Technical Report
802.11g Long-distance Measurements: Antenna Placement and Orientation

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1 Overview

This technical report documents tests conducted to measure the effects of wireless interference on throughput. Our experiments consisted of 802.11g wireless network throughput measurements in various overlapping ad-hoc node configurations in order to better understand interference when using yagi antennas to extend the range of the wireless transmission. We were particularly interested in the behavior at the multi-hop node, which has 2 antennas in close proximity as would be required on a communications tower. The following 13 tests show our results. In each test nodes 1 and 2 are on essid *pair1*, and nodes 3 and 4 are on essid *pair2*, this allows use to force the traffic to be routed through the multi-hop node instead of the overlap just reaching the far reciever in some cases. For each of 5 network configurations, we conducted 2 experiments; we tested througput in a 2-hop routing configuration (where we consider the middle node as a virutal single node), and we tested throughput in a non-routing configuration where 2 nodes, one from each essid, are sending at the same time. In the non-routing test the multi-hop node is sending on one interface and recieving on the other. For each test we graph the throughput standard deviation, and signal strength deviation, as measured by 10 30-second iperf measurements and we vary the channels 1-6 on *pair2* while keeping *pair1* on channel 1. In addition, for the non-routing tests we also graph a comparison chart overlapping signal and throughput for both networks. It should be noted that we tested overlap up to 5 channels of separation because after that there is such minimal overlap in the spectrum, that the results would not vary. Also, for 802.11g studies show [1] that the maximum throughput in our scenario is 27 Mbps which is half of 54 Mpbs.

2 Equipment

The test equipment consists of 4 Lenovo T60 notebooks running slackware Linux with the 2.6 kernel, and using Proxim WLAN adapters (atheros chipset), and we are using the opensource MadWifi drivers for the wireless cards. These PCMCIA cards are connected to an external Hyperlink Yagi antenna to extend their range. We make a special point to note that MadWifi driver includes a proprietary HAL that controls many key aspects of the adapters, one of which being the use of measured RSSI values to sense whether the channel is in use, contrasted with the RTS/CTS scheme that other wireless cards use to sense the channel. We suspect that this channel contention scheme leads to some unexpected behavior in our ad-hoc test network.

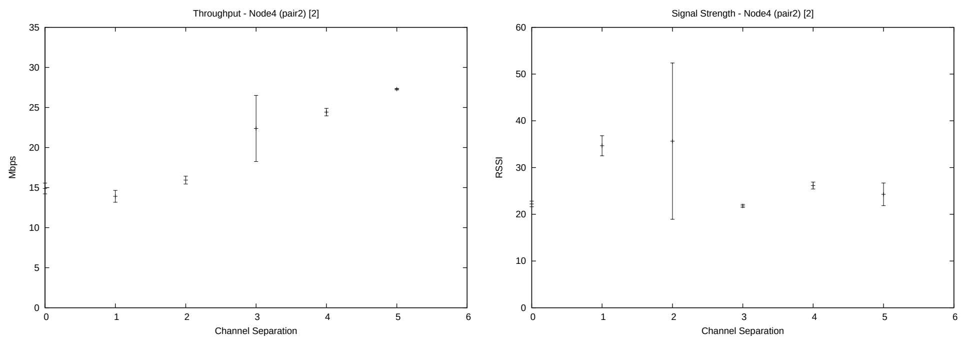


Figure 1: Throughput and signal strength

3 Test Description & Results

3.1 Test 1: N4 → N3 | N2 ← N1

In this test we look at the interference when two nodes are sending towards a multi-hop node and the multi-hop node is recieving on both interfaces. The nodes are in a straight line, 180°. Nodes 1 and 4 transmit at the same time towards the center node. We see a steady increase in throughput as we extend the channel seperation. The signal strength did not match the throughput results exactely, it increased at a separation of 2 and 3, and dropped down to 20-30 RSSI for the remainder (see Figure 1).

3.2 Test 2: N4 → N3 | N2 → N1

In this test we look into interference when two nodes transmit at the same time. Nodes 2 and 4 transmit at the same time and the multi-hop node is sending on one interface and recieving on the other. The antennas at the center node are separated by 5'. The nodes are in a straight line, 180°. We noticed that there was a lot of variance in the throughput on this test, and we suspect that this may be due to the way that the wireless interfaces contend for the channel. Another reason for the variance could be that node 4 is overshooting the multi-hop node and is being sensed at node 1 as node1 is recieving from node2. The throughput is consistently higher on the *pair2* network which seems to support this idea. Also, on channel 4 *pair2* had throughput upwards of 24 Mbps, but all of a sudden around run 7 of 10 it seemed to lose the channel and *pair1* started to take over. This is why there is such a large variation at a channel seperation of 3 (see Figure 2).

3.3 Test 3: N4 → N3 → N2 → N1

In this test we have configured the multi-hop node as a gateway for each end node, and so node 4 is running the iperf client, and node 1 is running the iperf server. The nodes are in a straight line, 180°. And the two nodes at the center are spaced about 5' apart. We experienced a throughput of 4.3 Mbps on channel 1, poor in comparison, but as the channels separate the throughput steadily grows to 27 Mbps (see Figure 3).

3.4 Test 4: N4 → N3 | N2 → N1

In this configuration we create a 135° angle between nodes 3 and 4 by rotating node 4 by 45°. No routing is used in this test and nodes 4 and 2 transmit at the same time. The antenna's at the center are spaces 5' apart. The performace is slightly better, definately more consistent at this angle, rather than directly facing each other yet it is worse on channel 2. Overall this angle is much better than the 90° setup which had 5 Mbps on channel 1 (see Figure 4).

3.5 Test 5: N4 → N3 → N2 → N1

This setup is a 135° test similar to test 4, except that we have enabled routing via the multi-hop node. The antenna's at the center are about 5' apart. The iperf server is run on node 1 and node 4 is the client. At this antenna orientation we have much better performance that in the 180° case, 13 Mbps vs. 4 Mpbs on channel 1. We think that this is due to the fact that the antenna pattern of the yagi's has a weak spot right at the 135° section (off center), and so we are not causing as much interference with the sender at the multi-hop node (node 2) (see Figure 5).

3.6 Test 6: N4 → N3 | N2 → N1

In this test we alter the antenna orientation to 90° off center, between node 3 and 4. The antenna's at the center are 5' apart. Again, both nodes are transmitting simultanously. Pair 1 seems to dominate the channels this time, and has much higher throughput (25 Mbps for pair1 vs. 5 Mbps for pair2). The sidelobes of the antenna are largest at 90° so this could account for the poor performance on pair2. It seems thought that in the scenario's where there are 2 simultaneous transmissions and no routing, that one side seems to dominate (see Figure 6).

3.7 Test 7: N4 → N3 → N2 → N1

This is a routing test which was conducted with a 90° antenna orientation between nodes 3 and 4. The antenna's at the center are 5' apart. Routing is enabled this time, with node 4 as the iperf client and node 1 as the server. The throughput here was a little worse than the 135° case, 10 Mbps here vs. 14 Mbps at 135°, yet much better than the 180° case which had a throughput of 3.5 on channel 1. We believe that the better results at low channel separations is due to orientation angle, and also in that when routing is enabled, the networks negotiate the channel better and share the bandwidth more evenly even with the side-lobe overlap (see Figure 7).

3.8 Test 8: N4 → N3 | N2 → N1

This test was conducted at a 90° orientation, and also the pair2 network has changed polarization of the yagi antennas from vertical to horizontal. The pair1 network is still at the vertical orientation. The antenna's at the multi-hop node are separated by 5'. Both Nodes 2 and 4 transmit simultaneously. In this case the channel is shared a little better than in test 7 where the only difference was in the polarization. But here pair2 dominates the channels an has higher throughput, except on channel 1 they are both right at 15 Mbps. In test 7 on channel 1 both pairs were at a difference of 20 Mbps. This suggests that the polarization has a large effect when operating on the same channel (see Figure 8).

3.9 Test 9: N4 → N3 → N2 → N1

This test was conducted at a 90° orientation with opposite polarizations on each network. Pair2 is set to horizontal polarization while pair1 is vertical. The antenna's at the multi-hop node are separated by 5'. Node 4 transmits to Node 1 by routing through the multi-hop node. This result is very similar to the 135° test when routing is enabled. Routing in this case seems to make both networks share the bandwidth regardless of the polarization (see Figure 9).

3.10 Test 10: N4 → N3 | N2 → N1

This test was performed at 180° and both networks were set to the same vertical polarization. The Height of the antenna's was altered so that pair2 was at an elevation of 11' and pair1 was at an elevation of 2'. We wanted to see if this would have an effect on interference at the middle node. Nodes 2 and 4 transmitted simultaneously. The performance was a little bit worse than in test 3, the 180° case with no additional adjustments. This is most likely due to outside interference due to the fact that the field we were testing in became a parking lot for an event, and the influx of cars on this occasion cause unmeasureable effects on the results. We repeat this test again in test 12

3.11 Test 11: N4 $\rightarrow$ N3 $\rightarrow$ N2 $\rightarrow$ N1

This test was performed at 180° and both networks were set to the same vertical polarization. The Height of the antenna's was altered so that pair2 was at an elevation of 11' and pair1 was at an elevation of 2'. We wanted to see if this would have an effect on interference at the middle node. Routing was enabled but performance was poor due to outside factors, the influx of cars on this occasion cause unmeasureable effects on the results. We repeat this test again in test 13

3.12 Test 12: N4 $\rightarrow$ N3 | N2 $\rightarrow$ N1

Simultaneous transmission height difference test - repeat of 10. Pair2 really dominated this time. The throughput on pair2 was much better than in test3, but pair1's thoughput was really poor. Again, channel contention algorithms have a big part in this phenomenon. Pair2 seems to have grabbed the bandwidth and stuck with it. Pair1's gains came during intervals of the 10 runs when pair2 stopped sending breifly to start another run.

3.13 Test 13: N4 $\rightarrow$ N3 $\rightarrow$ N2 $\rightarrow$ N1

Routing height separated test - repeat of 11. Here we actually do worse than in the 180° non-height separated routing scenario. We are not really sure why, we expected a benefit.

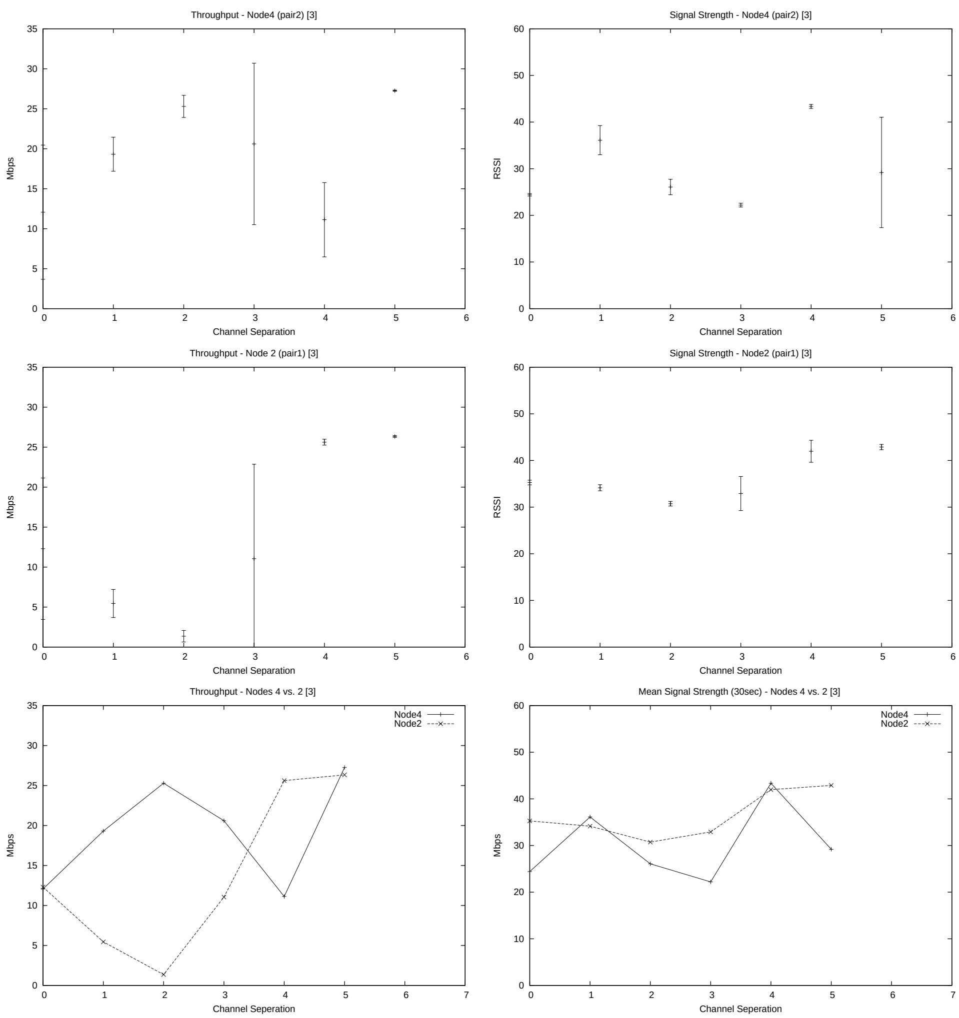


Figure 2: Signal and throughput measurements from each network, and overlapping comparisons. Notice how the throughputs are almost mirror images of eachother. In this case pair2 dominated the spectrum

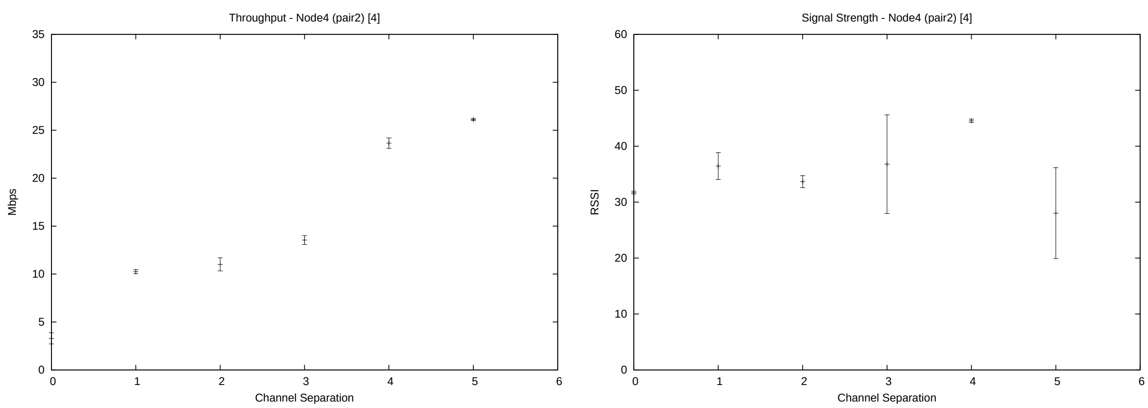


Figure 3: Signal and throughput measurements, throughput increases steadily but is poor on channel 1

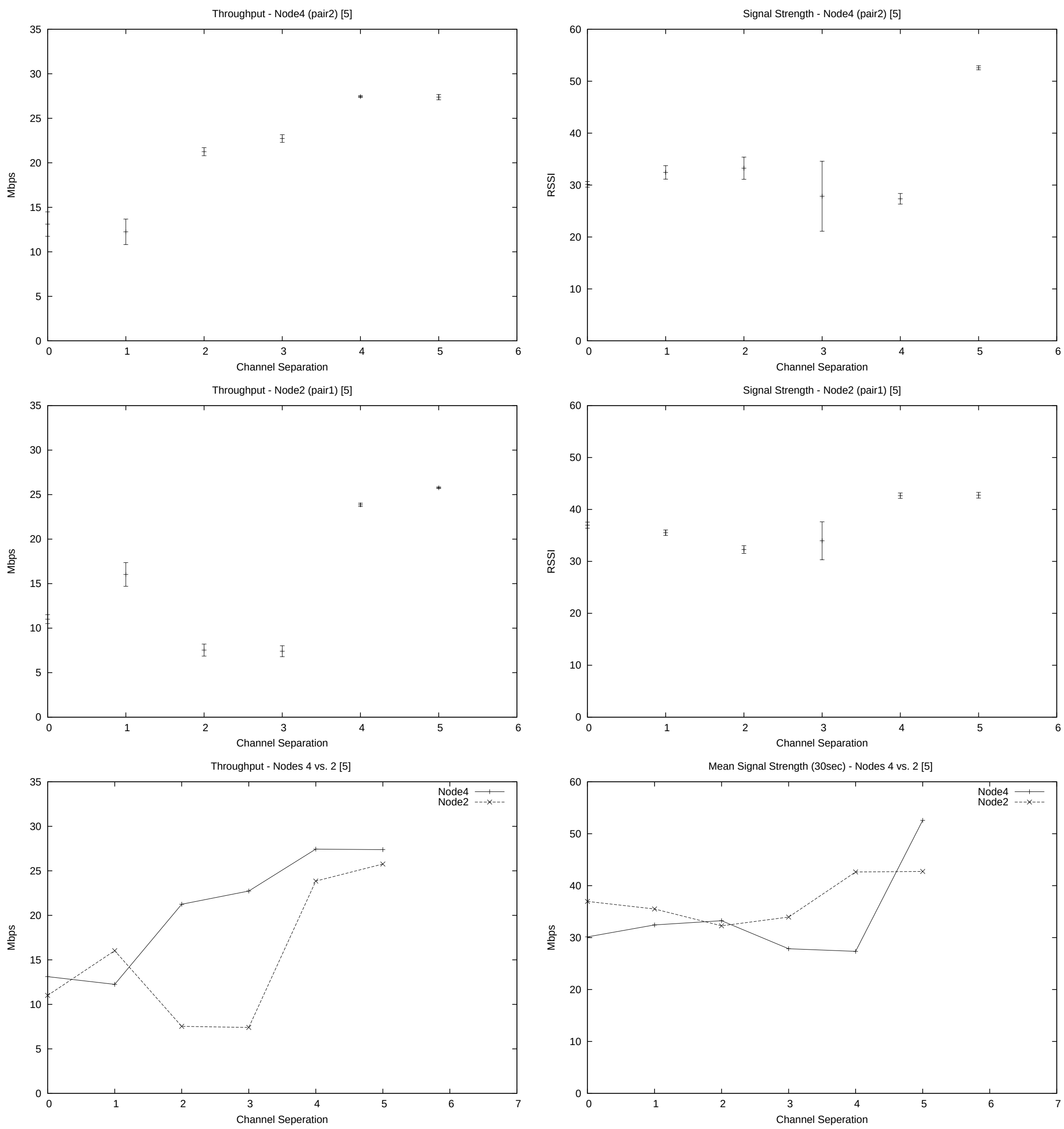


Figure 4: Signal and throughput measurements from each network, and overlapping comparisons. Noticeable improvements in performaces vs. 90° and 180°

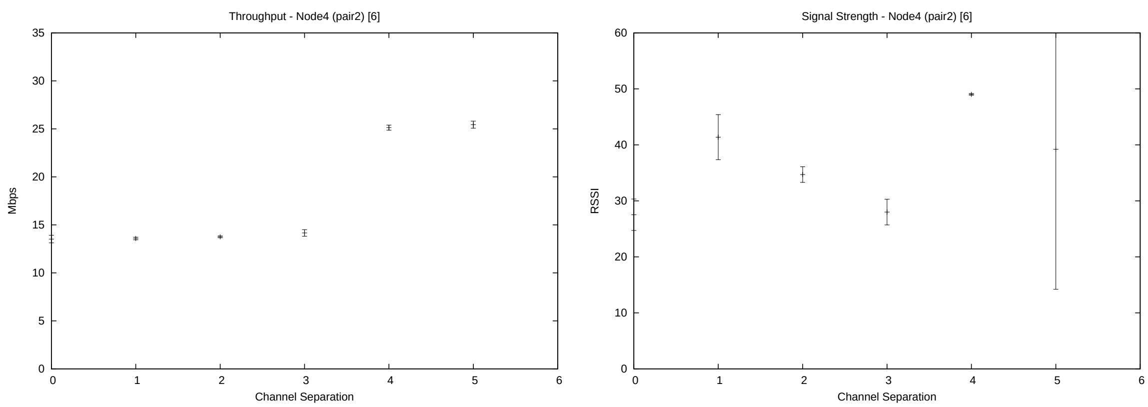


Figure 5: Signal and throughput measurements, much better performance on channel 1. Routing enforces better sharing of bandwidth

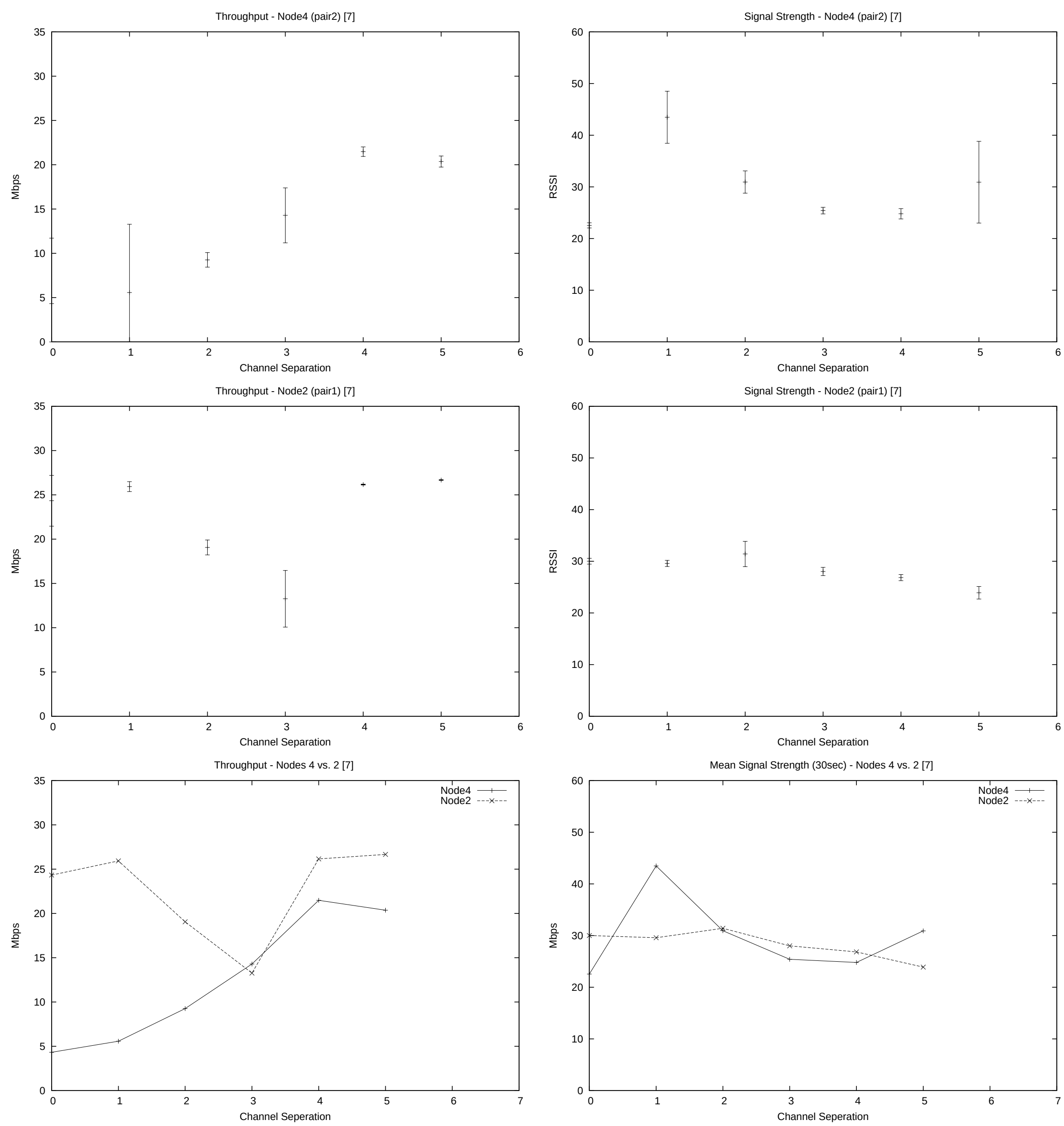


Figure 6: Signal and throughput measurements from each network, and overlapping comparisons. 90° configuration, pair1 network is dominating the available bandwidth on contended channels

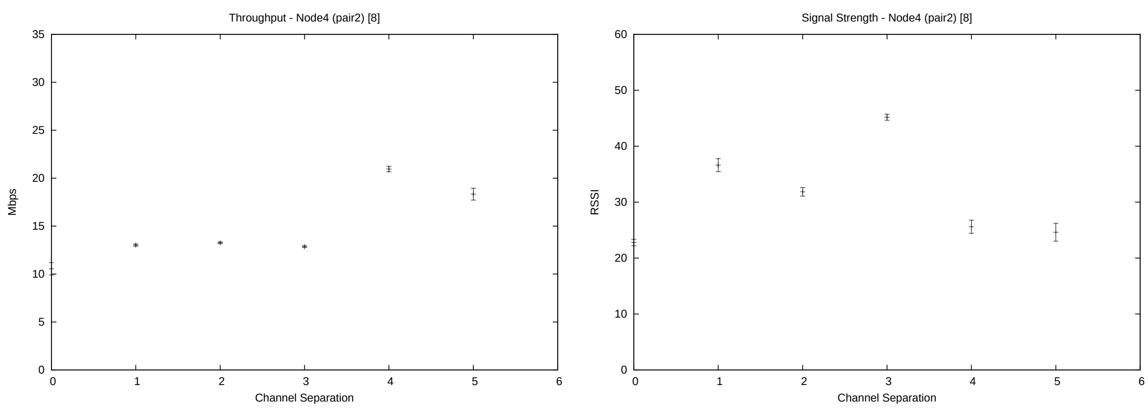


Figure 7: Signal and throughput measurements, 90 ° configuration with routing.

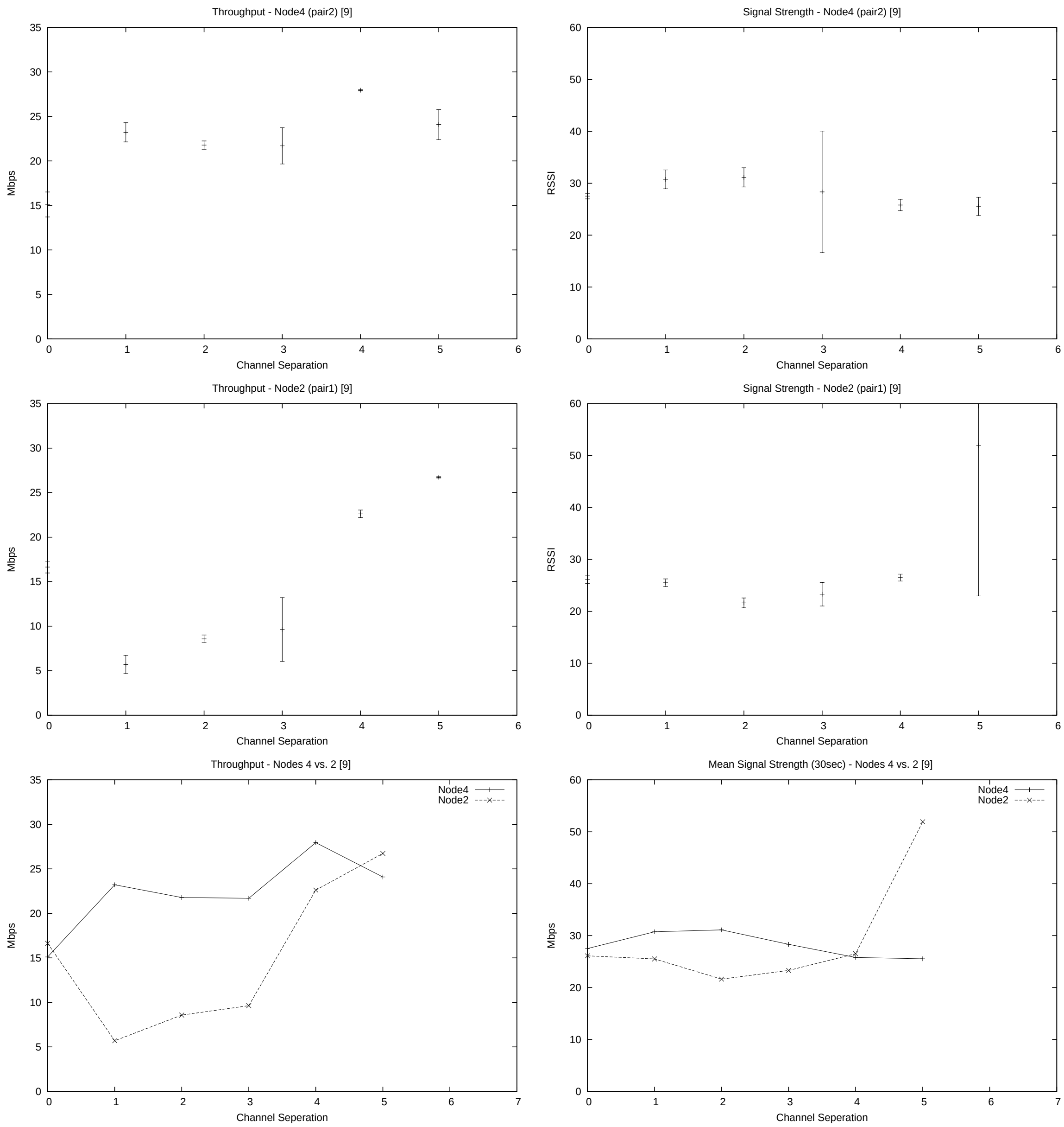


Figure 8: Signal and throughput measurements from each network, and overlapping comparisons. Polarization has a significant effect when operation on the same channel.

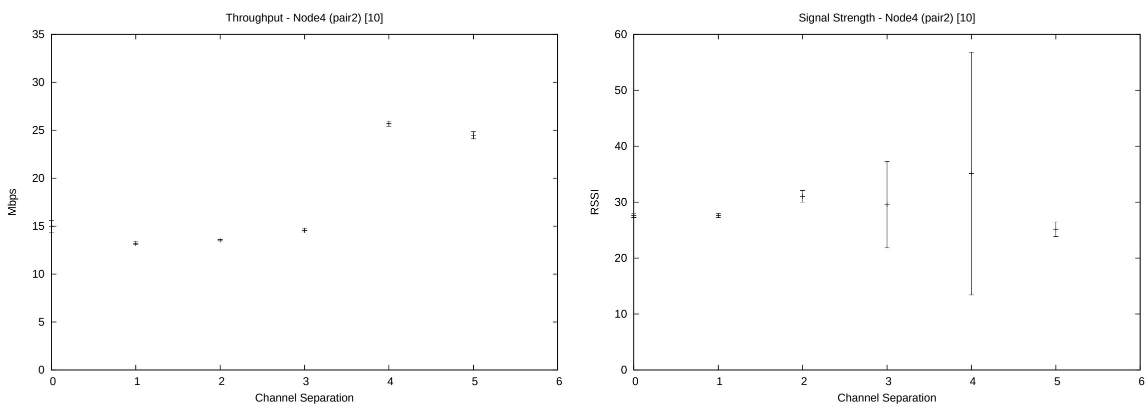


Figure 9: Signal and throughput measurements,

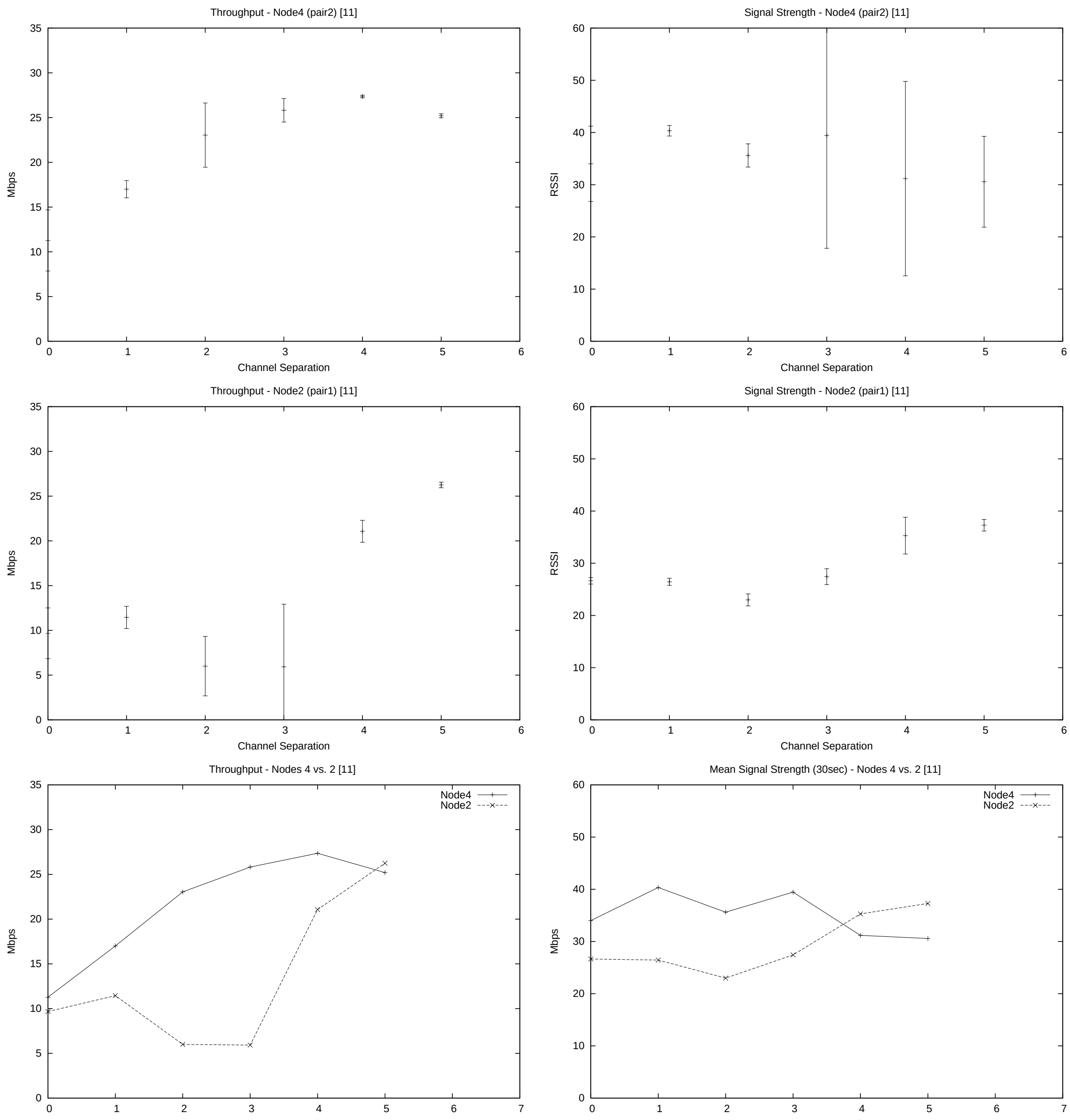


Figure 10: Signal and throughput measurements from each network, and overlapping comparisons. Height separated, outside interference - additional interference from cars.

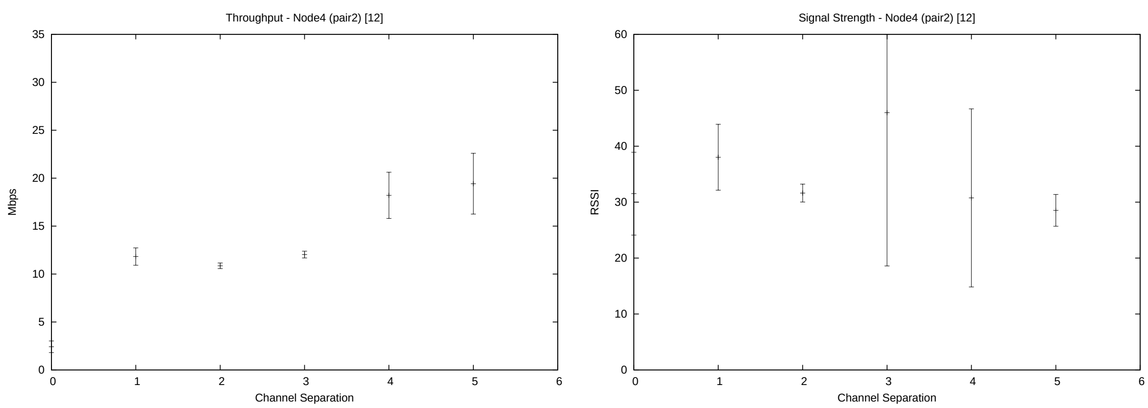


Figure 11: Signal and throughput measurements, interference from cars

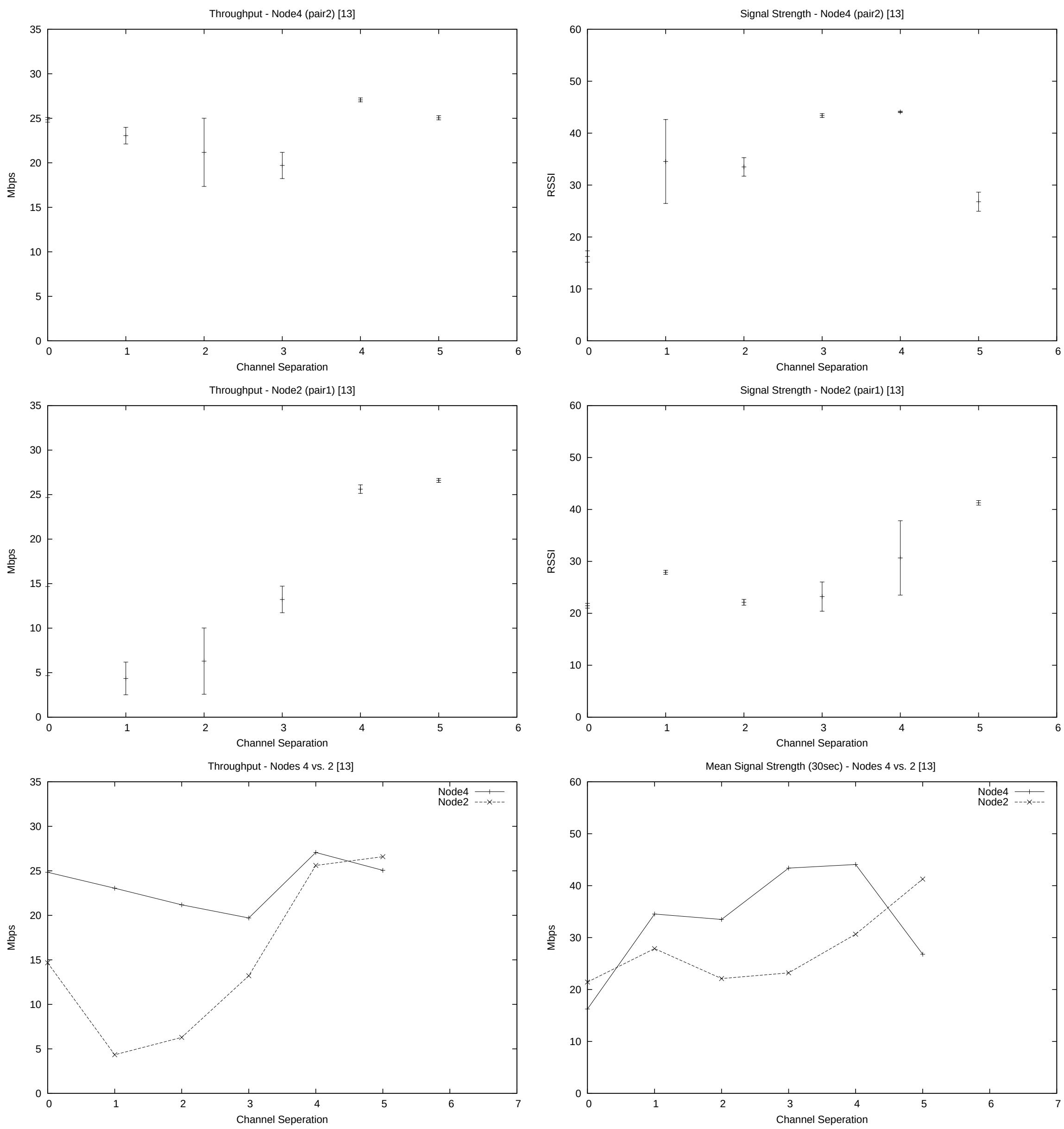
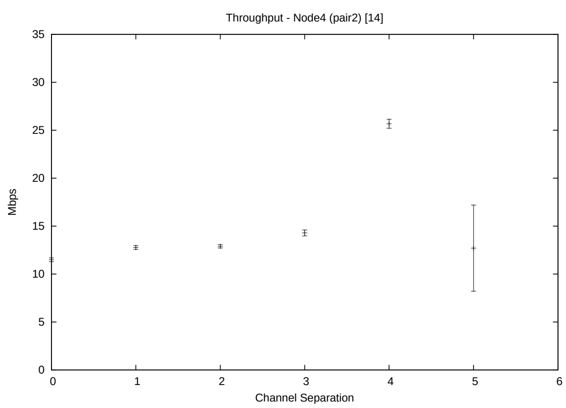


Figure 12: Signal and throughput measurements from each network, and overlapping comparisons. Height separation seems to benefit throughput.



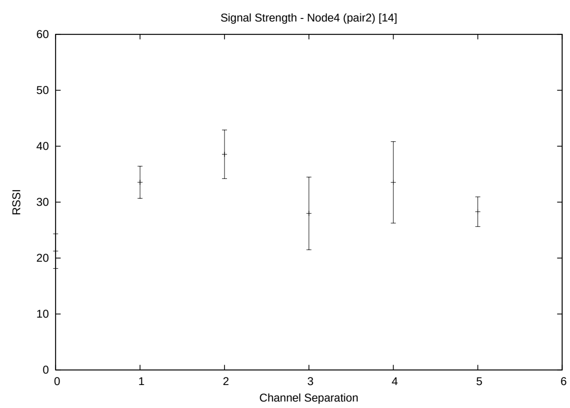


Figure 13: Signal and throughput measurements, no improvement in routing height-separated case