NOVARUM

The Value of Smart Antennas: Campus Mesh Network Performance Benchmark

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1.0 Overview

Novarum had a unique opportunity to benchmark campus mesh network wireless systems. Curiously, there seem to be no extant third-party benchmarks setting a baseline for performance and service quality for any campus products. Clearly such research is valuable to potential users in advance of making deployment decisions.

This lack of comparative research is doubly relevant considering the major technology change in 802.11 - from legacy 802.11a/g radios to smart antenna technology in 802.11n. 2009 has been the beginning of the major transition in WLAN deployments, as many new large scale deployments are moving to upgrade from legacy 802.11b/g networks to contemporary dual band (2.4 and 5 GHz) 802.11n networks. However, this technology change has been slow to move to outdoor mesh networks, with only a few vendors announcing products. And there remains doubt and sometimes skepticism about the value that 802.11n MIMO[1] wireless LAN technology can bring to the campus environment - particularly if one reads WiMax advocates.

We benchmarked wireless mesh network systems from the market leading vendors BelAir and Cisco and compared them to the 802.11n campus mesh system available from Ruckus. All of them are campus class wireless mesh systems with integrated security and management tools that are designed to handle very large deployments. All of the systems are 802.11, WMM multi-application capable. Ruckus and Cisco employ a mesh controller that addresses the complexity of managing, securing and deploying these systems, while BelAir does not use a controller. Ruckus, in addition to 802.11n, adds smart antenna[2] technology that further improves performance by minimizing the local interference so common in mesh networks.

Our goal was to design and execute a benchmark suite that accurately reflects campus-level mesh network metrics within the microcosm of a single benchmark deployment. Since campus deployments typically have dense AP deployments, we focused on two key areas:

1. throughput performance and
2. coverage predictability (as measured by equity between clients)

as the primary metrics for campus-class mesh network evaluation.

We do not assert that these benchmarks are exhaustive, but we do believe they accurately represent the capabilities of each of these products.

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[1] Multiple In Multiple Out - the core technology of 802.11n that uses multiple transmit and receive radios in parallel to take the challenges of the real radio world - multipath, obstructions, trees, buildings - and turn them into advantages through improving performance and capacity. MIMO is the core technology that all modern wireless technologies (802.11n Wi-Fi, WiMax, and LTE) use to improve quality, capacity and performance.

[2] Ruckus smart beamforming antennas dynamically electronically “focus” packet transmissions much like a steerable gain antenna – optimizing performance in the direction of current client device and “deafening” interference from other access points and clients in other directions by more than a factor of 5. This feature has the bonus of materially easing deployment by effectively including an automatically pointed gain antenna in the physical AP package.

We evaluated the following performance metrics.

Throughput: Raw TCP “goodput” of successful, reliable data transfer - both upstream from the client to the performance server attached through the root mesh node and downstream from the root to the clients.

Coverage Quality: We measured how equitably the mesh delivered service by measuring how many of the client data flows at different locations actually transferred data.

Novarum is a strong believer in Over-The-Air (OTA) benchmarking of wireless systems rather than “wired” benchmarking using simulated RF conditions. One of the key capabilities of a WLAN is dealing with an RF environment that naturally consists of imperfect RF transmission, interference and contention between clients and access points for airtime on the shared channel. In fact, 802.11n depends on imperfect RF conditions from multi-path reflections for the majority of its performance improvement over legacy WLAN technology. RF simulations poorly emulate RF conditions and are best used for evaluating functional behavior rather than system performance. These simulations are rarely reflect predictable live performance.

1.1 Key Findings

This real-world benchmark of campus mesh networks revealed several major conclusions:

- A new generation of 802.11n MIMO based high-performance mesh networks are available that provide high throughput, effective indoor and outdoor coverage, and are simple to deploy.
- There is an enormous price/performance disparity, up to a 12:1 ratio, between the available outdoor mesh products.
- Ruckus Wireless has a demonstrable performance advantage over Cisco (4:1) and BelAir (6:1) in serving laptops through a campus Wi-Fi 802.11n mesh network.
- To solve capacity needs of the network, Cisco would need 4x the number of nodes, catapulting the solution to10x of the Ruckus Smart Mesh system.

In addition, this benchmark pointed towards the following take-aways:

802.11n the only real choice	The Ruckus 802.11n smart antenna mesh network outperformed its legacy 802.11ag competitors by 4:1 (Cisco) and 6:1 (BelAir). In addition, the coverage quality, or the ability of laptops to successfully connect from anywhere, particularly indoors, was superior with the Ruckus kit.
Best can be the least expensive	Deployment time and cost as significantly lower with the Ruckus Wireless campus mesh equipment. Ruckus outdoor mesh equipment could be deployed at half the cost of BelAir and one-third the cost of Cisco an in a fraction of the time.
Ruckus excels	Ruckus was clearly the highest performing system, the easiest to deploy and the lowest cost over both BelAir and Cisco. A pleasant result was that the entire campus was served from “outside pointing in” using relatively few outdoor nodes.

BelAir challenged	BelAir is a workhorse legacy 802.11a/g system but clearly showing its technology age. It was the midrange in cost, but lowest in performance. While straightforward to deploy, it had poor indoor penetration.
Cisco average and high cost	Average performance. Highest price. Physically challenging form factor for deployment. Poor network configuration tools and poor automatic mesh configuration.
Deploy 802.11n and 802.11n clients preferentially	The benchmark results clearly demonstrate the value of deploying BOTH 802.11n clients AND infrastructure. 802.11n demonstrated both the highest performance AND the lowest cost.

2.0 Benchmark Methodology

There are many ways to benchmark network performance. Two major categories for such benchmarking are synthetic (simulated) and real-world. For wireless systems, particularly modern wireless systems with advanced antenna systems, these are extraordinarily complex systems and it is easy to "game" a synthetic benchmark. It is almost impossible to construct a synthetic benchmark that adequately models the reality of multi-path radio environments indoors or outdoors.

Consequently, Novarum structured our benchmark testing to represent a realistic deployment environment that included buildings, tree cover, elevation change and client devices deployed both indoors and outdoors.

2.1 The Location

Novarum conducted the benchmark on the campus of the Woodside Priory School in Woodside, CA with their consent and cooperation.

The Priory school is an independent college preparatory school in the San Francisco Bay Area that is in the midst of upgrading its Internet access and this was a prudent time to evaluate available options. The Priory campus covers approximately 40 acres within 0.5KM by 0.3KM rectangle. Our goal was to evaluate signature products illustrating contemporary technology for providing campus wide indoor and outdoor wireless access to the Internet.

Fig 1: Priory School Campus

RF scans showed that we could “hear” other access points and wireless LAN traffic from neighboring businesses, but at a very low power and usage levels. The benchmarking was conducted on a weekend to minimize interference. No significant in-band interference was judged to be present during the network benchmarking.

Fig. 2: Roof mounted APs, POE cable carries power only

2.2 Wireless Mesh Infrastructure

We chose wireless Wi-Fi mesh infrastructure equipment from three vendors: two historical leaders: - BelAir and Cisco - as well as one of the newest entrants, Ruckus Wireless. known for its innovations in the area of dynamic beam-forming and high-gain intelligent antenna arrays, Ruckus is one of the first vendors to announce and deploy mesh technology based on the IEEE 802.11n standard. Novarum's past research has strongly indicated that smart antenna technology (such as 802.11n) will substantially increase the performance of mesh network systems.

	Controller	Software	Access Point
BelAir	None	BA100 8.0.8.G.2009.02.10.09.47 (r21450)	BelAir 100 - 11DC dual radio 802.11 g/a access point BELAIR100_11-C 802.11a - single omni 8dBi antenna 802.11g - omni 8 dBi primary antenna, internal diversity patch antenna
Cisco	Cisco 4402 Wireless LAN Controller	6.0.182.0	Cisco AP1522 dual radio 802.11g/a access point AIR-LAP1522AG-A-K9 802.11a - single omni 8 dBi antenna 802.11g - single 8 dBi omni Tx antenna, three 8 dBi omni Rx antennas
Ruckus	Ruckus ZD1000 controller	8.1.0.2.2	Ruckus ZF7762 dual band outdoor 802.11a/g/n access point Integral adaptive smart antenna

Novarum deployed four mesh nodes (from each vendor) around the core of the Priory School campus - on rooftop locations where we best judged good coverage would result. The nodes were co-located in the same locations. Only one vendor's mesh system was powered on at any one time.

The mesh nodes from all vendors under test are dual band, with simultaneous performance on both the 2.4 and 5 GHz bands. We configured the 2.4 GHz radio to serve client devices and the 5 GHz radio to support the mesh connections between access points.

The 5 GHz mesh radios were all tuned to the same channel for each mesh. We manually configured the 2.4 GHz radios for the four mesh nodes to minimize interference but using all three 20 MHz 2.4 GHz channels (1, 6, and 11).

All benchmarking was done in the clear with no encryption. All mesh nodes were connected to AC power (802.3af power over Ethernet) to ensure maximum performance.

One of the key items of mesh performance is the depth of forwarding of traffic between mesh nodes. More than one hop in mesh forwarding can dramatically decrease mesh throughput so it is desirable to minimize mesh forwarding This is because a mesh node cannot send and receive at the same time, it loses ½ of its bandwidth as it attempts to relay packets up and down the wireless backhaul (relay) path. A loss of ½ with each hop implies that after 4 hops, a user would be left with (½*½*½*½) = 1/16 of the bandwidth available at the Ethernet link. This is a $1/(2^N)$ relationship where this equation defines the fraction of the bandwidth that is available to a user after N hops. This simple analysis does not take into account additional capacity degradation from packet collisions and interference overhead from the additional traffic.

Novarum attempted to configure each mesh identically to highlight the comparison between products and technologies. We desired most nodes to attach directly to the root node but to configure one mesh node to forward one level deep through another mesh node.

The root of each mesh was at Node 2 (in Fig. 3) and three other mesh nodes were deployed within 100m of the root. Node 2 was deployed on a balcony at the back of the school cafeteria. Node 1 was deployed on the roof of three story auditorium at the center of campus. Node 3 was deployed on one of the dormitory buildings and Node 4 was deployed on a classroom building located on the upper portion of the campus.

Both Node 1 and Node 3 are roughly 100m from Node 2. Both have modest tree obstructions to Node 2 (see Figure 3). Node 4 is blocked by both buildings and trees from Node 2 and has modest tree coverage and 20m elevation change to Node 3 - about 60m from Node 3. By our professional estimate, the best configuration for this topography was direct connection of Nodes 1 and 3 to Node 2 and Node 4 to connection to the mesh via forwarding through Node 3.

Both the BelAir and Ruckus products incorporate features that self-optimize the configuration of the mesh route so that Node 2 was the root directly connected to both Nodes 1 and 3, while Node 4 was connected to forward its traffic via Node 3 to the root. All benchmarks with these two meshes used this configuration. Ruckus and BelAir also permit hand-optimization of mesh routes to force a certain arbitrary mesh topology, if desired.

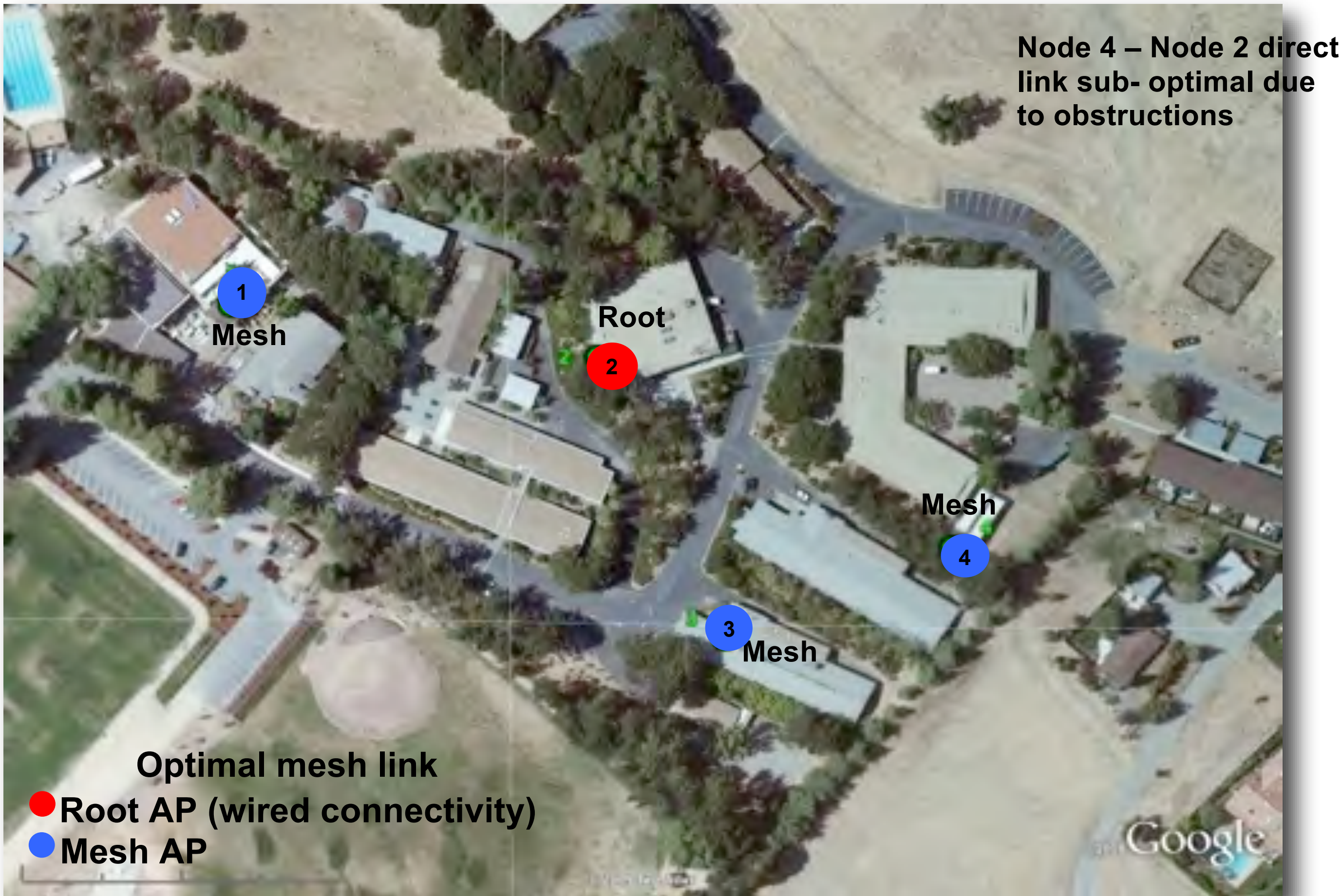

Fig 3: Placement of APs and optimal mesh paths

The Ruckus mesh was quite comfortable with this configuration and formed quickly and reliably. For the BelAir mesh, Node 4 did not attach to the mesh in any place. Only patient rebooting finally enabled Node 4 to connect to the mesh in the preferred configuration through Node 3. The Cisco mesh had no tools for manually structuring a preferred mesh configuration. While the mesh initially came up in a configuration in which Nodes 1, 3 and 4 were directly connected to Node 2. Unfortunately, the Cisco system repeatedly reconfigured itself into a rather unfortunate configuration of Node 1 connected to Node 3 connected to Node 4 connected finally to Node 2. This configuration ensured poor mesh forwarding performance. Novarum had no choice but to benchmark the Cisco mesh in a configuration deemed to be less than optimal. However the Cisco mesh control software insisted on using this mesh topology.

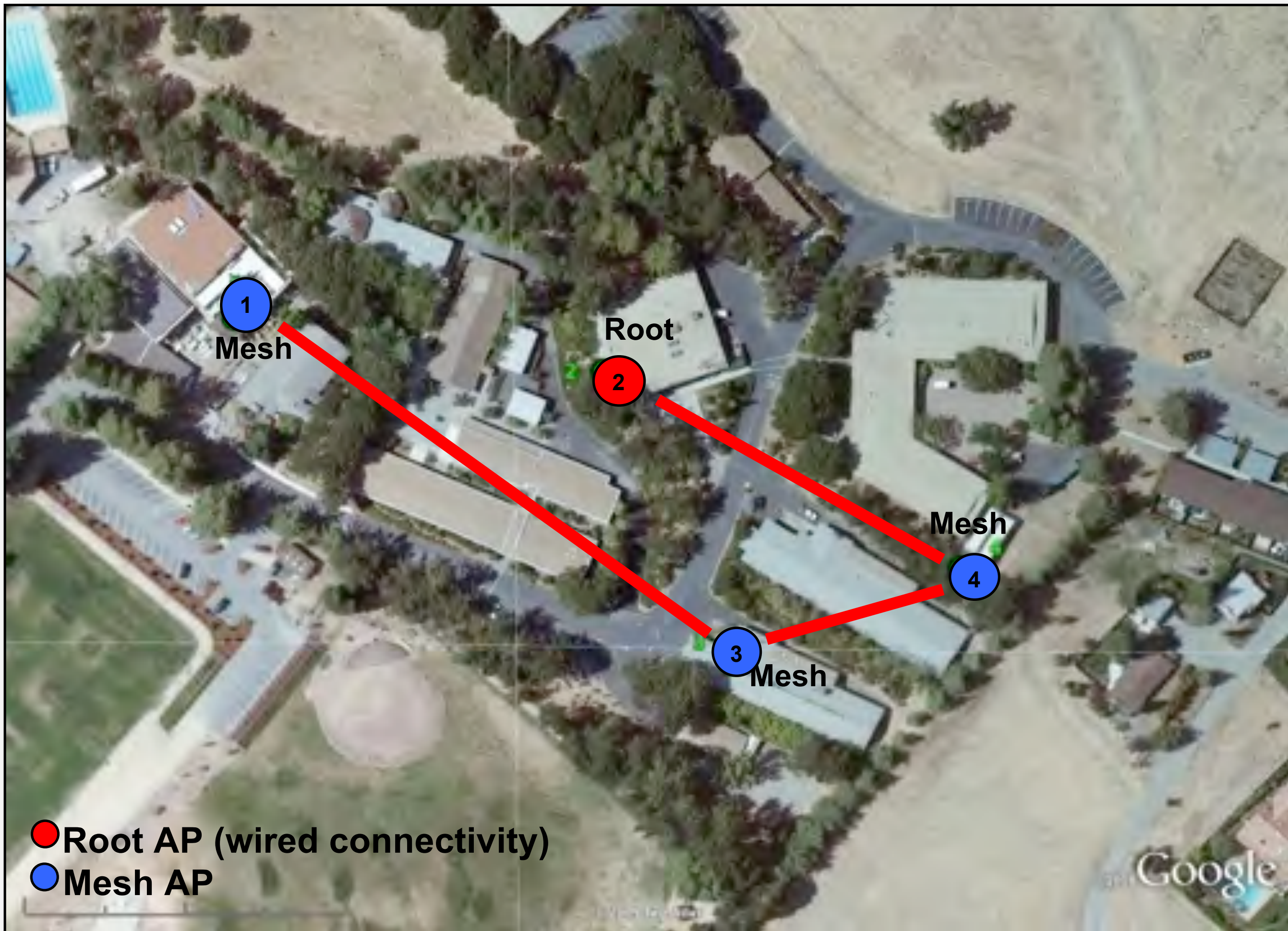

Fig. 4: Cisco chose sub-optimal configuration

2.3 Wireless Client Equipment

Clients used for the mesh benchmark testing were 10 industry standard laptops with integrated Intel 5100 dual band 802.11n Wi-Fi adapters. All client reading locations were within 100m of a mesh node - often much closer, as shown in Fig. 5. Half of the clients were located and tested indoors and half outdoors. In a real deployment, we would expect most users to make use of the network indoors.

Client Brand	Software	Network Adapter
Lenovo ThinkPad SL500	Windows XP SP3 XP Driver (12.4.5.9)	Intel 5100 802.11 a/g/n dual-band, 2x2 MIMO 30 mW

Fig. 5: Client performance and coverage quality reading locations

2.4 Benchmark Metrics

The focus of this benchmark is campus wide wireless mesh performance. We were specifically looking to evaluate the following performance metrics.

Throughput: Raw TCP "goodput" of successful, reliable data transfer - both upstream from the client to the performance server attached through the root mesh node and downstream from the root to the client. Novarum measured client performance at the locations indicated in figure 5. TCP is used for the transport protocol so there is substantial bidirectional packet traffic. Ixia Chariot 4.2 was used as our traffic generation and measurement instrument. The clients and mesh are configured without security. Each client laptop was configured as a Chariot endpoint. The Chariot console generates a stream of TCP traffic using the same Chariot throughput script that continuously sends an incompressible 1,000,000 byte file as fast as TCP will allow for 60 seconds. The same script is used for all runs of this benchmark with all vendors.

Coverage Quality: Novarum measured how equitably the mesh delivered service by measuring how many of the client data flows actually transferred data. In the complex RF environment of the campus network, multi-path and hidden RF nodes, all clients may not be able to connect and transfer data.

Novarum ran each metric test three times for each vendor, averaging the results of the three runs.

3.0 Benchmark Results and Analysis

3.1 –Throughput: Indoor Performance Needs Smart Antennas

In our benchmark, the Ruckus infrastructure outperformed both BelAir and Cisco by a wide margin -in both upstream and downstream benchmark tests. The Ruckus wireless mesh outperformed the BelAir mesh by a 6:1 margin on the average downstream/upstream throughput to the indoor clients

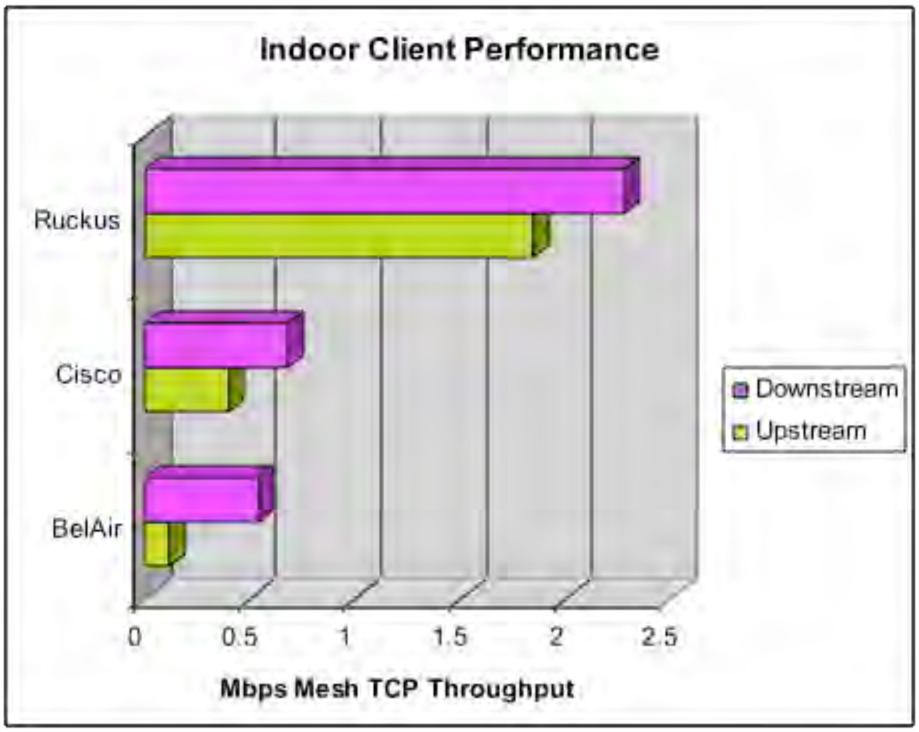

Fig 6: Average Client Throughput

This demonstrated that the implementation of dynamic beamforming within the Ruckus 802.11n syistem is highly effective for campus and outdoor applications, where a few high-performance outdoor APs can be used to cover relatively large, and hard-to-penetrate indoor areas with good performance.

3.2 Mesh Quality - Not All Systems Are Created Equal

A clear pattern can be seen with respect to the performance of the mesh network serving individual clients at various locations. The upstream traffic flows from clients to mesh were consistent - for every benchmark nearly every client succeeded in transferring some data. No clients were frozen out due to mesh forwarding or mesh self interference

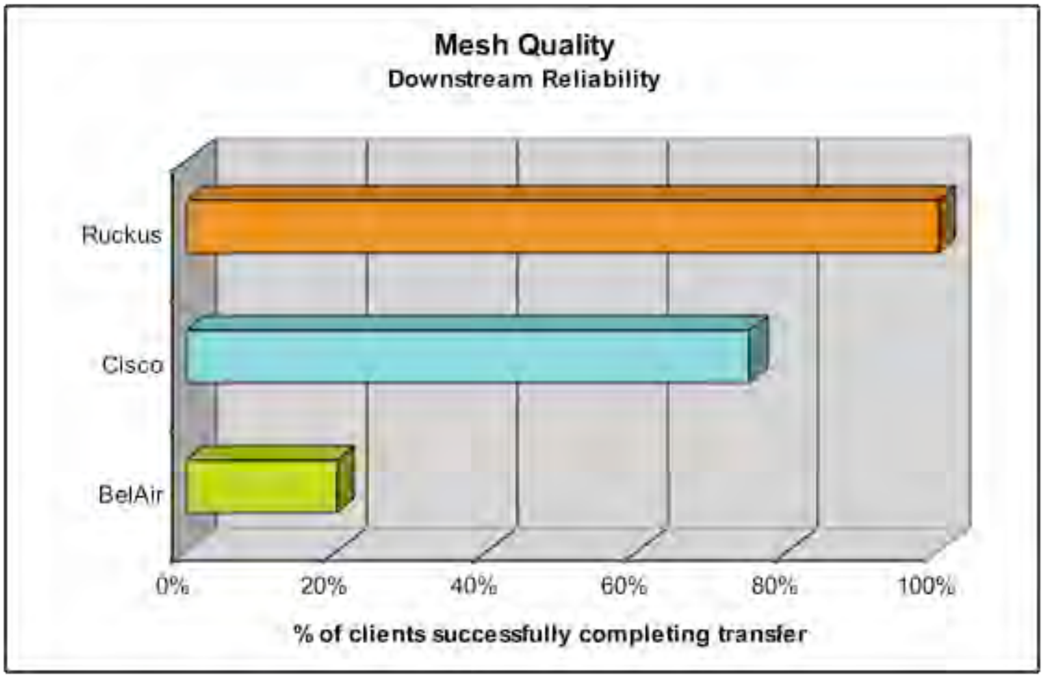

Fig 7: Mesh Quality

However, this symmetry breaks in the downstream direction from mesh to client. There is poor uniformity of successful downstream data transfer for both the BelAir and Cisco meshes – nearly crippling the network. For instance within the BelAir mesh network only 20% of the client locations reported successful data transfer during the benchmarks.

The Ruckus 802.11n mesh succeeded not only in transferring the most aggregate data by a factor of 6x over BelAir and almost 4X over Cisco but also succeeded in delivering coverage to all client locations throughput the campus. No client locations were frozen out.

3.3 Dramatic Price/Performance Range

All three of these mesh networking solutions have a cost to deploy. Below is a basic cost/benefit analysis based on publicly available list pricing

BelAir			
Component	***Number***	***Unit Price***	***Total Price***
BA100 Mesh Node	4	$4,150	$16,600
2.4 GHz Antennas	8	$235	$1,880
5 GHz Antennas	4	$235	$940
Node Mounting Kit	4	$140	$560
BelAir Total			$19,880

Cisco			
Component	***Number***	***Unit Price***	***Total Price***
AP 1522	4	3995	15,980
2.4 GHz Antennas	12	$320	$3840
5 GHz Antennas	4	$200	$800
Node Mounting Kit	4	$100	$400
Power Cable	4	$300	$1200
WLC4402-12 Controller	1	$995	$995
Cisco Total			$32,215

Ruckus			
Component	***Number***	***Unit Price***	***Total Price***
Ruckus 9962 Mesh Node	4	$1995	$7980
Includes Antennas,			
Mounting, Cable			
Ruckus ZD1006 Controller	1	$1200	$1200
Ruckus Total			$10,180

It's important to note that both the Cisco and Ruckus products require controllers and this cost is added into the cost of the network. Ruckus was able to add another 2 mesh nodes and Cisco another 8 nodes under the currently priced controllers. No controllers were required for the BelAir network - although with larger networks, a better network management system would no doubt be required. The Ruckus solution was the lowest cost by a factor of 2 compared to BelAir, and three times lower than Cisco. The Ruckus equipment was also lightweight and much simpler to deploy with no additional antennas, expensive power cables, or other such accessories required.

Mesh Product	Cost ($)	Indoor Client Performance (Mbps)	Relative Cost	Relative Performance	Relative Cost/Performance
BelAir	$19,880	0.33	1.6	1	1.6
Cisco	$32,215	0.54	1	1.6	1.64
Ruckus	$10,180	2.1	3.2	6.3	20.0

Comparing the cost efficiency of these solutions, using Cisco as the baseline, and the mean of downstream and upstream performance numbers reveals some interesting findings. On a relative cost/performance basis, the gap between Ruckus and the other two vendors is quite large – a 12x higher price performance over Cisco and BelAir.

3.4 Other Observations

The execution of these benchmarks also demonstrated a number of smaller compatibility issues with respect toease of use (or lack of) and deployment ease. The following notes summarize our impressions on each of the components we evaluated during these benchmarks.

BelAir BA100

- Easy to set up for the small number of nodes used in the Novarum testing. A larger network would require the purchase of an external network management system.
- Indoor penetration was poor.
- Physically light and compact unit was easy to deploy and simply powered via PoE.

Cisco AP 1522

- Ultra heavy. At 22 lbs, the Cisco mesh nodes were 3x the weight of either BelAir or Ruckus, and with their standard cantilevered mounting system, almost dangerous to deploy.
- The Novarum team actually received bruises in wrestling these nodes onto roof tops. Needs four 2' external antennas - yielding a physically large and awkward package.
- Awkward mounting.
- Non PoE powered.
- No way to configure mesh and the default mesh configuration algorithm seems to pick a spectacularly poor result.
- Average performance. Highest price.

Ruckus 7762

- Impressive simplicity of deployment.
- Highest performing benchmark system by a substantial margin.
- Physically light and compact unit.
- Easy to deploy.
- Simply powered via PoE. Smart antenna system included in package and required no expertise to configure and no awkwardness to deploy.

Intel 5100 802.11n Adapter

- The 5100 is Intel’s current generation entry level dual band 802.11n miniPCI adapter. It is a 2x2 MIMO design and delivered very good performance.
- However, we happened to have an older Lenovo laptop (not used in the benchmarks) with the older Intel 2x3 MIMO 4965. We ran some basic benchmarks and noted that the 4965 uniformly outperformed the 5100 with all three mesh networks.
- We would recommend that users deploy the highest MIMO clients available to improve coverage and performance. While not evaluated in this benchmark, the Intel 5300 miniPCI is a 3x3 MIMO and would likely substantially improve coverage and performance - particularly with the smart 802.11n Ruckus mesh network.

Appendix A - Full Disclosure

Novarum fully stands by these results. This study was sponsored by Ruckus . We took our role as independent analysts very seriously. We defined and executed the benchmarks. We worked hard to configure each mesh and client for best performance. We followed the manufacturers' guidelines for deployment and configuration. We made sure that all of the benchmarks were conducted under the same conditions.

In our judgment, all these systems were configured and deployed as well as they would be if one of their authorized VARs did the installation and any remaining errors are within the bounds of OTA benchmark reproducibility.

