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Single AP Competitive 802.11n Testing Meru AP320 3.4.SR3-113 vs. Cisco 1252 IOS 12.4(10B)JA

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Introduction and Executive Summary

The primary purpose of this document is to baseline the performance of Meru’s AP300 access point and to provide relevant comparisons to the Cisco autonomous (fat) AP1252 using the latest shipping code from each vendor. Cisco’s controller-based solution (LWAPP) was not tested in this report but specific performance tests in LWAPP mode are available upon request.

Another objective is to prove basic interoperability and solid performance with a range of different client chipsets with Meru’s solution and under what conditions different clients perform well or under-perform for either vendor. All 802.11n client chipsets available to Meru’s Technical Marketing team at the time of testing were tested for performance and all chipset types (Intel, Marvel, Atheros, and Broadcom) were tested.

By developing this test matrix, a baseline for each chipset and driver combination has been constructed so that future code enhancements by Meru can be tracked from a performance perspective. Also, for multi-AP tests there is a focus on higher densities of clients which draws upon the comparison data for single client and single AP tests.

In summary, Meru outperforms Cisco in most test cases with especially strong results using the following client adapters:

- Atheros chipset (internal 5008 and D-Link 652)
- Intel 4965
- Macbook Pro (Atheros based)

Cisco performs best with Marvell-based clients due to the more optimized interaction with their Marvell-based AP.

Below are some selected results based on a downstream-only TCP test using Chariot¹.

Client/Adapter Type	Meru Performance (Mbps)	Cisco Performance (Mbps)	% Improvement (Meru vs. Cisco)
1 D-Link 652 (Atheros)	171	119	44%
10 D-Link 652 clients	130	42	210%
1 Atheros 5008	179	109	64%
1 Intel 4965	128	111	15%
1 Macbook Pro	181	74	145%

¹ Note: test results conducted in an RF chamber with multiple downstream TCP flows with the highest result obtained shown for each vendor.

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1 Test Setup

1.1 Equipment and Network Diagram

Equipment	Meru Setup
Controller Model	MC 3000 Controller (real license enabled)
Controller Version	3.4.SR3-113
Access Point Model	1 AP 320 dual radio 802.11n Access Point

Equipment	Cisco Setup
Controller Model	No controller used in these tests (autonomous or "fat" AP)
Code Version	12.4(10B)JA (FCS)
Access Point Model	1 AP 1252 Access Point

Equipment	Common Infrastructure
Enterprise Switch	1 HP Procurve 2824 Gigabit Ethernet Switch
Power	Both Cisco and Meru used external AC power supplies for power.
Chariot Server	1 HP NC6220 with Chariot Server v4.2

802.11n Client Adapter	Driver Version	Dated	Type/OS
D-Link 652	6.9.3.107	7/23/07	PCMCIA Cardbus/XP
Atheros AR5008E-NX	7.3.1.127	10/17/07	Internal (T61)/Vista
Intel 4965	11.1.1.16	6/20/07	Internal (T61)/Vista
Macbook Pro	1.2.2		Internal/Mac OS X
Linksys 4400N	2.1.4.3	10/4/06	PCMCIA Cardbus/XP
Netgear 511T	2.1.4.3	10/4/06	PCMCIA Cardbus/XP

The network diagram below depicts our setup in the RF chamber (all tests were conducted in an RF chamber for isolation in both 2.4 and 5 GHz bands). Laptops were placed at a distance of 10 feet from the Access Point with line of site between the AP and the client. Both AP radios were enabled but clients connected to only one radio at a time. Meru's AP had both 2.4 and 5 GHz radio antennas set to use an x, y, z coordinate system. Tests run with Chariot were TCP downstream-only, TCP upstream-only, and TCP downstream + upstream, as well as a similar set of UDP tests.

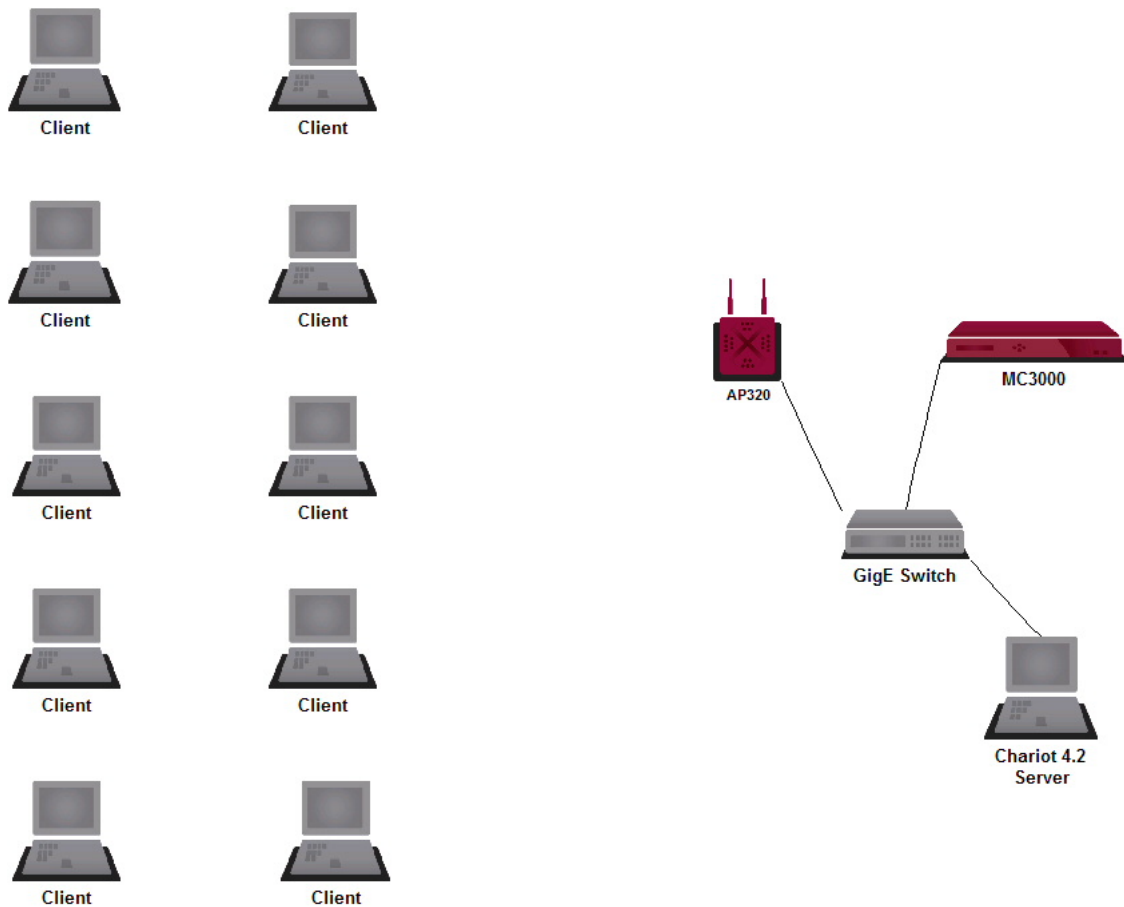


Figure 1 RF Chamber Test Setup

1.2 Windows XP Client Regedit Modifications

When using Chariot and other testing tools to obtain optimal performance with Windows-based client/server devices, it is crucial that the TCP buffers be configured to unleash the promise of 11n. Please see the appendix for an explanation on why these changes are necessary, paraphrased from a 3rd party 802.11n testing guide.

These registry changes are the addition of two DWORDs to the following location:

```
[HKEY_LOCAL_MACHINE\SYSTEM\CurrentControlSet\Services\Tcpip\Parameters  
"TCP1323Opts"=dword:00000003  
"TCPWindowSize"=dword:00040000
```

The Tcp1323Opts entry allows the sender to advertise support for Windows Scaling and Timestamp options. The TcpWindowSize entry allows better RTT calculation in the TCP stack. You must reboot your system for these changes to take effect, and changes must be made to both server and client endpoints.

1.3 Chariot Modifications

For Chariot to run at peak 11n performance, run four pairs (streams) of the Chariot Throughput.scr script from endpoint 1 to endpoint 2 with the following modifications to the standard script:

```
File_Size = 1,000,000 bytes  
send_buffer_size = 65535 bytes  
receive_buffer_size = 65535 bytes
```

The TCP advertised window size is the minimum of the TCP socket buffer size and the maximum TCP window size (defined by the registry edits described above). Thus it is crucial that multiple Chariot pairs be used in order to approximate a single TCP stream supporting a maximally-sized receive window. To simulate a 512 kB receive window, four pairs should be created. Each pair has a 64 kB buffer size, which corresponds to a 128 kB outstanding byte count, so $4 * 128 = 512$ kB which is the target advertised window size used to maximize throughput.

The Packetblast.scr Chariot script can be used to highlight UDP performance. The send and receive buffers can be kept at the default value, or the send buffer can be set to ~1400 Bytes to mitigate the effects of the Meru tunnel. The main thing to be aware of when running Packetblast tests is to make sure that the aggregate data rate sent over the air is manageable. For example, four streams of 50 Mbps are 200 Mbps, which should oversubscribe the air interface. However, four streams of 30 Mbps should be manageable in either upstream or downstream directions.

2 Test Results

2.1 D-Link 652

The D-Link 652 is an Atheros-based chipset 802.11n cardbus adapter. The driver is version 6.9.3.107 dated 7/23/07. Tests run were TCP downstream, TCP upstream, and TCP downstream + upstream and a similar set of UDP tests. These tests were run in the RF chamber with 1, 5, and 10 clients for both Meru and Cisco single APs. Below are the results.

Channel	MIMO	Channel Width	Number of Clients	TCP/UDP	# of Flows	Up/Down	Cisco Aggr. Tput (Mbps)	Meru Aggr. Tput (Mbps)	% Improvement (Meru vs. Cisco)
11	2x2	40MHz	1 client	TCP	4	down	117	171	46%
11	2x2	40MHz	1 client	TCP	4	down	118	171	45%
11	2x2	40MHz	1 client	TCP	4	down	119	155	30%
11	2x2	40MHz	1 client	TCP	4	up	44	49	11%
11	2x2	40MHz	1 client	TCP	8	up	42	48	14%
11	2x2	40MHz	1 client	TCP	8	up+down	52	70	35%
11	2x2	40MHz	1 client	TCP	8	up+down	51	74	45%
11	2x2	40MHz	1 client	UDP(30)	4	down	119	111	-7%
11	2x2	40MHz	1 client	UDP(50)	4	down	131	160	22%
11	2x2	40MHz	1 client	UDP(30)	4	up	32	42	31%
11	2x2	40MHz	1 client	UDP(50)	4	up	31	42	35%
11	2x2	40MHz	1 client	UDP(30)	8	up+down	131	114	-13%
11	2x2	40MHz	1 client	UDP(30)	8	up+down	131	114	-13%

Figure 2 D-Link 652 Single AP, 1 Client Performance Comparison

Channel	MIMO	Channel Width	Number of Clients	TCP/UDP	# of Flows	Up/Down	Cisco Aggr. Tput (Mbps)	Meru Aggr. Tput (Mbps)	% Improvement (Meru vs. Cisco)
11	2x2	40MHz	5 clients	TCP	5	down	56	121	116%
11	2x2	40MHz	5 clients	TCP	5	down	62	115	85%
11	2x2	40MHz	5 clients	TCP	10	down	66	123	86%
11	2x2	40MHz	5 clients	TCP	20	down	64	126	97%
11	2x2	40MHz	5 clients	TCP	5	up	21	45	114%
11	2x2	40MHz	5 clients	TCP	10	up	20	44	120%
11	2x2	40MHz	5 clients	TCP	10	up+down	38	79	108%
11	2x2	40MHz	5 clients	TCP	10	up+down	38	80	111%
11	2x2	40MHz	5 clients	UDP(30)	5	down	56	106	89%
11	2x2	40MHz	5 clients	UDP(30)	5	down	61	105	72%
11	2x2	40MHz	5 clients	UDP(30)	5	up	19	25	32%
11	2x2	40MHz	5 clients	UDP(30)	5	up	17	25	47%
11	2x2	40MHz	5 clients	UDP(10)	10	up+down	41	56	37%
11	2x2	40MHz	5 clients	UDP(30)	10	up+down	40	84	110%

Figure 3 D-Link 652 Single AP, 5 Client Performance Comparison

Channel	MIMO	Channel Width	Number of Clients	TCP/UDP	# of Flows	Up/Down	Cisco Aggr. Tput (Mbps)	Meru Aggr. Tput (Mbps)	% Improvement (Meru vs. Cisco)
11	2x2	40MHz	10 clients	TCP	10	down	41	126	207%
11	2x2	40MHz	10 clients	TCP	10	down	42	113	169%
11	2x2	40MHz	10 clients	TCP	20	down	39	130	233%
11	2x2	40MHz	10 clients	TCP	10	up	16	38	138%
11	2x2	40MHz	10 clients	TCP	20	up	20	35	75%
11	2x2	40MHz	10 clients	TCP	20	up+down	27	82	204%
11	2x2	40MHz	10 clients	TCP	20	up+down	26	85	227%
11	2x2	40MHz	10 clients	UDP(10)	10	down	54	84	56%
11	2x2	40MHz	10 clients	UDP(30)	10	down	51	105	106%
11	2x2	40MHz	10 clients	UDP(10)	10	up	9	27	200%
11	2x2	40MHz	10 clients	UDP(30)	10	up	7	27	286%
11	2x2	40MHz	10 clients	UDP(10)	20	up+down	17	62	265%
11	2x2	40MHz	10 clients	UDP(10)	20	up+down	15	61	307%

Figure 4 D-Link 652 Single AP, 10 Client Performance Comparison

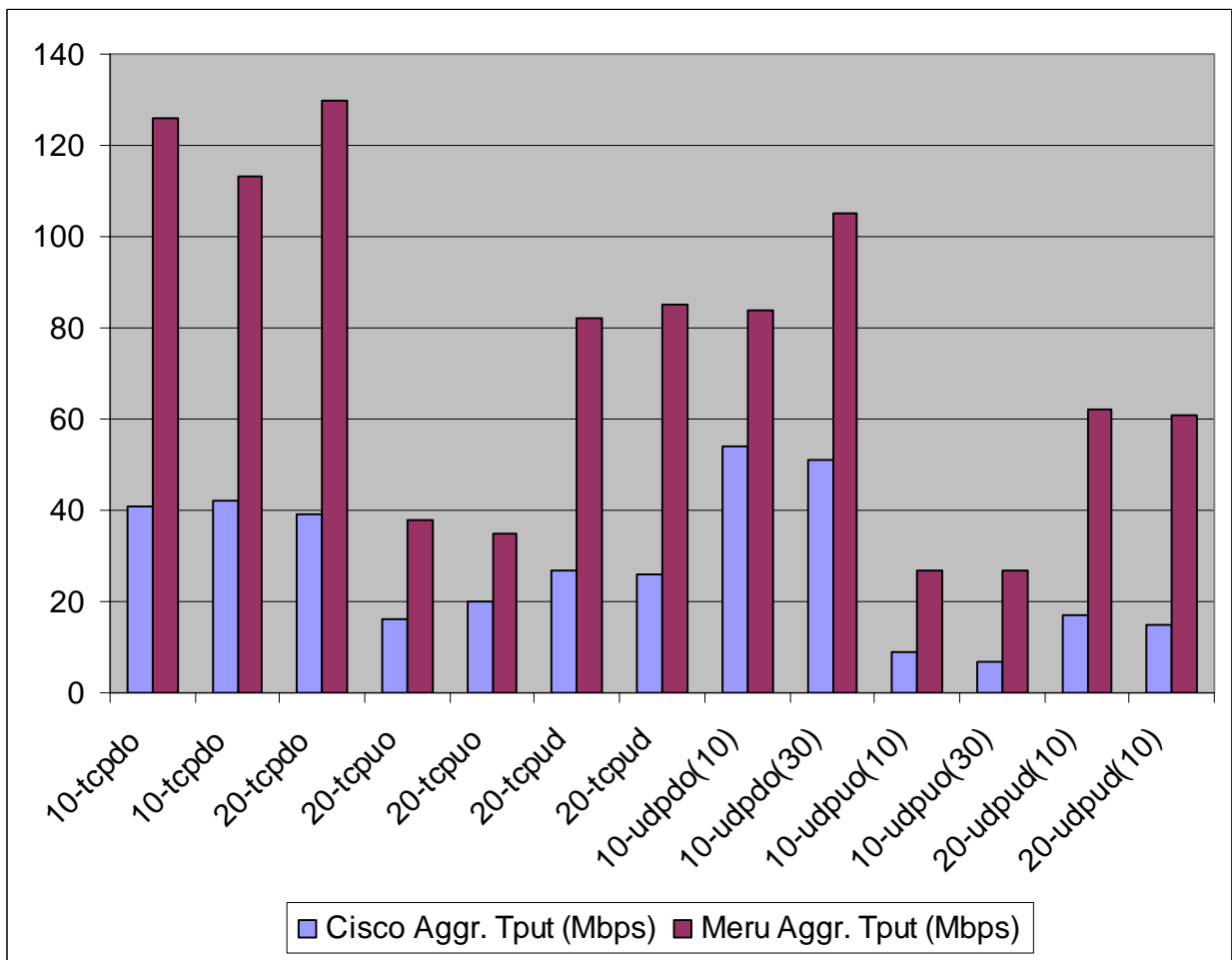


Figure 5 Graphical Comparison of D-Link 652 Single AP, 10 Client Performance

Meru exhibits significantly better results as the client density increases from 1 to 5 and then to 10 clients. Only one small modification was made in the Meru AP. Please contact the Technical Marketing Team for more information on this modification.

The D-Link 652 is clearly a high-performing 2.4 GHz BGN adapter overall. The upstream performance is not as good as some of the other adapters tested², but it offers solid performance for downstream-only testing as well as mixed upstream and downstream tests.

² Meru has found enhancements to Chariot scripts in subsequent testing that also improves upstream performance.

2.2 Atheros AR5008E-NX

The Atheros AR5008E-NX with driver version 7.3.1.127 dated 10/17/07 is an internal chipset that is included in a Lenovo T61.

Channel	MIMO	Channel Width	Number of Clients	TCP/UDP	# of Flows	Up/Down	Cisco Aggr. Tput (Mbps)	Meru Aggr. Tput (Mbps)	% Improvement (Meru vs. Cisco)
36	2x2	40	1	TCP	4	down	109	143	31%
36	2x2	40	1	TCP	4	down	107	179	67%
36	2x2	40	1	TCP	4	down		170	n/a
36	2x2	40	1	TCP	4	up	126	163	29%
36	2x2	40	1	TCP	4	up	100	162	62%
36	2x2	40	1	TCP	4	up+down	106	154	45%
36	2x2	40	1	TCP	4	up+down	105	173	65%
36	2x2	40	1	UDP (30)	4	down	119	117	-2%
36	2x2	40	1	UDP (30)	4	up	32	51	59%
36	2x2	40	1	UDP (30)	4	up	29	45	55%
36	2x2	40	1	UDP (30)	4	up+down	61	115	89%
36	2x2	40	1	UDP (30)	8	up+down	114	114	0%

Figure 6 Atheros 5008 Single AP, 1 Client Performance Comparison

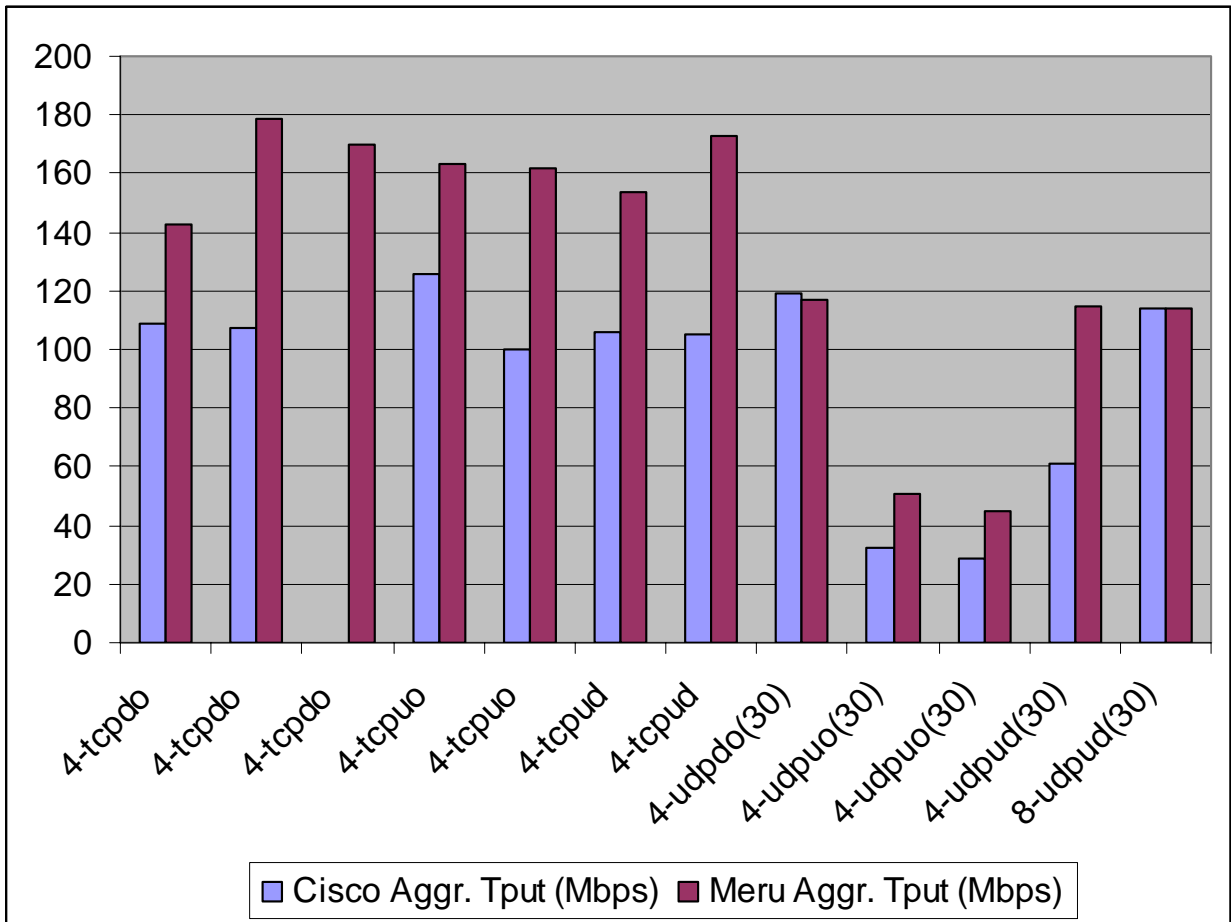


Figure 7 Graphical Comparison of Atheros 5008 Single AP, 1 Client Performance

Meru has superior performance in most tests and generally pushes the limit of theoretical performance in both upstream and downstream tests. This is an excellent client for 5 GHz performance.

2.4 GHz tests have not yet been conducted with this adapter.

2.3 Intel 4965

The Intel 4965 with driver version 11.1.1.16 dated 6/20/07 is an internal chipset that is included in a Lenovo T61.

Channel	MIMO	Channel Width	Number of Clients	TCP/UDP	# of Flows	Up/Down	Cisco Aggr. Tput (Mbps)	Meru Aggr. Tput (Mbps)	% Improvement (Meru vs. Cisco)
36	2x2	40	1	TCP	4	down	99	128	29%
36	2x2	40	1	TCP	4	down	109	120	10%
36	2x2	40	1	TCP	4	up	111	156	41%
36	2x2	40	1	TCP	4	up	109	147	35%
36	2x2	40	1	TCP	4	up+down	112	144	29%
36	2x2	40	1	TCP	4	up+down	104	150	44%
36	2x2	40	1	UDP (30)	4	down	113	110	-3%
36	2x2	40	1	UDP (30)	4	up	15	43	187%
36	2x2	40	1	UDP (30)	2	up	8	27	238%
36	2x2	40	1	UDP (30)	4	up+down	65	64	-2%
36	2x2	40	1	UDP (30)	8	up+down	116	69	-41%

Figure 8 Intel 4965 Single AP, 1 Client Performance Comparison

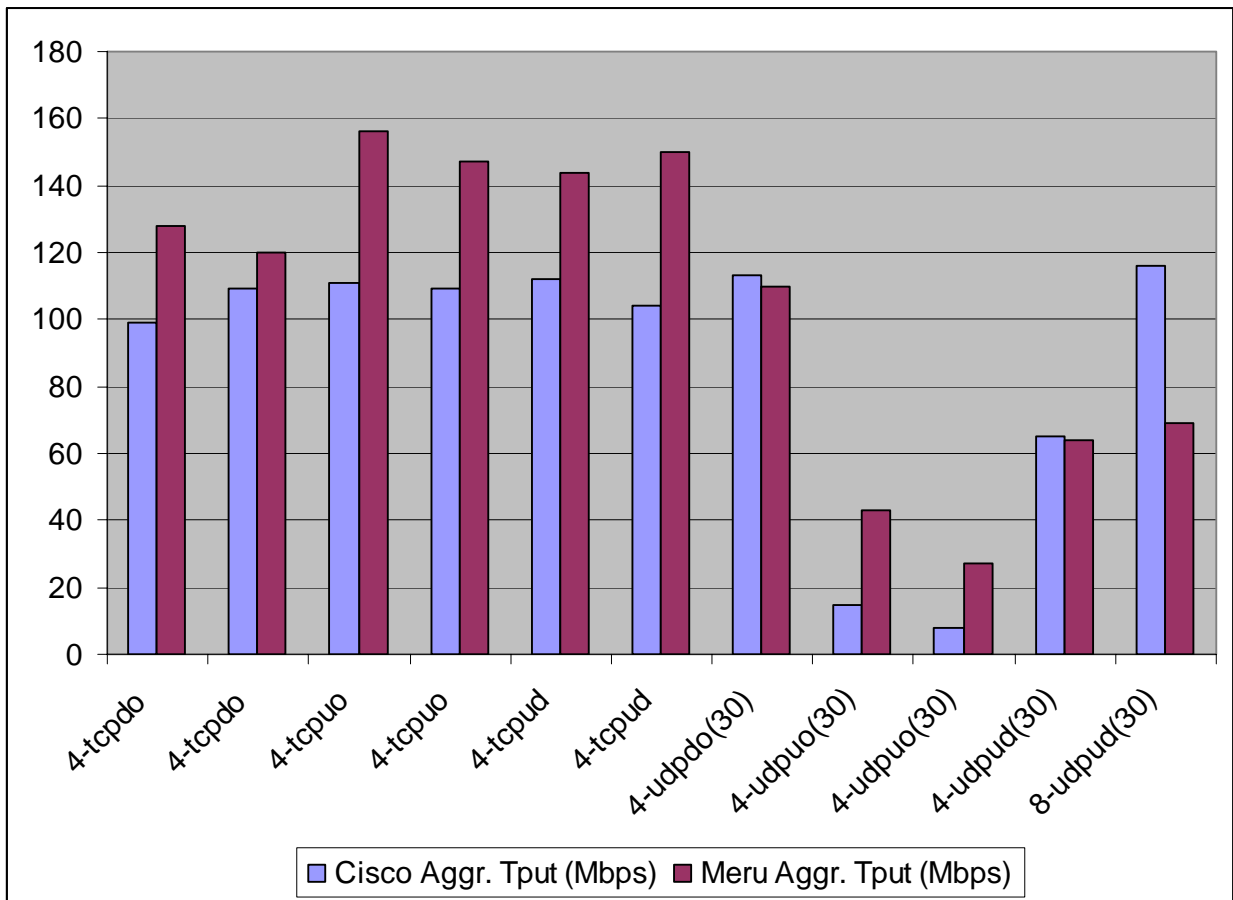


Figure 9 Graphical Comparison of Intel 4965 Single AP, 1 Client Performance

Meru has superior performance in most tests and generally pushes the limit of theoretical performance in both upstream and downstream TCP tests. This is an excellent client for 5 GHz performance.

Intel 4965 does not support 40 MHz in the 2.4 GHz band. Some tests were run with 20 MHz channel-width in the 2.4 GHz band with good results.

2.4 Macbook Pro

The Macbook Pro (based on Atheros 5008 chipset) with driver version 1.2.2 is an internal chipset that is included in a in the Macbook OS X client.

Channel	MIMO	Channel Width	Number of Clients	TCP/UDP	# of Flows	Up/Down	Cisco Aggr. Tput (Mbps)	Meru Aggr. Tput (Mbps)	% Improvement (Meru vs. Cisco)
36	2x2	40MHz	1	TCP	4	down	71	176	148%
36	2x2	40MHz	1	TCP	4	down	74	162	119%
36	2x2	40MHz	1	TCP	8	down	72	181	151%
36	2x2	40MHz	1	TCP	4	up	79	88	11%
36	2x2	40MHz	1	TCP	4	up	94	83	-12%
36	2x2	40MHz	1	TCP	8	up	83	104	25%
36	2x2	40MHz	1	TCP	8	up+down	77	111	44%
36	2x2	40MHz	1	TCP	8	up+down	83	121	46%
36	2x2	40MHz	1	UDP(30)	4	down	86	113	31%
36	2x2	40MHz	1	UDP(30)	8	down	84	109	30%
36	2x2	40MHz	1	UDP(30)	4	up	42	39	-7%
36	2x2	40MHz	1	UDP(30)	8	up	52	51	-2%
36	2x2	40MHz	1	UDP(30)	8	up+down	80	113	41%
36	2x2	40MHz	1	UDP(30)	8	up+down	76	107	41%

Figure 10 Macbook Pro Single AP, 1 Client Performance Comparison

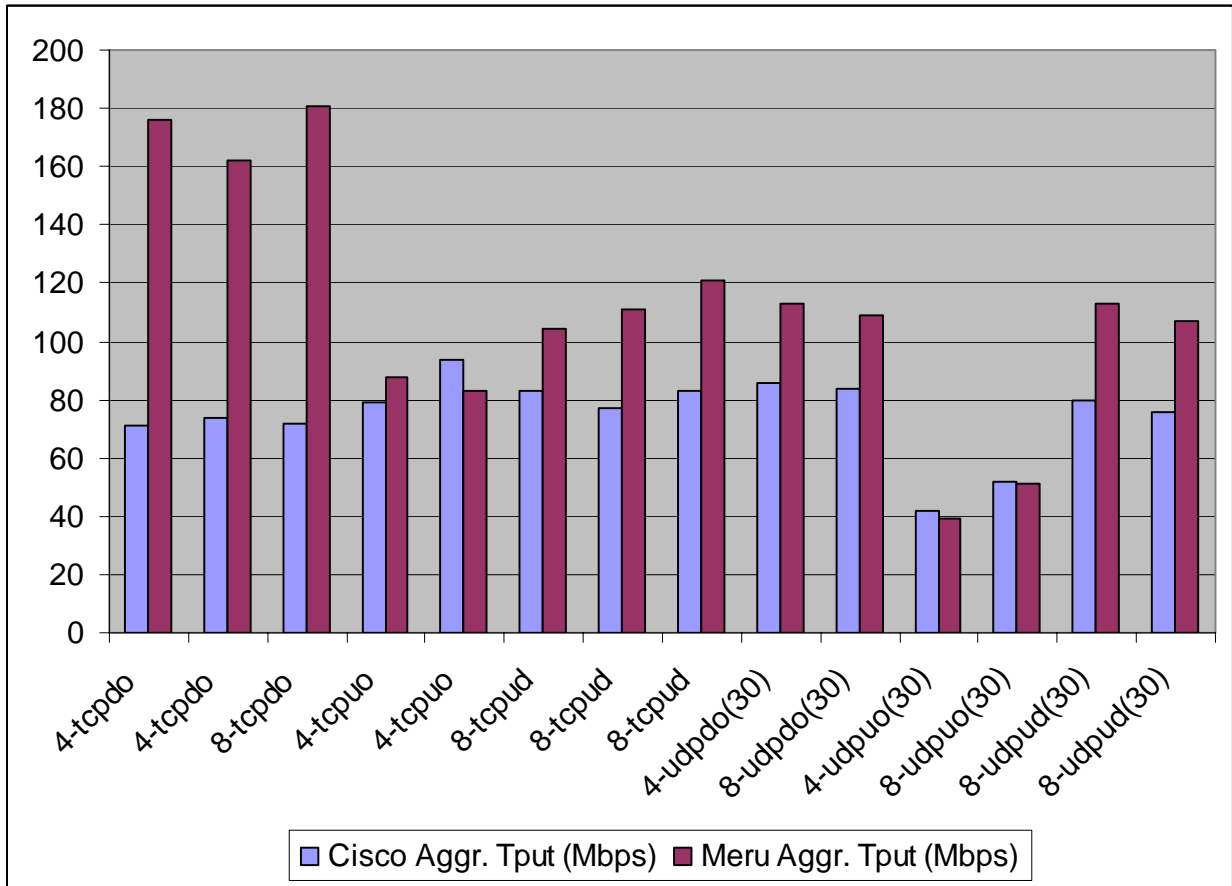


Figure 11 Graphical Comparison of Macbook Pro Single AP, 1 Client Performance

Meru has superior performance in most tests and does very well downstream with good performance upstream and in mixed upstream and downstream tests. This is an excellent client for 5 GHz performance.

2.4 GHz tests have not yet been conducted with this adapter.

2.5 Other Comparisons: Linksys 4400N, Netgear 511T, and NEC Warpstar

The Linksys 4400N (Marvell chipset) with driver version 2.1.4.3 dated 10/4/06 compares favorably for Meru vs. Cisco in the single client downstream TCP and UDP tests but less favorably in the upstream tests or with a mix of upstream and downstream traffic.

The Netgear 511T (Marvell chipset) with driver version 2.1.4.3 dated 10/4/06 compares less favorably for Meru vs. Cisco in most single client tests except for upstream UDP.

The NEC Warpstar WL300NC (Atheros 5008 chipset) is a good performing abgn adapter. For most tests Meru compared favorably well with Cisco, however, TCP upstream and mixed upstream and downstream tests were not on par with the other higher-performing 5 GHz adapters (Atheros 5008, Intel 4965, and Macbook Pro). This adapter has not yet been tested in the 2.4 GHz band.

Please see the document “Single AP Competitive 802.11n Testing Meru vs. Aruba External.doc” for details of this performance and interoperability testing.

2.6 Clients with Known Issues: Broadcom 4321 & Linksys WPC600N

In general, 802.11n client cards are evolving at a rapid pace. There are several clients in the market today, with various levels of driver maturity. An Atheros driver bug was identified and fixed for interoperability with Broadcom chipsets (also used in the Linksys WPA600N), but this fix was not available in time for this testing document.

Please see the document “Single AP Competitive 802.11n Testing Meru vs. Aruba External.doc” for details of this performance and interoperability testing.

3 Summary

In general it is recommended that Chariot be used for performance benchmarking tests with the regedit changes as described in the Appendix for Windows XP clients as well as the Chariot modifications described in the earlier section. All 802.11n drivers should be upgraded to the latest versions whenever possible.

The best performing client adapters based on this testing are the following:

- D-Link 652, operating in 2.4 GHz
- Atheros AR5008E-NX chipset (internal), operating in 2.4 or 5 GHz
- Intel 4965 chipset (internal), operating in 5 GHz (20 or 40 MHz channel width) or 2.4 GHz (20 MHz channel width)
- Macbook Pro (internal), operating in 2.4 or 5 GHz

For optimal results, one or more of the same client type can be used as at least 4 TCP flows should be used for each test (single clients should have 4 or more flows, while multiple clients can have one or more flows depending on the client density).

Please contact Meru's Technical Marketing for more information regarding specific clients or tests that do not appear in this document.

4 Appendix A: TCP Buffer and Regedit Change Explanation

TCP is a bi-directional protocol, and frames must be acknowledged by the receiver. The amount of time required for data to be transmitted over a wireless interface will inherently take longer than over a wired connection. TCP employs a receive window size for flow control so that the sender does not overflow the receiver's buffer. This receive window size is advertised in each acknowledgement sent from sender to receiver, and this can be set to a maximum of 65535 bytes. Thus if the receiver buffer is empty at most this maximum number of bytes can be sent without receiving an acknowledgement which requires one round-trip time.

Maximum TCP throughput is calculated by taking the maximum number of bytes in flight and dividing by this round-trip time. For a 10 ms RTT, this means that at most the throughput is $65535 \text{ Bytes} * 8 \text{ bits/Byte} / 0.01 \text{ sec} = 52.4 \text{ Mbps}$.

RFC 1323 allows for an option called Receive Window Scaling, which scales this TCP receive window value by shifting it left by n bits. Not all TCP stack implementations enable this feature by default, and notably Windows XP does not enable this. Thus in order to enable larger TCP window sizes and higher throughput, changes to the Windows registry must be made for optimal performance.

These registry changes are the addition of two DWORDs to the following location:

```
[HKEY_LOCAL_MACHINE\SYSTEM\CurrentControlSet\Services\Tcpip\Parameters  
"TCP1323Opts"=dword:00000003  
"TCPWindowSize"=dword:00040000
```

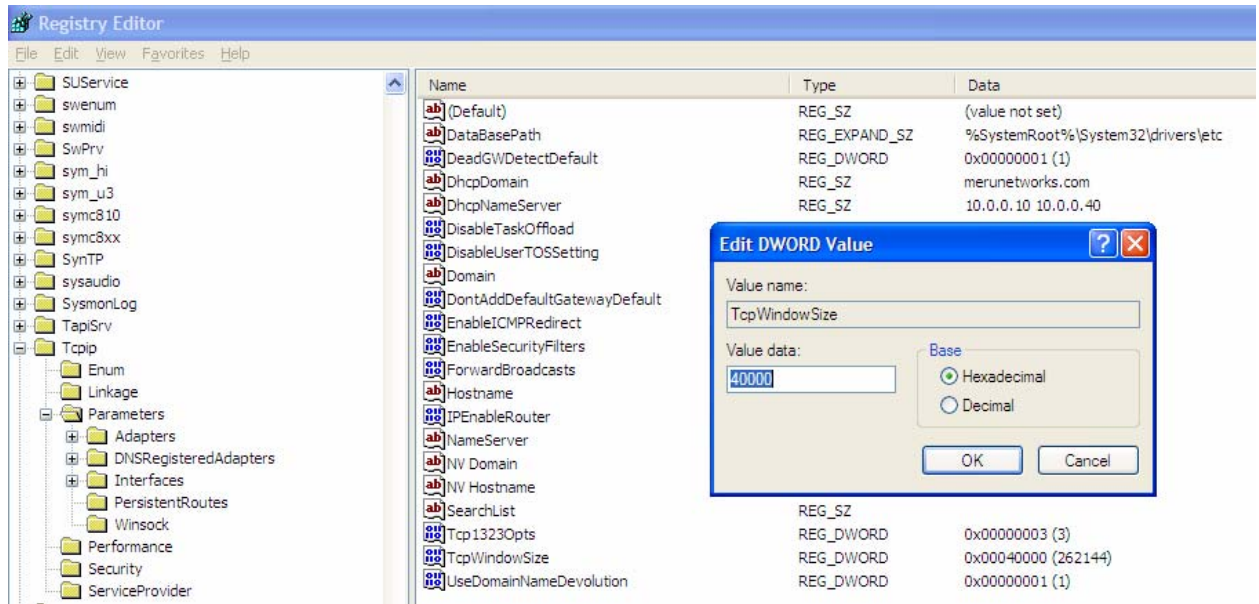


Figure 12 Regedit change for TcpWindowSize Example

The Tcp1323Opts entry allows the sender to advertise support for Windows Scaling and Timestamp options. The later allows better RTT calculation in the TCP stack. You must reboot your system for these changes to take effect, and changes must be made to both server and client endpoints.

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