

Metro-Scale Mesh Networking with Tropos MetroMesh™ Architecture

A Technology Whitepaper
July, 2007

Photo courtesy of NASA Image eXchange.
Image use in no way implies endorsement by NASA of any of the products, services, or materials offered by Tropos Networks, Inc.

RELIABLE BROADBAND EVERYWHERE FOR EVERYONE

Tropos brings the benefits of true, affordable broadband data communications anywhere, anytime, for any application (DSL alternative, municipal workforce automation, public safety wireless access, Mobile Internet). An examination of available alternatives shows that they do not measure up to the task. Meeting this challenge requires a unique marriage of the ubiquitous coverage of cellular with the ease and speed of Wi-Fi. Tropos Networks offers this via the first MetroMesh architecture and a new class of product called the MetroMesh router.

Broadband Over Cellular: The Numbers Don't Add Up

Cellular telephony networks offer anytime, anywhere voice and, more recently, limited data capabilities (SMS, 2.5, 3G). However, they are extremely costly to own and operate and require expensive add-on end-user devices such as proprietary modems.

Furthermore, aggregate capacity is a bottleneck for broadband over cellular networks. 3G solutions such as1xEV-DO propose to deliver best-effort shared data service (2.4 Mbps peak download, 400 – 700 kbps expected download, 144 kbps peak upload, 60-80 kbps expected upload) by allocating a single CDMA carrier largely from existing cell sites. With a cell density that is roughly one cell per square mile, traditional cellular networks upgraded to 1xEV-DO or similar technologies can hope to offer broadband to only a handful of users.

Wi-Fi is fast, cost-effective, and easy, yet today is limited by wires and scalability

Due to standardization, widespread vendor adoption and ease of use, Wi-Fi networks have enjoyed tremendous success in delivering broadband within the home, office and coffee shop hot spot while keeping client costs to a minimum. Today, Wi-Fi is standard on most mobile devices such as laptops and PDAs, and many cell phones.

Tropos MetroMesh Architecture: Combining the Best of Cellular and Wi-Fi

By combining the ubiquitous coverage of cellular with the ease and speed of Wi-Fi, Tropos Networks produced the first MetroMesh architecture that is capable of cost-effectively and securely delivering broadband data to standard Wi-Fi clients in coverage areas spanning not just hot-spots or hot-zones, but entire metro-areas. Actual throughput in the range of 1 Mbps (symmetrical) is consistently delivered to standard Wi-Fi client devices by overcoming the effects of interference and multi-path fading across the mesh. Tropos outdoor MetroMesh routers deliver these benefits using the revolutionary, patent-pending Tropos MetroMesh

architecture and the Tropos Predictive Wireless Routing Protocol (PWRP™) which,

- eases deployment and scaling through a self-organizing network
- allows wired backhaul to be added in line with subscriber growth by eliminating the need to wire every node
- maximizes available throughput: achieves 2x that of competing routing approaches even in large networks
- ensures reliability with an efficient self-healing architecture
- offers accessibility and mobility to standard Wi-Fi clients

In MetroMesh networks, Tropos MetroMesh routers are placed throughout the city at densities ranging from 25 to 40 per square mile depending upon application, foliage and topography.



A fraction of the MetroMesh routers, configured as gateways, are connected to the wired Internet backbone using optical fiber or point-to-multipoint wireless links. The remaining routers, referred to as nodes, are connected via mesh wireless links. The ratio of gateways to nodes is driven by capacity needs and is determined by typical over-subscription models for fixed and mobile broadband networks.

The remaining MetroMesh routers, configured as nodes, route traffic over one or more mesh hops back to the gateways. The Tropos MetroMesh OS selects the best path through the mesh for high throughput and low latency, provides reliable mobile client connectivity for a wide range of standard Wi-Fi clients and extracts the maximum packet-carrying capacity from available airtime across all available Wi-Fi channels.

Wi-Fi client devices in MetroMesh networks access the Internet by associating with Tropos MetroMesh routers (gateways or nodes). MetroMesh routers employ multiple omni-directional antennas both to provide coverage to connect these Wi-Fi client devices and to route client traffic through the wireless mesh to/from the Internet using single-radio and multiple-radio router options that leverage unlicensed frequencies in the 2.4 GHz and 5 GHz frequency bands.

Tropos Predictive Wireless Routing Protocol

The algorithms incorporated into PWRP have been developed and honed over seven years and incorporate real-world experience from more than 500 successful deployments in 30 countries. Applications as diverse as mobile broadband for public safety, residential broadband, video surveillance, voice services and mobile public access operate on these networks.

Wireless mesh networking systems have been successfully employed for military applications since the late 1970s. These first-generation systems required the use of proprietary (purpose-built) end-user devices. Furthermore, the wireless routing protocols developed for these military systems were designed to support client interconnection (i.e., communications from any point A to any point B within the mesh) on the battlefield, rather than access to a wired network such as the Internet.

The focus on client interconnection places fundamental limitations on these routing protocols, making them unsuitable for today's client-server computing environment. First, because of excessive routing overhead and degradation of throughput across multiple hops, mesh interconnect technology cannot scale to create large networks. Second, because of the focus on client interconnection, they did not optimize the data path between wireless client and wire-line servers. Because

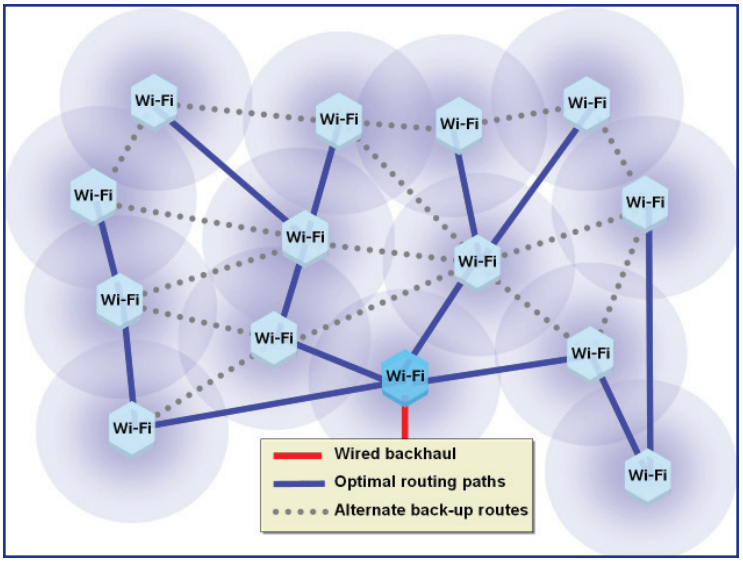


Figure 1: Tropos MetroMesh routers self-organize to maximize wireless throughput to backhaul

mesh networks were primarily used in ad hoc, peer-to-peer networks, these problems went largely unsolved for over two decades after mesh's advent in the late 1970s. Designed with client-server computing as the primary application, PWRP addresses these limitations.

Self-Organizing and Scalable

In prior metro-scale wireless architectures, including cellular and point-to-multi-point, experienced RF planners and technicians had to be involved in meticulous site surveys, planning, and link-engineering. Once deployed, the systems were inflexible. Making changes or reacting to failures in backhaul or link connectivity requires expensive redeployment and reconfiguration.

The Tropos MetroMesh architecture was designed from the ground up to provide the maximum flexibility in installation and the ability to react and respond to failures – whether disruption of wireless backhaul due to factors such as interference or loss of a wired backhaul link – with a minimum of operator intervention. After Tropos MetroMesh

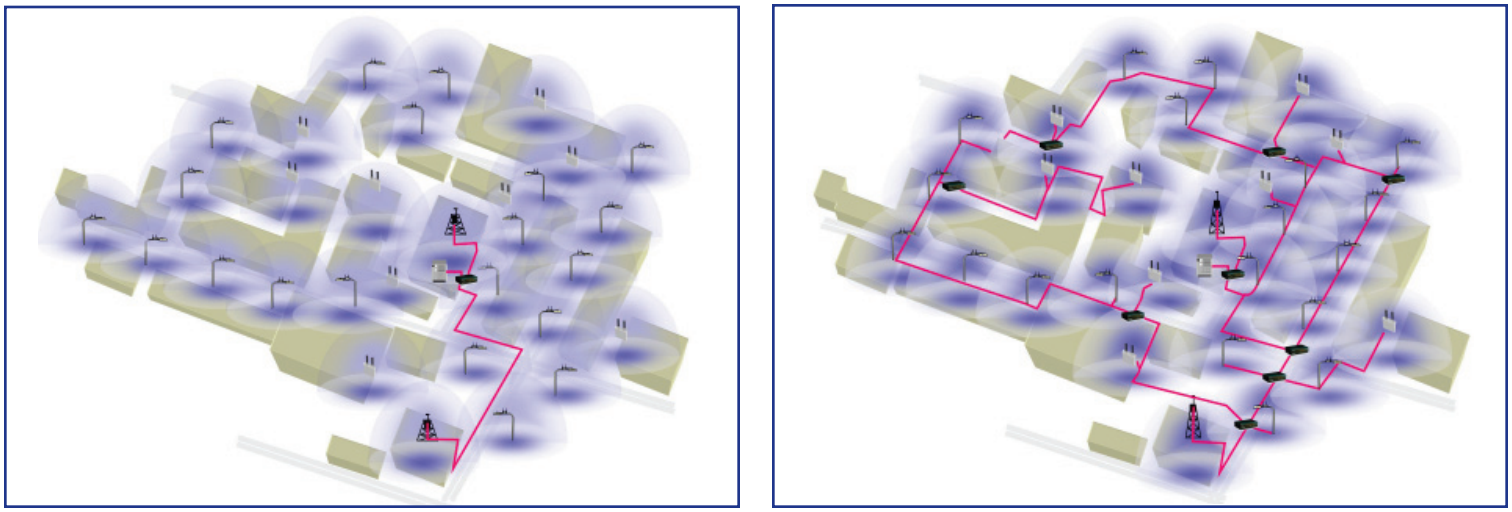


Figure 2: Tropos MetroMesh routers use wireless backhaul (left) instead of requiring wires to every mesh router

routers are deployed throughout out the coverage area, the network takes care of the rest by creating and maintaining routes that offer the highest throughput to the end-user.

- Careful link-by-link wireless planning is unnecessary since the fully distributed PWRP automatically sets up and maintains routes by dynamically identifying the path from MetroMesh router to MetroMesh router across multiple hops that will achieve the highest throughput between the Wi-Fi client and a wired backhaul connection.
- PWRP adapts based on changing interference conditions or new backhaul options that open up as new MetroMesh routers are added to extend or fortify the existing coverage area.

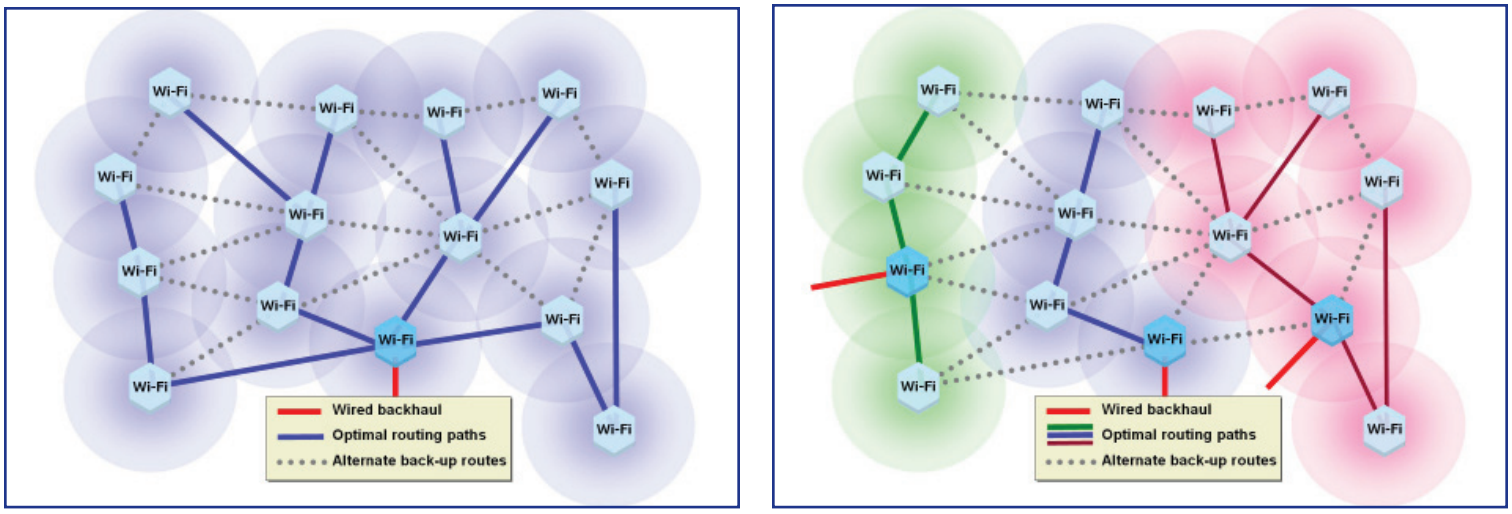


Figure 3: Tropos MetroMesh routers automatically reorganize to take advantage of new backhaul

- PWRP provides resiliency against link and node outages, ensuring there is no system-level single point of failure.
- Advanced RF spectrum management capabilities incorporated into PWRP adapt to the dynamic RF environment through automatic channel selection, adaptive transmit power and data-rate control and Adaptive Noise Immunity (ANI) algorithms.

Eliminating Wired Backhaul to Every Mesh Router

Delivering backhaul to each and every MetroMesh router covering a city using conventional wired or wireless backhaul options (e.g., fiber, T-1, DSL, cable, fixed wireless) is both difficult and expensive to install and provision, costly to maintain and involves recurring charges that make such a wire-hungry network economically untenable. The Tropos MetroMesh architecture enables deployment of the dense cellular network in a cost-effective manner by decoupling coverage from backhaul capacity. PWRP ensures that cells automatically reorganize to take advantage of new backhaul points as soon as they are provisioned. As the number of subscribers on the network grows and new wired backhaul capacity is provisioned to meet the demand, the MetroMesh routers distribute traffic flows among the expanded backhaul resources. This enables success-based capital investment in line with subscriber growth and expansion of the wireless coverage area.

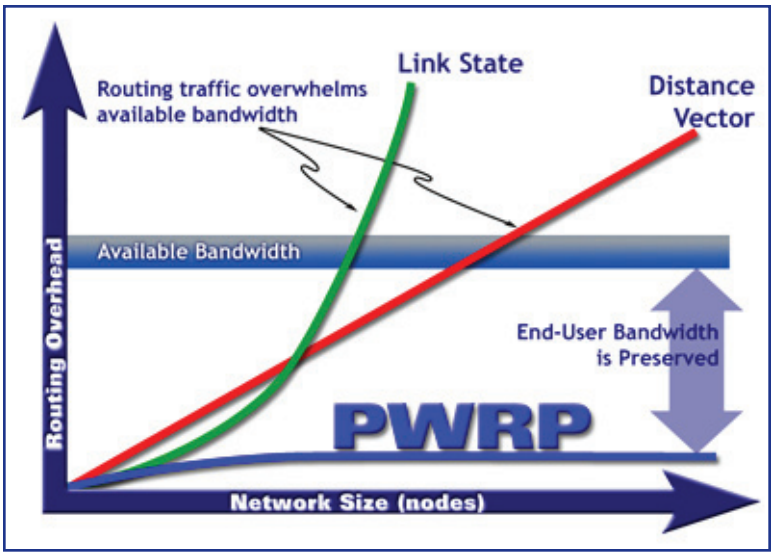


Figure 4: Scalability and Routing Overhead

Maximizing Throughput in Large Networks

Maximizing throughput in large networks requires both that minimal network bandwidth is required for control protocol traffic and that the optimal client-server data path be maintained in the face of highly variable RF conditions. PWRP is uniquely designed to meet these challenges.

Removing Protocol Overhead

Wireless link bandwidth is a finite resource. Any traffic used for control of the network takes away from the capacity available to client-server computing. Traditional interconnection-based client meshes maintain routes between all nodes in the network, using either link state or distance vector protocols. As a result of the manner in which these routing protocols operate, the routing tables and information exchanged between nodes grows proportionally to, or faster than, the size of the network. After the network reaches a certain size, the routing overhead dominates the wireless links, which takes away from bandwidth available to client traffic.

With PWRP, the network scales easily to deployments of thousands of nodes covering hundreds of square miles while keeping the routing overheads to less than 5% of airtime utilization. This is in contrast to distance vector and link state approaches where the overheads grow linearly or quadratically with the size of the network. The architecture is designed to accommodate incremental capacity addition as the usage grows and automated tools that Tropos has developed can be used to pinpoint nodes in the network that can be converted to gateways to further increase system capacity.

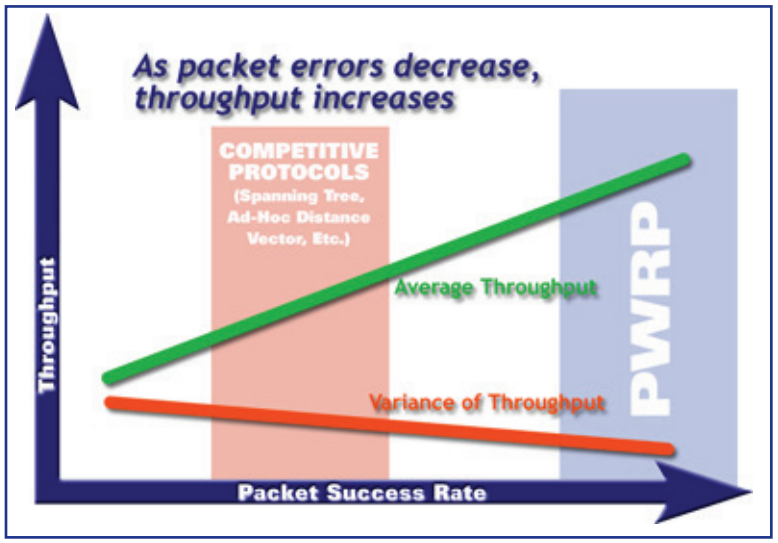


Figure 5: Wireless Throughput and Packet Errors

Unlike client meshes designed for interconnection, the traffic in client-server networks flows between wireless clients and servers located on the wired network. By optimizing the client-server data path, PWRP maintains minimal routing overhead as network elements grow in number (clients, cells, backhaul) and can therefore scale to arbitrarily large network sizes.

Eliminating the Problems Caused by Packet Errors

Wireless links are prone to multi-path fading and interference. These effects are dynamic, asymmetric, and change over time ranging from milliseconds to months, especially when the transmitter and receiver are moving but also when they are stationary. Ultimately, these effects manifest themselves as 802.11 packet reception errors, making them the major

source of throughput loss on the wireless data link. In sharp contrast to wired networks where link-status is binary (i.e., either operational with virtually no packet loss or down), throughput measured across one or more wireless hops can fluctuate anywhere between 0 and 100% of its theoretical maximum due to packet errors. Further, recent research at MIT has shown that routing algorithms that minimize hop-count or rely solely on RF signal strength-measurements to make routing decisions will fail to converge on a useful network topology and offer poor throughput. The reason is simple: Their routing decisions are uncorrelated with the throughput and therefore achieve far less than the maximum possible throughput over time. This includes the vast majority of wired routing protocols as well as the wireless routing algorithms employed by interconnect-based client meshes.

In contrast, PWRP is particularly sensitive to these variations in throughput by taking bi-directional measurement samples multiple times per second across wireless links. Based on history of these measurements, predictive algorithms dynamically tune the selection of the multi-hop paths from among the many that are available within the mesh. PWRP selects the highest throughput and most reliable paths through the mesh by reducing the total transmission time (and link layer retransmissions) required per packet across multiple mesh links between the client and the gateway. In 802.11, all links are subject to stochastic physical effects in the environment such as RF fading and interference—these effects are the primary root causes of reduced link performance manifested as link-layer retransmissions. PWRP exploits dynamic path diversity to consistently select the highest performing end-to-end path through the wireless mesh, achieving more than two times higher usable throughput. This is in contrast to other approaches that just attempt to minimize hop count without factoring in the impact to throughput of selecting paths with high packet error rates that necessitate high numbers of retransmissions resulting in lower throughput. Even when there are only a handful of paths to choose between, the difference

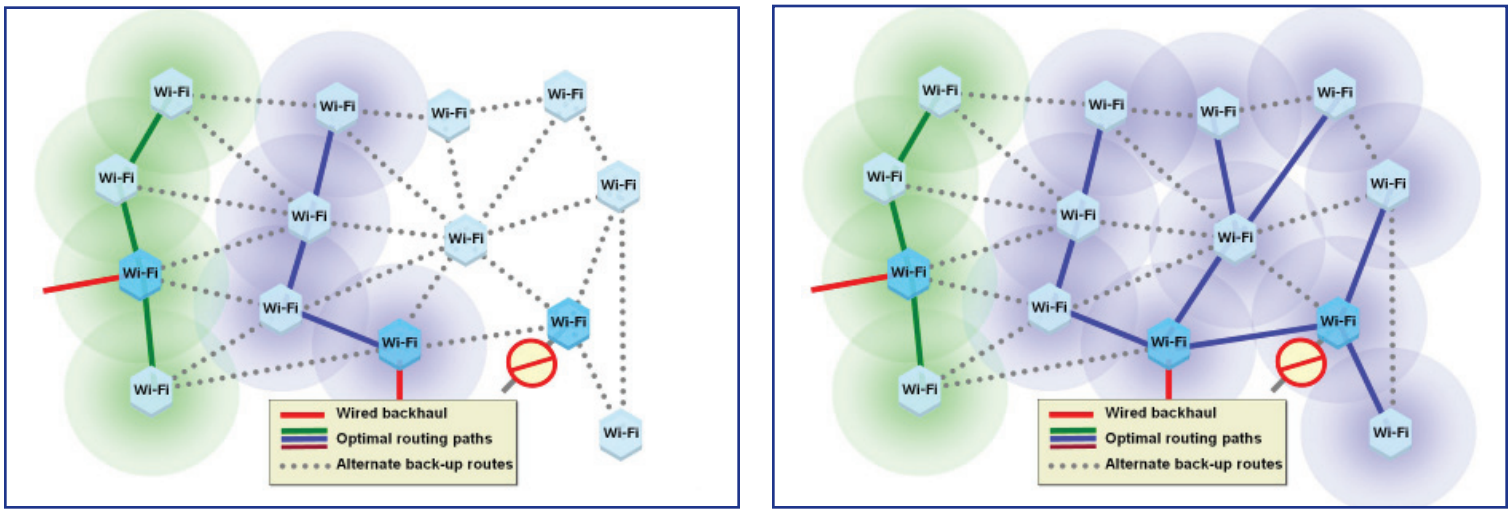


Figure 6: Tropos MetroMesh routers are not susceptible to single points of failure

between choosing the best path and any other path can often result in dramatically different throughput and reliability. In deployments with 25+ nodes per square mile, the average node often has over 10 available paths to choose between. This is independent of the ratio of nodes to gateways. Therefore, selecting the best path is important even when the gateway-to-node ratio is small. MetroMesh consistently delivers 1+ Mbps throughput with less than 50ms latency across the mesh using paths that vary from one to four hops.

The plot to the left, depicting data from a deployed network demonstrates the PWRP advantage. Whereas the available mesh links span a uniform distribution across Packet Success Probabilities (PSP), PWRP consistently selects high PSP links, resulting in a distribution that is strongly peaked around high quality wireless links.

By estimating the throughput of each alternate path using advanced multi-hop metrics, PRWP ensures that is consistently selects paths in the top few percentiles of all available paths. On average this achieves more than twice the throughput of competing routing approaches which are, in effect, choosing their paths at random with respect to throughput.

Network Layer Resilliency

Traditional cellular telephony networks are prone to service interruption due to loss of centralized controllers, central offices, or cell-towers. In addition, Wi-Fi is prone to temporary localized interference that is unpredictable in nature. PWRP incorporates network-layer resiliency and self-healing features that enable the operator to design a network to their desired level of system availability. PWRP is fully distributed and eliminates all single points of failure allowing for geographic distribution and rapid restoration. Tropos MetroMesh routers quickly detect wired backhaul failures and degradation in wireless backhaul links and automatically re-route traffic over the wireless mesh to other MetroMesh routers with wired backhaul. Routing protocols typically rely on a small number of “hello” packets to detect the status of a link. PWRP has the unique capability to discriminate between temporary wireless fades and an actual loss of wireless links due to changes in the interference environment or failures of a MetroMesh router itself. In the unlikely event of an actual failure at any MetroMesh router or wireless link, the rest of Tropos MetroMesh routers will correctly route around the failure and continue to deliver full service to the Wi-Fi device, including maintenance of the Wi-Fi device’s IP sessions, as if nothing ever happened.

Figure 4: The Tropos 5320 Outdoor MetroMesh router

RF spectrum management

PWRP continuously and dynamically optimizes the use of available spectrum through the use of patented algorithms for automatic channel selection, adaptive data rate selection, automatic transmit power adjustment and adaptive noise immunity.

These algorithms have many benefits including:

- Dynamic interference rejection by switching to unutilized or interference-free channels factoring in a number of metrics including airtime utilization, noise level, and other measurements.
- Maximization of airlink capacity and efficient spatial-reuse by enabling concurrent operation in multiple frequency channels in a given area, selecting the optimum data rates for link operation, and tuning MAC level packet detection registers to adapt to the RF environment.
- Contention management by automatically adjusting transmission power and data rates to ensure balanced link budgets on mesh and client links to ensure uniform and reliable connectivity to lower power client devices.

These algorithms have been extensively tested and verified in real-world deployments and are growing in importance as deployments become denser and coverage requirements increase.

Multi-mode routing

On multi-mode platforms, PWRP has the ability to automatically use 5 GHz to close mesh links when they happen to be available to increase system capacity. However it also has the ability to operate those mesh links that cannot close over 5 GHz using 2.4 GHz. This enables the mesh to be deployed at node densities similar to those for 2.4 GHz-only networks while simultaneously increasing overall system capacity through the opportunistic use of 5 GHz. In addition, the use of the higher capacity multi-mode product enables larger clusters with higher overall hop counts without sacrificing throughput or capacity.

Dynamic rate-limiting and traffic management

In networks with heavy usage, a small number of users often end up consuming a disproportionate share of the bandwidth through applications like peer-to-peer transfers. These high traffic streams can have a negative impact on the network performance of the remainder of the users, unless proactive traffic shaping policies are applied to these bandwidth-hungry applications. PWRP provides the ability to proactively identify these classes of users (based on traffic stream characteristics) and to apply selective rate-limiting policies so as to allow for a more equitable distribution of bandwidth and to apply more granular operator-specified policies on network usage. Tropos developed this feature-set based on operator feedback and an analysis of usage data gathered from some of our most heavily-used production networks.

Correlated Mesh Data Protocol (CMDP)

CMDP™ collects and correlates mesh-wide usage and performance data using a distributed data-collection paradigm. Mesh nodes leverage CMDP's extensive data and statistics collection during mesh operation and CMDP edge intelligence is used to filter and summarize the collected data to feed back to Tropos Control and Tropos Insight for analysis and post-processing. Using this protocol, the mesh provides precise information correlated across nodes on the network about network performance and end-user statistics. For example, data collected using CMDP is regularly used recently to optimize production networks by generating automated recommendations on optimal nodes to convert to gateways in order to improve overall system capacity.

Patents

Many patents on PWRP are pending and five patents have been issued by the USPTO to date:

- "Selection of routing paths based upon path quality of a wireless mesh network" US Pat. 6965575
- "Method for allowing a client to access a wireless system" US Pat. 7016328
- "Method and system to provide increased data throughput in a wireless multi-hop network" US Pat. 7031293
- "Method and apparatus to provide a routing protocol for wireless devices" US Pat. 6704301
- "Selection of routing paths based upon routing packet success ratios of wireless routes within a wireless mesh network" US Pat. 7058021

Mobility Using Standard Wi-Fi Clients

When compared to any other wireless standard, Wi-Fi is being incorporated into the broadest array of mobile client devices by far. These devices range from laptops to PDAs to cell phones and the users of these devices won't stand still. The Tropos MetroMesh architecture actively tracks standard Wi-Fi devices as they move through the coverage area, managing handoffs from MetroMesh router to MetroMesh router by adapting the layer-3 host routes in the mesh to reflect changes in the Wi-Fi device's location. As it roams, the Wi-Fi client maintains all its networked IP flows including such applications as VPNs, streaming and real-time multimedia (voice, video), and TCP-based protocols such as HTTP, FTP, and Telnet. In this manner, the Tropos MetroMesh creates Wi-Fi client mobility requiring neither additional client software nor any additional infrastructure, apart from the Tropos MetroMesh routers themselves.

PWRP ensures that client sessions are maintained as the client devices roam, even at vehicular speeds exceeding 60 mph. This is accomplished transparently to the end-user with no special client software required. PWRP enables fast handoffs even in cross-subnet roaming situations through the use of IP-in-IP tunnels and BGP. PWRP mobility is scalable to networks of thousands of nodes, hundreds of subnets and hundreds of thousands of client devices. Many public safety agencies throughout the U.S. utilize PWRP mobility for mission-critical applications today.

RF Quality: The Key to Uniform and Reliable Coverage

Achieving broadband speeds with Wi-Fi requires a strong signal at the receiver that rises above the receiver's noise floor and interference level just like other wireless radio technologies. The metro-area environment is composed of buildings, trees, and the like that absorb and scatter the energy of wireless signals creating dips and nulls in the wireless signal strength received from a single transmitter. In analogy to sound, sources of (loud) localized interference in the unlicensed band can exist in random locations. Rather than compete with nature, the Tropos architecture overcomes the challenges of propagation and interference by employing distributed MetroMesh routers to create uniformly strong and reliable Wi-Fi coverage throughout cities, just like street-lights provide light at night time. To ensure maximum RF performance, Tropos MetroMesh routers incorporate advanced, highly linear radios operating at the maximum allowed regulatory limits in conjunction with high-gain omni-directional (7.4dBi) antennas. The high-performance receiver achieves industry-leading 802.11b/g receiver sensitivity (-100dBm) and, therefore, Tropos MetroMesh routers offer excellent range to lower-power Wi-Fi clients.

MetroMesh System Software Architecture

Tropos' MetroMesh software architecture is the mature product of over 7 years of development and deployment in over 500 networks. It comprises several key functional modules including PWRP, SABRE, AMCE, CMDP, MESM, Tropos Control and Tropos Insight Management Software.

Data from Real-World Networks

Below we detail the operational performance characteristics of two Tropos® MetroMesh™ networks operating in two different U.S. cities. One of the networks offers access free-of-charge; the other requires a paid subscription for access. Both networks support a mix of consumer, business and city automation services.

The cities profiled in this paper are suburban, with populations ranging from 20,000 and 30,000, footprints of 9 to 13 square miles and housing densities in the neighborhood of 1,000 homes per square mile. The installations described here are for the dual-band designs

using Tropos 5210 single-radio (2.4 GHz) MetroMesh routers for client access and inter-mesh links and 5.8 GHz point-to-multipoint wireless links for backhaul.

Client Usage

Based on statistics gathered using Tropos Insight, the for-fee network uses mostly higher power Wi-Fi modems (for DSL-alternative service) that are stationary and always on while the free network employs a mix of fixed and mobile client types. All networks are heavily-used based on traffic-per-client statistics. In addition, mobility is becoming important, with 5-6% of clients moving more than half a mile during the 24-hour period, though other networks display mobility patterns reflecting 10-15% of mobile devices roaming over distances of half a mile. A wide range of Wi-Fi device types (64-83 unique device types) connected to these open-standard networks during the day

Network Usage by End-User

	For-Fee Network	Free Network
Daily Routed Client Devices	2,242	1,861
7-day Routed Client Devices	3,735	3,377
Daily Active Clients > 1 MByte Downloaded	1,626	1,309
7-day Repeat Clients > 1 MByte Downloaded	1,528 (94% of daily)	595 (46% of daily)
7-day Active Clients > 1 MByte Downloaded	2,310	2,382
Total Download (24 Hours)	143 Gigabytes	71 Gigabytes
Average Download per Client (24 Hours)	64 Megabytes	38 Megabytes
Total Bytes Uploaded (24 Hours)	50 Gigabytes	22 Gigabytes
Average Upload per Client (24 Hours)	29 Megabytes	12 Megabytes
Total Number of Client Device Types	64	83
Number of Devices Roaming > 2500 Feet	104 (5%)	117 (6%)

Client Link Performance

The average packet error of the client link varies widely (3-22%) depending on the type of client device. Fixed, high-power bridges placed in the home or office such as the 200 mW PePWave and Senao bridges experience lower packet error rates and they transfer more data on average. In general, devices such as the PePWave bridge that are compliant with Tropos' TMCX (Tropos MetroMesh Compatible eXtensions) show superior performance compared with non-TMCX-compliant devices. Portable and handheld devices tend to have lower transmit power (battery-constrained) and also are highly mobile, resulting in higher packet error rates. Conditional measurements of packet error rate based on the manufacturer of client device below show that it is varies inversely with increases in the transmit power and directly with increases in the mobility of the client device. These trends are exhibited across both networks. Since TCP/IP protocol retransmits lost packets allowing the applications to recover from temporary outages, the client link packet error rates observed in these networks result in a satisfactory user experience as shown by the average hourly bytes transferred for devices from each manufacturer. Usage rates of 5 MB/hour (as shown below) correspond to steady usage average of 11 Kbps, consistent with usage patterns in consumer DSL networks.

For-Fee Network

Most Common Client Devices (% of total)	Fixed Senao 200 mW modem 977 (44%)	Fixed PePWave 200 mW modem 694 (31%)	Mobile Intel Centrino 196 (9%)	Gemtek 111 (5%)
Average Uplink Signal Power	-64 dBm	-68 dBm	-80 dBm	-77 dBm
Average Packet Error Rate	4%	3%	12%	13%
Average Distance Roamed	44 feet	22 feet	148 feet	89 feet
Number of Devices Roaming > 2500 Feet (% of this device)	39 (4%)	12 (2%)	9 (5%)	3 (3%)
Average Hourly Bytes Transferred	3.6 Mbytes	5.5 Mbytes	0.8 Mbytes	1.0 Mbytes

Free Network

Most Common Client Devices (% of total)	Fixed PePWave 200 mW modem 477 (26%)	Mobile Intel Centrino 298 (16%)	Gemtek 223 (12%)	Cisco Linksys 220 (12%)
Average Uplink Signal Power	-75 dBm	-82 dBm	-81 dBm	-78 dBm
Average Packet Error Rate	6%	22%	15%	11%
Average Distance Roamed	82 feet	1194 feet	359 feet	189 feet
Number of Devices Roaming > 2500 Feet (% of this device)	12 (3%)	40 (13%)	11 (5%)	4 (2%)
Average Hourly Bytes Transferred	2.3 Mbytes	1.4 Mbytes	2.1 Mbytes	2.6 Mbytes

Mesh Network Performance

Using PWRP, the 2.4GHz mesh creates a network with a path length that is on average less than three hops, and 85-90% packet success probability (PSP—the probability of a packet traversing the mesh successfully) and, on average, delivers 3-4 Mbps and < 25 ms round-trip latency upstream and downstream. Using multiple 5 GHz links at the gateways to backhaul traffic, the mesh architecture is resilient to backhaul failures and provides reliable access for clients.

Mesh Network Performance

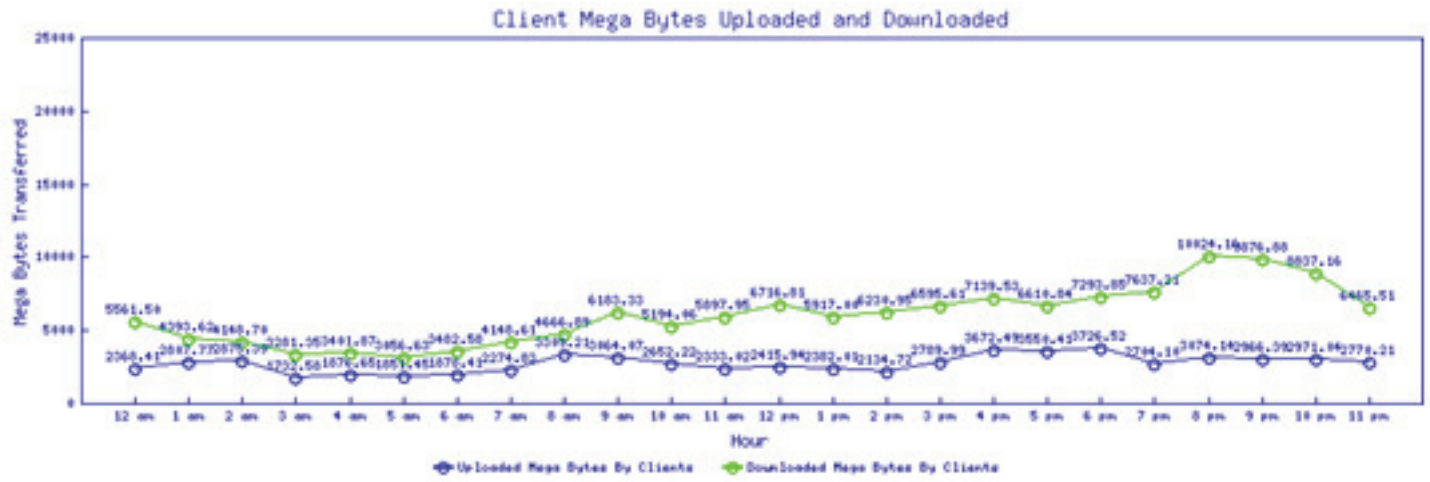
	For-Fee Network	Free Network
Average Mesh Node Downstream	4.0 Mbps	3.1 Mbps
Average Mesh Node Upstream	3.8 Mbps	2.7 Mbps
Average Mesh Node Round-Trip Latency	20.2 ms	16.8 ms
Average Mesh Node Unicast Packet Loss	0.36 %	1.1%
Average Mesh Node Hop Count*	1.7	1.9
Average Mesh Node Broadcast PSP on Active Link	89%	88%
Average Gateway Backhaul Downstream	26.4 Mbps	7.2 Mbps
Average Gateway Backhaul Upstream Throughput	14.6 Mbps	2.7 Mbps
Average Gateway Round-Trip Latency	3.4 ms	13.1 ms
Average Gateway Unicast Packet Loss	0.02%	0.24 %

* add one additional hop for clients

Hourly Usage Patterns

For-Fee Network

The relatively low variability in network usage throughout the day suggests a good amount of business utilization (“Active Clients”). The constant background of upstream traffic (“Uploaded Mega Bytes By Clients”) across all hours is generally indicative of peer-to-peer applications.



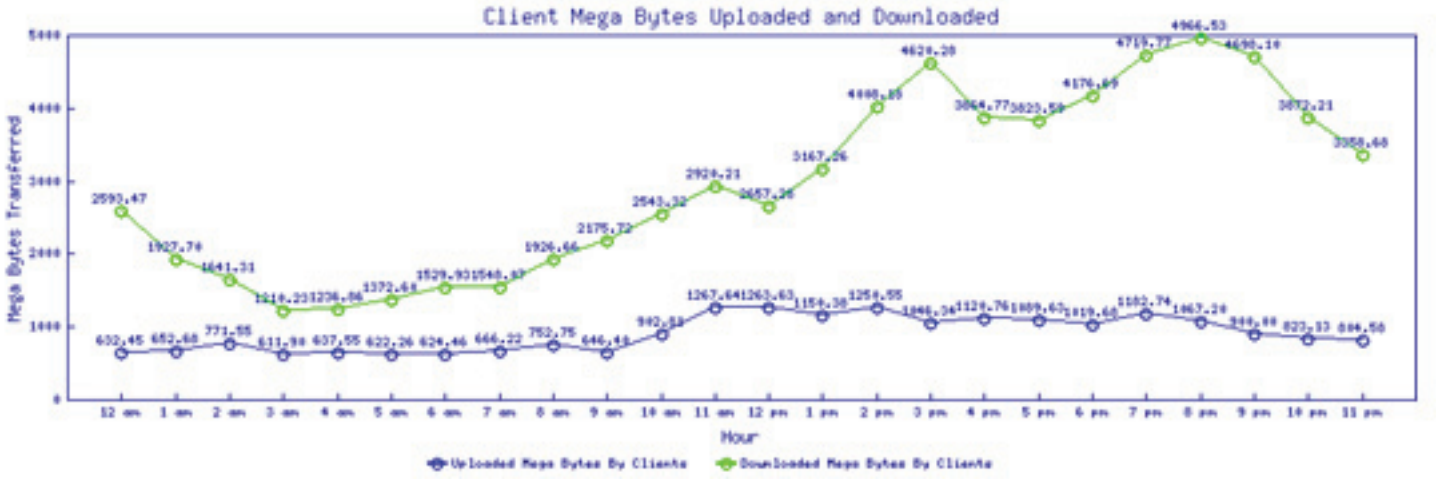
Total Client Bytes Transferred Per Hour (For-Fee Network)



Active Clients Per Hour (For-Fee Network)

Free Network

As shown in Figure below, this network shows a strong pattern of consumer usage with the peak in users and traffic during prime-time "busy hours" between 5:00 P.M. and 10:00 P.M. This peak usage is also reflected in the three-fold increase in download traffic during "busy hours" seen below ("Download Mega Bytes By Clients").



Total Client Bytes Transferred Per Hour (Free Network)



Active Clients Per Hour (Free Network)

Results from these Tropos MetroMesh networks suggest highly utilized, heavily used networks serving a wide variety of Wi-Fi devices that are providing fixed as well as mobile services. Throughput, latency, capacity and packet error rate statistics suggest utilization levels similar to U.S. DSL networks and performance significantly better than typical 3G cellular data offerings.

SUMMARY

Tropos products, shipping in volume today, are providing an increasing number of public safety agencies and service providers worldwide with the benefits of metro-scale Wi-Fi networks. These networks are enabling mission-critical broadband applications in mobile public safety environments, such as mobile database access, video surveillance, and GIS inquiries. No one else has the unique technology needed to build metro-scale Wi-Fi networks, as evidenced by Tropos Networks successful deployments in many outdoor, mission-critical applications.



555 Del Rey Avenue • Sunnyvale, Ca 94085
phone 408.331.6800 • fax 408.331.6801
www.tropos.com • sales@tropos.com

©2003-2007 Tropos Networks, Inc. All rights reserved. Tropos and PWRP are registered trademarks of Tropos Networks, Inc. Tropos Networks, MetroMesh, AMCE, TMCX, SABRE, CMDP, MESM and Metro-Scale Mesh Networking Defined are trademarks of Tropos Networks, Inc. All other brand or product names are trademarks or registered trademarks of their respective holder(s). Information contained herein is subject to change without notice. The only warranties for Tropos products and services are set forth in the express warranty statements accompanying such products and services. Nothing herein should be construed as constituting an additional warranty. Tropos shall not be liable for technical or editorial errors or omissions contained herein.contained herein.