Wireless Design & Development

Cover Story

Mobile Wireless Connection Made Easy

Strategies to optimize transceiver range and mitigate congestion in metro WiFi backhaul include dealing with issues such as spectral efficiency, signal degradation and congestion control.

By Dr. Michael Nova

The growing popularity of metropolitan WiFi networks highlights the strengths and weaknesses of using a mesh architecture for WiFi backhaul. More broadband applications, such as VoIP, HDTV and streaming multimedia, are starting to share the ether with e-mail and web traffic, which means WiFi networks have to deliver more bandwidth with better QoS and roaming performance. The conventional solution is to add more nodes to handle more data traffic. A more cost-effective approach is to upgrade installed nodes, using software to substitute TDMA packet handling for CSMA at the MAC layer. The result provides higher throughput and better packet handling for mixed data and QoS services, and is ideal for metro WiFi backhauls.

Rather than relying on wireless hot spots, cities are starting to deploy metro WiFi to blanket the metropolis, providing WiFi coverage with continuous connectivity, similar to cellular phone service. However, the requirements for a metropolitan WiFi backhaul infrastructure are radically different than those of a conventional wireless office LAN. Wireless LANs are normally indoor, short-range infrastructures that deliver broadband using centralized wireless switch points instead of network cable. When you scale a wireless network to service a metropolitan area, the challenge becomes supporting a backhaul with sufficient bandwidth. Interconnecting outdoor access points (APs) normally becomes the most expensive part of deploying any metro-scale WLAN, which is why most metro WLANs use a wireless mesh approach to share the broadband load among nodes.

Factors that Dictate Mesh Performance

Wireless mesh allows APs to connect to other APs within their range to relay packets to the next access point to form the backhaul. This means a service provider can cover a wide area with no cost for each interconnection. Since the backhaul is wireless, additional access points can be added to improve performance as customer demand and traffic increase; backhaul and user traffic compete in a mesh environment so adding more mesh nodes increases overall bandwidth. However, the performance and scalability of any metro WiFi fixed backhaul network is limited by two key factors:

Estimated Savings from KMT
To demonstrate the potential cost savings realized from upgrading existing wireless mesh hardware with multi-channel TDMA routing software, consider the following:

Estimated network node density
- San Francisco estimates it needs 2000 to 3000 WiFi nodes to cover entire city (46.7 sq miles) or 43 to 64 nodes per square mile.
- Philadelphia's network planned by EarthLink reported to average 37 nodes per square mile.
- Mountain View, California estimates it will need 300 nodes to cover a portion of the city (the covered area was not quantified but the city is 12 square mile) or about 25 nodes per sq mile.
- Assume average density is 40 nodes per square mile.

Estimated cost per node
- Node units manufactured by Tropos are priced at about $3,300 each.
- A two-man crew costs $1000 per day and can install 5 nodes per day or $200 per node.
- 1 gateway per 10 nodes or 10% cost 23 to install or $400 per gateway (assuming a gateway node is priced the same as non-gateway node).

Estimated capital cost savings per square mile with KMT
- Influenced by level of voice and video traffic
- Influenced by user capacity
- Influenced by number of hops to gateway node
- Sample savings calculation per square mile assuming 30% of nodes are installed to handle capacity concern rather than range limitation: (40 3 30% 3 $3300) + (40 3 30% 3 $200) = $42,000.

Estimated operating and maintenance cost per node with KMT
- Electricity cost per node estimated at 18 W operating 24 3 7 at $0.10/kilowatt hour.
- Service cost estimated at hour per node per month at $75/hr.
- Replacement cost estimated at 2.5% per year.
- Sample O&M savings calculation per node: (18 W 3 24 hours 3 365 days 3 $0.0001/W) + (1/4 hour/month 3 12 months 3 $75) + (1 node 3 2.5% 3 $3500) = $329
- Estimated 15 year project life cost per node assuming general inflation at 5% discounted to present value at 10%: $3,300.

Determining the number of nodes needed for congestion control versus transceiver range will depend on project-specific conditions. The ratio will also likely to change over time as consumer familiarity and municipal WiFi use increases, and more demanding multimedia applications become common. Estimated savings per square mile are shown in Table 2 over a range of deployment conditions.

1) Transceiver range. Transceiver range establishes the maximum distance between nodes. Individual nodes can function as either gateway APs that provide wide area network (WAN) backhaul access or as non-gateway mesh routers that act as APs to local client devices but route to a gateway for WAN access. Both environmental conditions (topology, buildings, trees, node placement, sources of interference, etc.) and the type of radio hardware used (antenna type, radio power, etc.) determine the effective distance between nodes.

2) Congestion control. Congestion control ensures that no single AP becomes overloaded with data traffic. Congestion is a function of the number of simultaneous users and the type of data traffic a single node can handle. The type of data traffic is relevant since time-critical traffic that needs quality of service (QoS), such as voice, video, or multimedia data streams, are much more sensitive to congestion than other applications. When designing mesh networks you also have to engineer for maximum traffic capacity, taking into consideration traffic routed for other nodes as well as direct connections between APs. With higher user density, more nodes will be needed to reduce the distance between nodes in order to shorten the transceiver range, which of course increases the cost.

A New Approach to WiFi Data Traffic

The real challenge of deploying a wireless mesh is that the same spectrum has to be used for local data access as well as the backhaul. Sharing the spectrum can reduce overall capacity by as much as 50%. In unconstrained mesh architecture, traffic is routed based on higher level protocols and when a disruption in service occurs, the mesh finds alternative data paths. While this approach is very resilient, it also can consume available bandwidth, which affects performance, particularly for QoS applications.

There are ways to improve backhaul performance, such as using a point-to-point system with dedicated nodes for high-speed backhaul links, or deploying a constrained mesh that uses designated nodes to create a virtual point-to-point backhaul. Of course, controlling the backhaul path offers some control over network performance, but it is more expensive to install and does not completely allow for increases in overall user traffic.

Rather than installing more hardware, a better approach is to modify installed hardware with software that changes the way the MAC layer handles packets, adopting a time-division multiple access (TDMA) routing model instead of carrier sense multiple access (CSMA). The current 802.11/802.11e MAC is CSMA-based and is not scalable and throughput tends to drop off quickly as the number of data hops and distance between nodes increases. QoS in 802.11x is weak as well, since CSMA/CA can't guarantee traffic flow. However, by implementing Kiyon's 802.11 compliant multi-channel TDMA MAC (KMT), you can increase overall capacity and gain better multihop performance for each mesh node.

Use of KMT offers three benefits for a WiFi backhaul:
1) It increases the amount of usable bandwidth by improving use of the available 802.11x spectrum efficiency.
2) It provides dynamic routing to mitigate QoS issues, such as spatial bias (distance between APs) and
3) It uses a cross-layer MAC routing protocol that considers time slot availability in addition to link quality for greater overall efficiency.

Let's review each in turn:

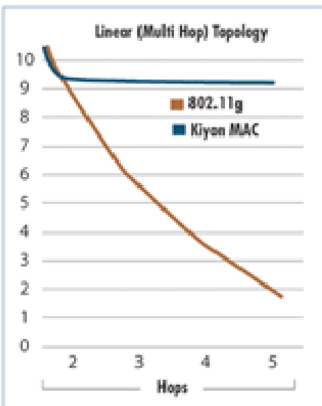
1. Improved Spectral Efficiency: Conventional WiFi uses one channel for all communications for all connections, but there are actually three non-overlapping channels available in the 2.4 GHz ISM band (802.11b/g) and many more for the 5 GHz (802.11a) ISM band. KMT makes all non-overlapping channels available for simultaneous use, which increases both the available bandwidth and the effective throughput by a factor of three or more. Consider that with conventional CSMA/CA, three separate WiFi devices would have to be connected to an AP using the same channel. With KMT, each device could have a dedicated channel.

2. Dynamic Routing: Logically, in a wireless mesh APs that are physically closer to gateway APs tend to have higher data rates than APs further away. To mitigate this spatial bias, most mesh hardware manufacturers statically limit the maximum data rate for users in order to reserve capacity for other nodes. Adopting dynamic routing eliminates the need for pre-set data rates for individual nodes. Instead, you can determine traffic conditions in real time and dynamically allocate bandwidth so any node can transmit at full capacity while other nodes are unused.

3. Cross Layer MAC Routing: Wireless mesh routing protocols typically operate at

Layer 3 and route based on link quality, rather than node availability. In a standard mesh architecture, some APs may offer better link quality and so quickly become congested during high traffic conditions, even when there are other pathways available.
Using cross layer MAC routing combines both link quality and time slot availability using information from Layer 2 for more efficient routing. And using a TDMA approach reserves time slots for time-restricted traffic, such as voice, video or multimedia data packets. preset data rates.

Applying KMT in a Wireless Mesh
Adopting KMT routing extends both the number of hops available in a wireless mesh and increases the overall efficiency of available bandwidth. Let's compare the performance of a WiFi AP using conventional CSMA/CA and KMT packet handling in the same device.



click to enlarge

Figure 1. Comparison of multi-hop throughput.

Figure 1 shows a comparison of multi-hop throughput and Figure 2 shows multi-client performance over a single hop. Clearly, the KMT offers higher throughput and more stable performance, no matter what the number of hops or users/clients.
Improving multi-hop performance (as shown in Figure 1) is extremely important in mobile networks and indoor networks, but in municipal WiFi networks, it also relieves demand for expansion base capacity. By substituting KMT on either single radio or multi-radio platforms, the entire network becomes more scalable since additional nodes can be deployed to extend coverage without adding new backhaul gateways.

Figure 2 demonstrates how congestion control can increase throughput. Let's assume that a typical municipal WiFi AP is designed to handle 200 users each day, with a diversity factor of 10% (which means only 10% or 20 users are expected to access that AP at any given time). As the number of TCP/IP users increases on the node, throughput declines, as shown by the red line. When the AP peaks with 20 simultaneous TCP/IP users, performance may be adequate for e-mail or web access, but running multimedia or voice may be difficult with so much background traffic.

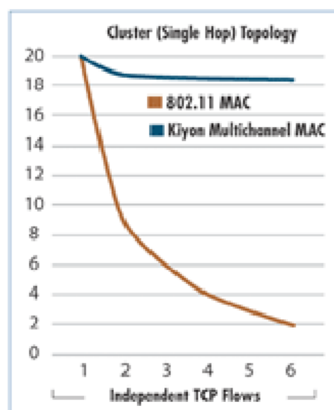


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Figure 2. Multi-client performance over a single hop.

Since traffic load is not evenly distributed across the network, some nodes are probably strategically placed to manage congestion control (as opposed to obviating transceiver range). Using KMT routing, bandwidth remains high, even as the number of data flows increases, because the TDMA scheme manages the data congestion by prioritizing traffic using multiple channels. And the TDMA software can improve performance for any hardware platform. The results in Figure 2 were achieved by testing on a consumer WiFi card (e.g., Linksys, D-Link AP) and show that with 12 users (six connections), bandwidth is approximately nine times greater using KMT. These values may differ with u

tility grade APs, but the relative improvement — a multi-fold increase in user capacity —should be comparable. Using KMT can significantly reduce the number of nodes deployed for congestion control.

Table 1. Simultaneous # Calls in 6 Hop Network with MOS ≥4.0

Background data traffic (UDP)

	45 Kb/s		1 Mb/s		3 Mb/s	
	TDMA Multi-Channel Channel MAC	Standard 802.11/11e Single-Channel MAC	TDMA Multi-Channel MAC	Standard 802.11/11e Single-Channel MAC	TDMA Multi-Channel MAC	Standard 802.11/11e Single-Channel MAC
Basic	16	1	12	0	8	0
PLC	28	6	26	0	20	0
SS	18	1	20	0	17	0
PLC +SS	48	16	40	0	40	0

PLC = packet loss SS: silence suppression (30% of activity)

click to enlarge

Table 1. Simultaneous # Calls in 6 Hop Network with MOS ≤4.0 Background data traffic (UDP)

Optimizing for QoS

The impact of poor QoS and low throughput in a WiFi mesh is a problem for time-sensitive applications, such as VoIP and streaming video, even when there are relatively few users accessing the network. If you have as little as 1 Mb/s of background traffic over a multi-hop connection with multiple users, it is impossible to handle QoS traffic such as VOIP (see Table 1). KMT improves performance for QoS traffic a minimum of three times, and often more. This means mobile users can access VoIP, IPTV, IP radio and other multimedia applications simultaneously over a municipal wireless mesh.

Table 2. Per Square Mile Savings Potential through Use of KMT

Congestion Control Nodes	Number of Nodes	Capital Cost	O&M (15 year life)	Total Savings
20%	8	$28,000	$26,400	$54,400
30%	12	$42,000	$39,600	$81,600
40%	16	$56,000	$52,800	$108,800
50%	20	$70,000	$66,000	$136,000

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Table 2. Per Square Mile Savings Potential through Use of KMT

Summary

So by utilizing Kiyon's 802.11 compliant multi-channel TDMA routing at the 802.11 MAC layer, a metro WiFi backhaul can be optimized to handle more data traffic and more types of traffic, from e-mail and HTML right up through high-definition video. It's a matter of taking advantage of all the data channels available, providing dynamic routing and implementing better QoS for time-sensitive applications.

About the Author

Dr. Michael Nova is founder, chairman and CEO of Kiyon, For additional information, visit www.kiyon.com

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