Repeatability of Illinois Wireless Wind Tunnel*

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Abstract

This report records the experimental results concerning the repeatability of Illinois Wireless Wind Tunnel (iWWT) [1], a testbed for experimental evaluation of wireless networks. The results show that even in the anechoic chamber, the repeatability of experiments can still be affected by some factors. These factors include randomness of protocol, imprecise position of devices, etc.

1 Introduction

The Illinois Wireless Wind Tunnel (iWWT), which is proposed in [1], is implemented in an electromagnetic anechoic chamber, with the following two properties: 1) signal outside the chamber cannot interfere the devices inside the chamber, and 2) signal inside the chamber is absorbed by the wall and thus cannot be reflected. With these two properties, the wireless experiments inside the chamber are supposed to be repeatable. This report records several experimental results and studies the repeatability of the experiments inside the anechoic chamber.

2 Repeatability Overview

Unlike using networks simulators in which all of the parameters are under control and the simulation is fully repeatable, several factors can affect the experiments inside the anechoic chamber, even though the chamber is a well-controlled environment.

- *Randomness of protocol*: 802.11a/b/g uses a random backoff mechanism to alleviate collisions. This brings uncertainty to the experiments. Although this should not affect the results over a sufficiently long period, no two experiments may be exactly the same due to the randomness of protocol.
- *Imprecise position of objects*: To guarantee the repeatability of experiments, the position of all the devices inside the chamber must be unchanged from different runs. However, once we move a device and try to put it back to its original position, there is usually some positioning error, no matter how small it is. Such small positioning error can sometimes dominate the experiments, which is shown in the next section.

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This report mainly focuses on the above two factors that may affect the repeatability. The next section presents several experimental results to demonstrate the impact of these two factors.

3 Experimental Results

3.1 Randomness of protocol

To study the impact of protocol randomness, we conducted an experiment with the following deployment. There is only one wireless link in this scenario, with one transmitter and one receiver. Two laptops are deployed at two end points inside the chamber, and the topology is shown in Figure 1. Laptop #1 acts as the transmitter and laptop #2 acts as the receiver, and their antennas are in a straight line without obstacles between them.

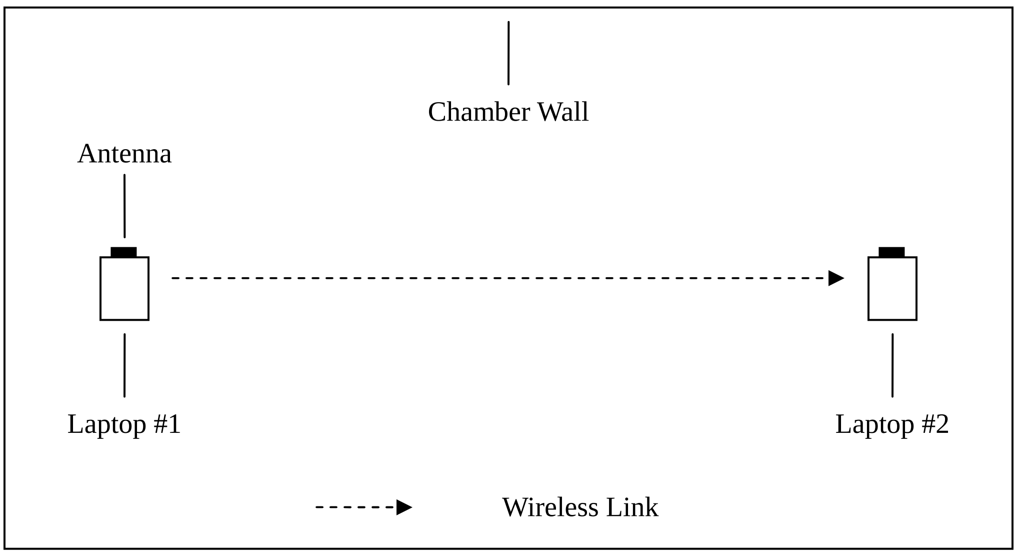


Figure 1: Topology of experiment #1

In this experiment, we used a simple C program, which records the sending time and receiving time of each packet, in order to track all the packets.

The duration of the test is set to be 1 second, 3 seconds, and 10 seconds respectively. For each duration, there are 10 runs. During the experiment, the position of the two laptops is unchanged. Table 1 shows the results for 3 seconds case. In Table 1, *latency* refers to the time period between two consecutive packet receipts.

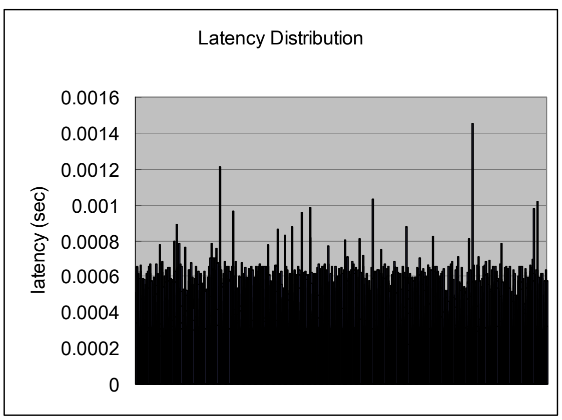
As we can see in Table 1, run #3~#10 show consistent result regarding to throughput. However, run #1 and #2 show a much lower throughput. After careful analysis of the trace file, we found that the transmitter is not transmitting all the time. However, when it is transmitting, the instantaneous throughput is around 33Mbps, which is comparable to run #3~#10. The best explanation for this we could find is given by the latest madwifi document (v0.9.4) [2]: “Ad-hoc mode is broken; symptoms are intermittent operation”. This perfectly matches the symptom that is happening in run #1 and #2.

Now let us focus on run #3~#8. We can see that results like throughput and average latency is repeatable.

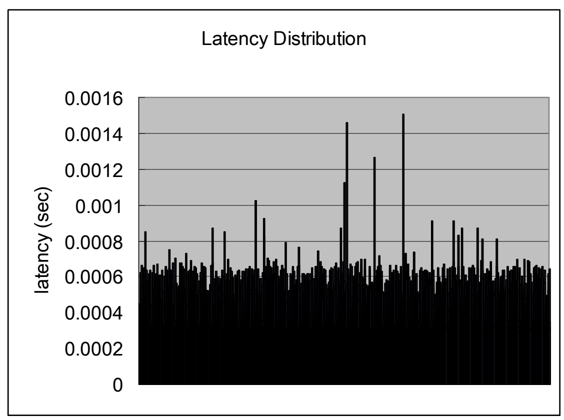
However, individual packet latencies are not repeatable. This is unlike experiment using network simulators, in which we can make two experiments identical by setting the same random seed number. To justify the difficulty of repeating individual packet latencies, Figure 2 plots the latencies of run #9 and run #10. As we can see, although the average latencies are almost the same, the distributions are different.

Table 1: results of topology #1, 1 link, 3 seconds

run id	thrpt (Mbps)	pkt sent	pkt recv	pdr	latency (sec)		
					max	avg	min
1	10.85	2970	2970	1.00	6.94E-02	1.03E-03	2.07E-04
2	11.84	3207	3123	0.97	6.96E-02	9.47E-04	1.88E-04
3	32.99	8866	8866	1.00	1.43E-03	3.40E-04	4.00E-05
4	33.03	8888	8888	1.00	6.92E-03	3.40E-04	1.30E-05
5	32.99	8861	8861	1.00	1.50E-03	3.40E-04	3.80E-05
6	32.96	8863	8863	1.00	2.09E-03	3.40E-04	1.33E-04
7	33.15	8918	8918	1.00	1.46E-03	3.38E-04	1.50E-05
8	33.07	8890	8890	1.00	6.58E-03	3.39E-04	1.20E-05
9	33.02	8865	8865	1.00	1.45E-03	3.40E-04	1.25E-04
10	33.09	8910	8910	1.00	1.50E-03	3.39E-04	4.00E-05



run #9



run #10

Figure 2: latency versus time of experiment #1, 1 link, 3 seconds

In summary, due to the randomness of the protocol, microscopic results are not repeatable in the chamber. However, macroscopic results are not affected by such randomness.

3.2 Imprecise position of objects

To study the impact of object position, we used the following topology, shown by Figure 3. To avoid the problem of intermittent operation of ad-hoc mode caused by madwifi, we used Soekris Net 4521 boxes [3] instead of laptops. Each node contains one wireless card and uses the internal antenna of that card. In this topology, four nodes are deployed in a straight line inside the chamber. Node #31 and #32 are transmitters, and node #19 and #26 are receivers. With these four nodes, there are two possible link pairs: 1) 31→19 & 32→26, and 2) 31→26 & 32→19. The throughputs of these two link pairs are tested respectively. In addition, to figure out the impact of obstacle, one absorbing material may be placed between node #32 and node #26.

In this experiment, we used iperf [4] to measure UDP throughput of a link. The test time is set to be 1 second, 3 seconds, and 10 seconds respectively. Possible transmission rates of a link are 6Mbps and 54Mbps (802.11a). Each sub case contains 10 runs, while maximum, average, and minimum throughputs of these 10 runs are recorded. Table 2 shows the results of 10-second case *without* obstacle.

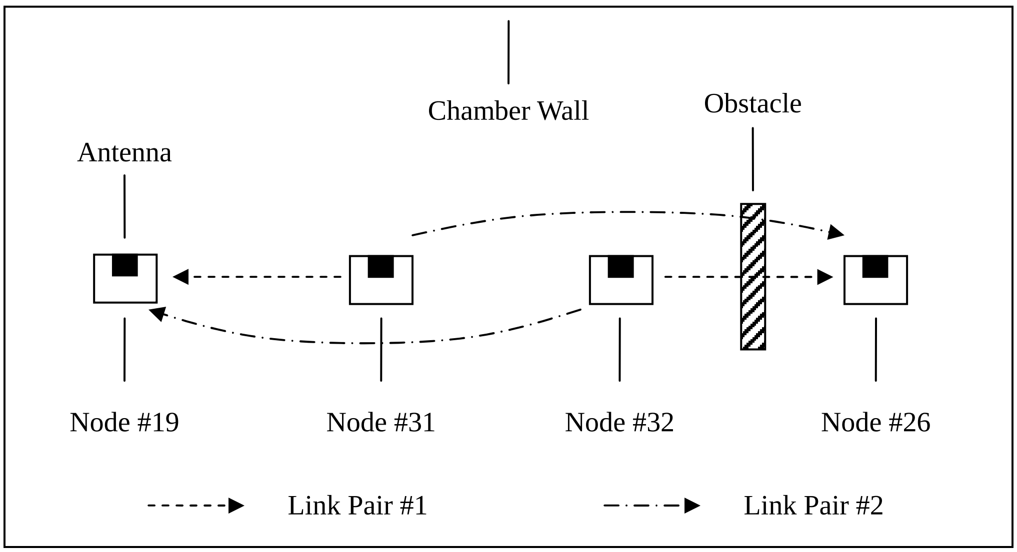


Figure 3: Topology of experiment #2

Table 2: results of topology #2, 2 links, 10 seconds, without obstacle

	link #1 thrpt (Mbps)			link #2 thrpt (Mbps)		
	max	avg	min	max	avg	min
link #1: 31→19 (6M) link #2: 32→26 (6M)	3.08	2.97	2.87	3.76	3.65	3.52
link #1: 31→26 (6M) link #2: 32→19 (6M)	3.05	2.94	2.74	3.56	3.22	3.03
link #1: 31→19 (54M) link #2: 32→26 (6M)	7.34	7.05	6.80	4.41	4.36	4.25
link #1: 31→26 (54M) link #2: 32→19 (6M)	6.80	5.40	3.58	4.70	4.41	4.17
link #1: 31→19 (54M) link #2: 32→26 (54M)	19.20	18.91	18.10	16.40	15.99	15.50
link #1: 31→26 (54M) link #2: 32→19 (54M)	17.90	17.64	17.50	7.99	7.17	5.13

As we can see in the table, the throughputs are not symmetric even though the two links are using the same data rate. This is due to the asymmetry of the two links. However, even though the two links are not symmetric, the throughput is expected to be repeatable. Table 2 indicates a fluctuation of throughput more than 20% in some cases (marked as gray background in the table), and thus is considered to be not repeatable. Such great fluctuations happen in link pair of 31→26 and 32→19, and with the 54Mbps link. The reason for this is that the four nodes are deployed in a straight line, so the node in the middle becomes an obstacle. For example, node #31 acts as an obstacle to link 32→19. When the link quality is poor and a high data rate is used, the throughput is not stable, resulting in a large fluctuation.

To study the impact of obstacles, we put an absorbing material between node #32 and node #26, while leaving the four wireless nodes unmoved. The same script is run again under this topology, and the results are shown in Table 3. As expected, some links experience a much lower throughput compared with Table 2, because of the added obstacle. Again, it demonstrates the previous explanation that when the link quality is poor, throughput fluctuates greatly, especially when using high data rate (54Mbps).

Table 3: results of topology #2, 2 links, 10 seconds, with obstacle
(percentage comparison with Table 2)

	link #1 thrpt (Mbps)			link #2 thrpt (Mbps)		
	max	avg	min	max	avg	min
link #1: 31→19 (6M) link #2: 32→26 (6M)	3.47	3.18 (↑7.07%)	2.88	2.67	2.27 (↓37.8%)	1.89
link #1: 31→26 (6M) link #2: 32→19 (6M)	3.41	3.09 (↑5.10%)	2.74	2.38	2.07 (↓35.7%)	1.92
link #1: 31→19 (54M) link #2: 32→26 (6M)	6.89	6.45 (↓8.51%)	6.09	4.51	4.46 (↑2.29%)	4.41
link #1: 31→26 (54M) link #2: 32→19 (6M)	0.58	0.53 (↓90.2%)	0.44	5.06	5.03 (↑14.1%)	4.98
link #1: 31→19 (54M) link #2: 32→26 (54M)	17.20	17.08 (↓9.68%)	16.90	6.78	6.55 (↓59.0%)	6.36
link #1: 31→26 (54M) link #2: 32→19 (54M)	4.37	4.23 (↓76.0%)	4.08	1.22	0.99 (↓86.2%)	0.88

Next step, to find out the impact of imprecise object positions, we picked up every object (including the nodes and the obstacle) and tried to put it back to its original position. Then the same test script is run again. Table 4 shows the results of this.

Compared with Table 3, some results in Tables 4 are quite different. We believe that this is due to error in placement of objects. The explanation is as follow. When the link quality is poor (due to obstacle), a small position change can change the channel quality greatly, reflecting in a large change in throughput.

Table 4: results of topology #2, 2 links, 10 seconds, with obstacle, slightly moved all the objects (percentage comparison with Table 3)

	link #1 thrpt (Mbps)			link #2 thrpt (Mbps)		
	max	avg	min	max	avg	min
link #1: 31→19 (6M) link #2: 32→26 (6M)	3.68	3.27 (↑2.83%)	2.98	2.46	2.16 (↓4.85%)	1.70
link #1: 31→26 (6M) link #2: 32→19 (6M)	4.84	4.72 (↑52.8%)	4.61	0.73	0.68 (↓67.2%)	0.60
link #1: 31→19 (54M) link #2: 32→26 (6M)	8.21	7.14 (↑10.7%)	6.27	4.33	4.15 (↓6.95%)	4.06
link #1: 31→26 (54M) link #2: 32→19 (6M)	3.11	2.77 (↑423%)	2.46	2.29	2.20 (↓56.3%)	2.10
link #1: 31→19 (54M) link #2: 32→26 (54M)	17.00	16.85 (↓1.35%)	16.70	2.92	2.75 (↓58.0%)	2.62
link #1: 31→26 (54M) link #2: 32→19 (54M)	8.98	8.35 (↑97.4%)	7.37	2.69	2.35 (↑137%)	2.17

To verify the above explanation, we placed the four wireless nodes on the vertices of a parallelogram, as shown in Figure 4. In this case, small change of position should not affect the channel quality too much, since the nodes themselves are not obstacles. The test results are shown in Table 5.

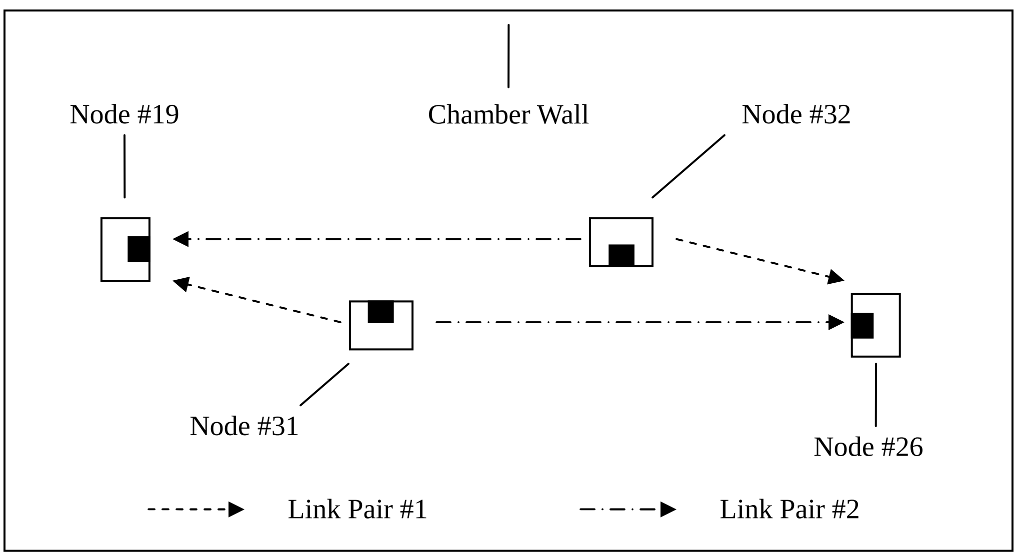


Figure 4: Topology of experiment #3

In Table 5, some links experience higher throughput compare with Table 2, because that there is no longer obstacles. As we can also see, the throughputs in Table 5 are more stable and have smaller fluctuation. To study the impact of each node's position change, we picked up only one node and put it back, and run the test script. Table 6 shows the results after moving node #19. It shows very little changes in average throughput. Then we picked up and put back node #26, node #32, and node#31 one by one. After each one move, we ran the test script again. The results show that none of these moves results in a large average throughput change.

Table 5: results of topology #3, 2 links, 10 seconds, without obstacle

	link #1 thrpt (Mbps)			link #2 thrpt (Mbps)		
	max	avg	min	max	avg	min
link #1: 31→19 (6M) link #2: 32→26 (6M)	2.75	2.67	2.58	2.98	2.90	2.80
link #1: 31→26 (6M) link #2: 32→19 (6M)	2.67	2.60	2.50	2.70	2.60	2.51
link #1: 31→19 (54M) link #2: 32→26 (6M)	12.20	11.81	11.20	3.82	3.75	3.70
link #1: 31→26 (54M) link #2: 32→19 (6M)	13.30	13.01	12.70	3.41	3.37	3.32
link #1: 31→19 (54M) link #2: 32→26 (54M)	19.80	19.48	19.30	16.80	16.54	16.20
link #1: 31→26 (54M) link #2: 32→19 (54M)	19.60	19.25	18.90	17.30	16.95	16.50

Table 6: results of topology #3, 2 links, 10 seconds, without obstacle, slightly moved node #19
(percentage comparison with Table 5)

	link #1 thrpt (Mbps)			link #2 thrpt (Mbps)		
	max	avg	min	max	avg	min
link #1: 31→19 (6M) link #2: 32→26 (6M)	2.82	2.75 (↑3.00%)	2.71	2.88	2.83 (↓2.41%)	2.77
link #1: 31→26 (6M) link #2: 32→19 (6M)	2.69	2.62 (↑0.77%)	2.58	2.62	2.56 (↓1.54%)	2.47
link #1: 31→19 (54M) link #2: 32→26 (6M)	12.60	11.85 (↑0.34%)	10.90	3.88	3.74 (↓0.27%)	3.64
link #1: 31→26 (54M) link #2: 32→19 (6M)	13.20	12.96 (↓0.38%)	12.30	3.47	3.38 (↑0.30%)	3.33
link #1: 31→19 (54M) link #2: 32→26 (54M)	20.00	19.34 (↓0.72%)	18.80	17.30	16.64 (↑0.60%)	15.70
link #1: 31→26 (54M) link #2: 32→19 (54M)	19.50	19.23 (↓0.10%)	19.00	17.30	16.93 (↓0.12%)	16.30

In summary, we conclude that the experiment inside the chamber is repeatable if and only if small change of an object's position does not change the channel quality greatly.

4 Conclusion

In conclusion, due to the randomness of protocol, small-scale experimental results are not repeatable, but the large-scale ones are repeatable. In addition, small changes of object's position can affect performance. The degree to which the performance will be affected depends on how great the channel quality is changed due to the change of object position.

Reference

[1] Nitin H. Vaidya, Jennifer Bernhard, Venugopal Veeravalli, P.R. Kumar and Ravi Iyer. "Illinois Wireless Wind Tunnel: A Testbed for Experimental Evaluation of Wireless Networks". SIGCOMM'05 Workshops

[2] Madwifi v0.9.4: http://madwifi.org/wiki/Releases/0.9.4

[3] Net 4521 hardware from Soekris: http://www.soekris.com/net4521.htm

[4] Iperf: http://dast.nlanr.net/Projects/Iperf/