Metropolitan-Scale Wi-Fi Mesh Networks

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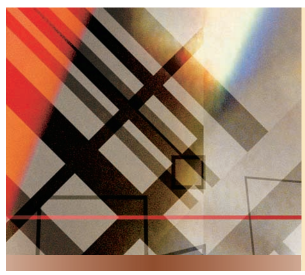
Standardization, widespread vendor adoption, low cost, and ease of use have all contributed to the explosive growth in Wi-Fi (IEEE 802.11) wireless broadband networks. Wi-Fi access is now available on most notebook computers and personal digital assistants, and it may be a standard feature on many cell phones in the future.

However, the limited reach of Wi-Fi propagation and high cost of installing and maintaining a wired network backhaul connection have limited Wi-Fi network deployments to homes, offices, public hot spots (in coffee shops, airports, hotels, and other similar locations), and some wide-area hot zones. In addition, installing, managing, and scaling multiple hot spots is difficult.

Dense-cellular Wi-Fi mesh networking has the potential to bridge this digital divide, foster economic development, increase public safety organizations' efficiency and effectiveness, and connect communities. The technology is making it possible, for the first time, to create truly unwired cities.



For the first time, it will soon be possible to create truly unwired cities.

BROADBAND OVER CELLULAR

Cellular telephony networks offer anytime, anywhere voice and, more recently, limited data capabilities. However, laptop users must purchase a wide-area modem card and pay a monthly service fee. Further, the aggregate capacity of broadband over cellular networks is limited.

Third-generation solutions such as 1xEV-DO (evolution, data-optimized) propose to deliver best-effort shared data service—2.4 Mbps peak download, 300-500 Kbps expected download, and 153 Kbps peak upload—by allocating a single CDMA (code division multiple access) carrier, largely from existing cell sites.

However, with a density that is roughly one cell per square mile, traditional cellular networks upgraded with 1xEV-DO or similar technologies can anticipate offering broadband to only a handful of users. A Wi-Fi cell with a range of 1,000 to 2,000 feet providing multimegabit throughput can provide significantly higher overall system capacity per square mile.

DENSE-CELLULAR WI-FI MESH ARCHITECTURE

Currently deployed metropolitan-scale wireless networks, including cellular and point-to-multipoint, require meticulous site surveys, planning, and radio-link engineering. These systems are inherently inflexible: Making changes or correcting failures in backhaul or link connectivity requires expensive redeployment and reconfiguration.

By combining cellular's ubiquitous coverage with Wi-Fi's ease and speed, Tropos Networks (www.tropos.com) has developed the first dense-cellular Wi-Fi mesh architecture capable of cost-effectively and securely delivering broadband data to standard Wi-Fi clients in citywide areas.

Predictive Wireless Routing Protocol

Our dense-cellular mesh architecture was designed to provide maximum flexibility in installation and the ability to react and respond to failures—whether disruption of wireless backhaul due to interference or loss of a wired backhaul link—with minimum operator intervention. After deployment of Wi-Fi cells throughout the coverage area, the network uses the Predictive Wireless Routing Protocol to take care of the rest.

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 cell to cell across multiple hops that will achieve the highest throughput between the client and a wired backhaul connection.

In addition, PWRP adapts based on changing interference conditions or new backhaul options that open up as the network operator adds new Wi-Fi

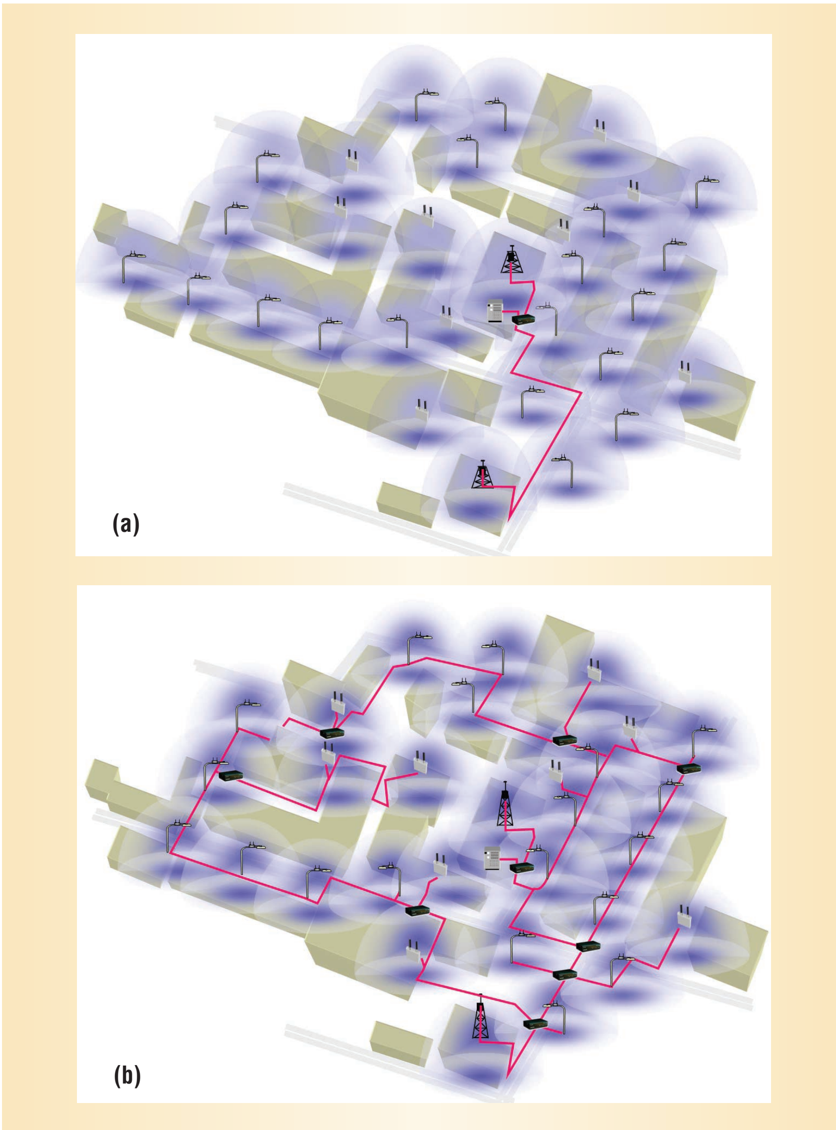


Figure 1. A dense-cellular Wi-Fi mesh network (a) uses a wireless backhaul connection rather than (b) requiring wires to every node.

cells to extend or fortify the existing coverage area.

Further, the network operator has the flexibility to provision or remove wired backhaul at any Wi-Fi cell. PWRP ensures that cells automatically reorganize to exploit new backhaul points as soon as the network operator provisions them.

Finally, PWRP provides resiliency against link and node outages, ensuring there is no single system-level point of failure.

Eliminating wired backhaul to every node

Installing and provisioning backhaul for each and every Wi-Fi cell covering a citywide area using conventional wired or wireless backhaul options—such as fiber, T-1, DSL, cable, or fixed wireless—is difficult and expensive, involving recurring charges that make such a wire-hungry network economically untenable.

As Figure 1 shows, a dense-cellular Wi-Fi mesh architecture enables cost-effective network deployment by decoupling coverage from backhaul capacity. As the number of subscribers on the network increases and the network operator provisions new wired backhaul capacity to meet the demand, the Wi-Fi cells distribute traffic flows among the expanded backhaul resources.

Maximizing throughput in large networks

To maximize throughput in large networks, control protocol traffic requires minimal network bandwidth. In addition, the system must maintain the optimal client-server data path in the face of highly variable radio frequency (RF) conditions.

Wireless-link bandwidth is a finite resource. Any traffic used for control of the network takes away from the capacity available for client-server computing.

Traditional interconnection-based client meshes maintain routes between all nodes in the network, using either link-state or distance-vector protocols. Consequently, the routing tables and information exchanged between nodes increase proportionally to, or faster than, network size. As Figure 2 shows, after the network reaches a certain size, the routing overhead dominates the wireless links, crowding out client traffic.

By optimizing the client-server data path, PWRP maintains constant routing overhead as network elements increase in number—clients, cells, backhaul—and can therefore scale to arbitrarily large network sizes.

Achieving 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. A metropolitan-area environment includes buildings, trees, and other objects that absorb and scatter the energy of wireless signals, creating dips and nulls in the signal strength received from a single transmitter.

Rather than compete with nature, the dense-cellular Wi-Fi mesh architecture overcomes the challenges of propagation and interference by employing distributed Wi-Fi cells to create uniformly strong and reliable coverage throughout cities, just as street lights do at night.

To ensure maximum RF performance, the cells incorporate high-powered radios operating at the maximum allowed regulatory limits (1 W) in conjunction with high-gain omnidirectional (7.4 dBi) or directional antennas. Because the high-performance receiver does not sacrifice any sensitivity (-98 dBm at 1 Mbps), it offers excellent range to lower-power Wi-Fi clients.

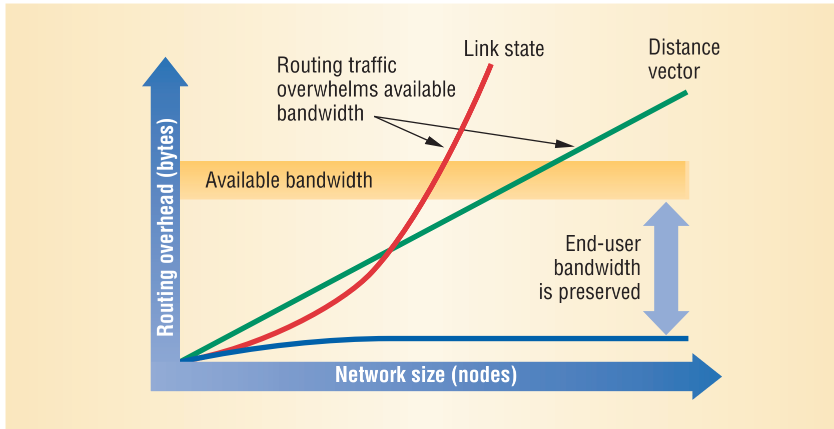


Figure 2. Scalability and routing overhead in traditional interconnection-based client meshes.

Public service agencies and service providers can deploy Wi-Fi cells with these RF performance capabilities to provide ubiquitous coverage at a density of 9 to 16 per square mile—with the nodes spaced one-quarter to one-third of a mile apart—in most environments.

WI-FI MESH NETWORK DEPLOYMENTS

Dense-cellular Wi-Fi mesh networking products, shipping in volume today, are providing the benefits of wireless broadband to an increasing number of cities and public safety agencies worldwide.

In the US, for example, Chaska, Minnesota, as well as Lompoc and Cerritos, California, employ the technology to deliver free or low-cost broadband to users in any locale, accessible via any Wi-Fi-enabled device. Philadelphia, Pennsylvania, has likewise announced plans to cover the entire city footprint with Wi-Fi connectivity.

Public safety networks have also been deployed in San Mateo and Milpitas, California; New Orleans, Louisiana; and North Miami Beach, Florida. In addition, a Wi-Fi mesh network spanning more than 600 square miles is part of a complete public safety communications system overhaul in Oklahoma City, Oklahoma.

Other cities that recognize the value of wireless broadband access have created mixed-use networks. Corpus Christi, Texas, for example, has deployed a network for automated meter reading, public safety, education, and public access.

All of these networks provide users complete mobility throughout the metropolitan-scale coverage area with no interruption of service.

Dense-cellular Wi-Fi mesh networks are enabling a wide range of mission-critical broadband applications in metropolitan-scale areas, including mobile database access, video surveillance, and geographic information system inquiries. Future networks will ride the rapid innovation curve of IEEE 802.11 and other standards-based technologies to provide economically viable mobile broadband with higher throughput and improved voice capabilities to millions of subscribers. ■

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