71294	44.5881	4579.95	3248039	2.00085	0.00910
Trace 18	1	1.46581	0.24883	2975.78	2337566	1.46581	0.24883
Trace 18	8	1.64850	35.3854	3111.88	2402251	1.53291	2.99492
Trace 18	15	6.86790	92.0367	4163.49	2781261	2.05324	3.75374
Trace 18	50	6.88618	1712.00	4166.38	2782003	2.05468	110.676
Trace 18	100	6.89890	1713.45	4166.91	2782148	2.05494	110.691

Trace No.	Burst Order	E(Burst Length)	VAR(Burst Length)	E(EFree BurstLength)	VAR(EFree BurstLength)	E(Wrong Bits per Burst)	VAR(Wrong Bits per Burst)
Trace 19	1	1.48307	0.24971	3277.33	2667693	1.48307	0.24971
Trace 19	8	1.50242	0.33835	3293.93	2675749	1.49059	0.25354
Trace 19	15	6.71919	42.6816	4415.68	3097024	2.00035	0.00529
Trace 19	50	6.71919	42.6816	4415.68	3097024	2.00035	0.00529
Trace 19	100	6.72490	43.3161	4415.92	3097092	2.00046	0.00551
Trace 20	1	1.47736	0.24948	3235.16	2625221	1.47736	0.24948
Trace 20	8	1.49999	0.34963	3254.94	2634849	1.48640	0.25502
Trace 20	15	6.78027	42.9593	4376.56	3057317	2.00078	0.00725
Trace 20	50	6.78027	42.9593	4376.56	3057317	2.00078	0.00725
Trace 20	100	6.78594	43.5067	4376.79	3057384	2.00089	0.00736

Table 4.44: Further Statistical Measurement Results of Campaign Two, Measurement Three

Chapter 5

Project Conclusions and Lessons Learned

Despite the findings and results of bit error behaviors on a per trace base, which we discussed in each of the different measurement's chapters, some more fundamental findings from these measurements are worth being mentioned. After performing the two campaigns we can make the following suggestions about setups and parameters for future use:

- Using the IEEE 802.11 PHY CCK modulation at more than 20 meters results in a very unreliable transmission, even if the specification suggests a distance of up to 40 meters. If these modulation types are used for data transmissions over longer distances than 20 meters, a functionality to switch the modulation type to a lower one in case of occurring errors would increase the reliability of data transmission.

- If you plan to use space diversity, it seems important to check the geometrical setup between the direction of the transceiver's radio signal and the orientation of the two space diversity antennas at the receiver. In the first measurement of the second campaign, we probably would have gotten other results, if we would have chosen a different orientation of the two antennas of the receiver unit. However, we cannot make any concrete assumptions about the accurate nature of any interference patterns.

- To find out more about the source of bit shifter occurrences a setup with two simultaneously receiving computers seems useful. If both receivers units would have the same or similar patterns of bit shifters in the received data, this would suggest that the problem is introduced already at the transmitter, not in the channel. As seen, bit shifters do not occur at all at campaign 1 whereas campaign 2 seems to be full of bit shifter packets. Therefore it is tempting to blame RF interference on the occurrences of bit shifter packets.

- The observed phenomena (packet losses, bit shifter) could theoretically be due to a faulty measurement setup. However, the fact that many traces show no errors at all and furthermore, that the occurence of phenomena likely can be attributed to characteristics of the environment, gives us confidence that our setup is ok.

- Like already described in [3], in our two campaigns bit errors tend to occur in the beginning of each packet. So still another campaign is necessary with changed transceiver and receiver units to determine if this effect is a general feature of the setup and has to be considered when modeling the channel [3] for 802.11 wireless channels. The results given in [4] indeed show that these effects occur with another set of modems.

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