INSIDE CLEARWIRE: A NETWORK REPORT

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Inside Clearwire: An in-depth look at the network behind the nation's biggest WiMAX wireless deployment

Executive Summary

After a year of aggressive market launches across the U.S., Clearwire Corp. is becoming fairly well recognized for its pioneering use of the wireless broadband technology known as WiMAX, the "Wi-Fi on steroids" technology that allows providers like Clearwire to build "hotspots the size of a city."

While WiMAX's ability to provide broadband Internet access with cellular-like mobility is certainly the most recognizable attribute of Clearwire's deployments, there is a lesser-known but just as important level of innovation taking place inside the company's network, from the connections to the Internet's core out through the radio towers and down to the end-user devices.

Those internal-network achievements, including Clearwire's primary use of microwave for traffic "backhaul" and its open, Internet Protocol-based core infrastructure, are not only providing Clearwire with an instant competitive advantage, but are perhaps part of a burgeoning blueprint for next-generation service providers looking for ways to cut costs while providing bandwidth to a user base that is more demanding and more mobile with every passing day.

In this paper we'll take an in-depth look at how Clearwire's innovative implementations of both backhaul and core network infrastructure allows the company to build out its network more quickly and cheaply than its cellular predecessors, and how the company's broad spectrum portfolio gives it the ability to scale quickly to address the imminent explosion in demand for mobile Internet connectivity.

(Editor's note: While Clearwire executives and representatives, along with representatives of Clearwire's suppliers, were interviewed for this report, and while the report focuses almost exclusively on Clearwire's network, neither Clearwire nor any of its resellers or suppliers had any control in the writing or editing of the report. What follows is an independent, objective in-depth look at Clearwire's internal network, and how its use of innovative technologies and open architectures might benefit Clearwire and other service providers who might follow a similar deployment path.)

While Clearwire undoubtedly faces huge challenges in trying to get consumers to subscribe to its nascent national WiMAX network -- after all, its main competitors, namely AT&T and Verizon, will likely spend more in a year on who's-your-daddy competitive TV ads than Clearwire will be able to spend building out its actual network -- it is apparent now that at least for the next two years Clearwire has enough captial funding to complete the first phase of its network buildout.

Clearwire antenna tower in Las Vegas

That plan in 2010 will add New York, San Francisco and Los Angeles to a market list of 30-plus cities that currently includes Chicago, Philadelphia, Dallas/Fort Worth, Portland, Ore., Las Vegas and Atlanta, among others. A new round of $2 billion-plus in funding in late 2009 provided mainly by major shareholder Sprint Nextel, along with previous investors Comcast and Time Warner Cable means that **while still a longshot, Clearwire enters 2010 on solid financial footing, with a year of market-launching experience under its belt.**

While Clearwire continues to tweak its go-to-market strategy as it launches services in new cities -- the company seems to constantly change pricing and plan bundles to find an attractive combo -- two things remain in place that were there from the start: A commitment to primarily use wireless microwave technology to "backhaul" Internet connectivity from the core network to the radio towers, and an open, IP-based network infrastructure that is allowing Clearwire to break the monopoly pricing stranglehold held by providers in the classic cellular infrastructure gear-supplier markets.

Of these two, the use of microwave for backhaul is undoubtedly a huge change of pace, so much so that Clearwire has had trouble finding enough qualified technicians to build out its networks in a timely fashion. On one hand, it's easy to understand why since microwave-based wireless transmission is historically seen as a less-reliable choice for connectivity than a wire or a strand of optical fiber. But Clearwire's conservative approach (it uses a mesh-type deployment where each tower has at least two wireless paths back to the core) seems to be working well, and it may be imitated by more providers going forward since the use of microwave backhaul can significantly speed up tower deployment simply by eliminating the need to dig trenches for cables and fiber.

On the network infrastructure side, the economic and innovative power of an open IP architecture model is very familiar to anyone who knows the history of enterprise

networking. In that business sphere the advent of open networking protocols in the 1990s (chiefly the Internet protocol, TCP/IP) helped enterprises move from the expensive, proprietary protocols and gear of the IBM/DEC past to the highly competitive, much cheaper and more flexible world of the open network model, championed by the likes of Cisco, Nortel, 3Com, Hewlett-Packard and others.

Instead of being able to "lock in" enterprises with their proprietary protocols (which would only work with gear from a single manufacturer), network equipment vendors in the era of TCP/IP were instead forced to compete on innovation and pricing, a change that led in part to the tremendous era of networking technical innovation and reduced equipment prices the networking industry has witnessed since TCP/IP became mainstream.

When cellular-based data services emerged, the highly complex nature of the infrastructure (which had to convert data packets into signals that could be transmitted by the voice-centric cellular networks, and vice versa) led to a return to the lock-in phenomenon, where one supplier (chiefly big providers like Ericsson, Alcatel-Lucent and Nokia Siemens Networks) provided end-to-end gear deployments that promised service providers dependibility and reliability in exchange for a premium price.

Inside look at a Clearwire tower cabinet. (Credit: Sidecut Reports)

Since its network was built from the ground up designed chiefly for data (and not circuit-switched voice communications), Clearwire started out in 2004 with a much smaller infrastructure footprint -- since it doesn't need the complex switches the cellular carriers use to translate between circuit-switched voice and packet-based data traffic, Clearwire's tower sites often need only a refrigerator-sized equipment cabinet, as opposed to the small houses needed to host the typical cellular provider's tower gear. And by adhering to an open, standards-based approach for its network -- and rewarding vendors who comply -- **Clearwire is breaking the monopoly of single-supplier architectures**, which should ultimately mean lower prices and more innovation if the 4G service-provider market follows the classic open-standards development curve.

Topping off such innovative approaches is Clearwire's crown jewel, its massive spectrum position at the 2.5 GHz band. Unlike the cellular providers, who are already testing the limits of their spectrum positions with their 3G deployments, Clearwire's average spectrum depth (the amount of bandwidth it has in any given market) is around 150 MHz per market, a number anywhere from three to seven times as large as the holdings for AT&T and Verizon in major markets across the country. While not yet fully exploited, **Clearwire's spectrum position gives the company plenty of running room for future bandwidth demands** as well as the ability to scale quickly and add capacity to existing networks without having to "split cells" or add additional towers to relieve network stress.

Other future attributes that Clearwire is building into its network today include the ability to support "off the shelf" WiMAX devices that might include WiMAX-enabled cameras, automobiles, or machine-to-machine devices like "smart" power meters. Clearwire is also already working with device and application developers who are interested in using the company's open application programming interfaces to network attributes like location, presence and preference, setting the stage for a future where devices and applications might make use of the network's knowledge to offer services directly connected to where a user is and what that user might want to do.

If and when such hyper-connected devices and applications emerge will depend in part upon Clearwire's ability to survive as a business in the increasingly competitive world of wireless broadband services. Let's take a closer look now at how Clearwire's currently deployed innovative strategies might help give the nascent national WiMAX provider a business edge in both cost savings and time-to-market deployment speed.

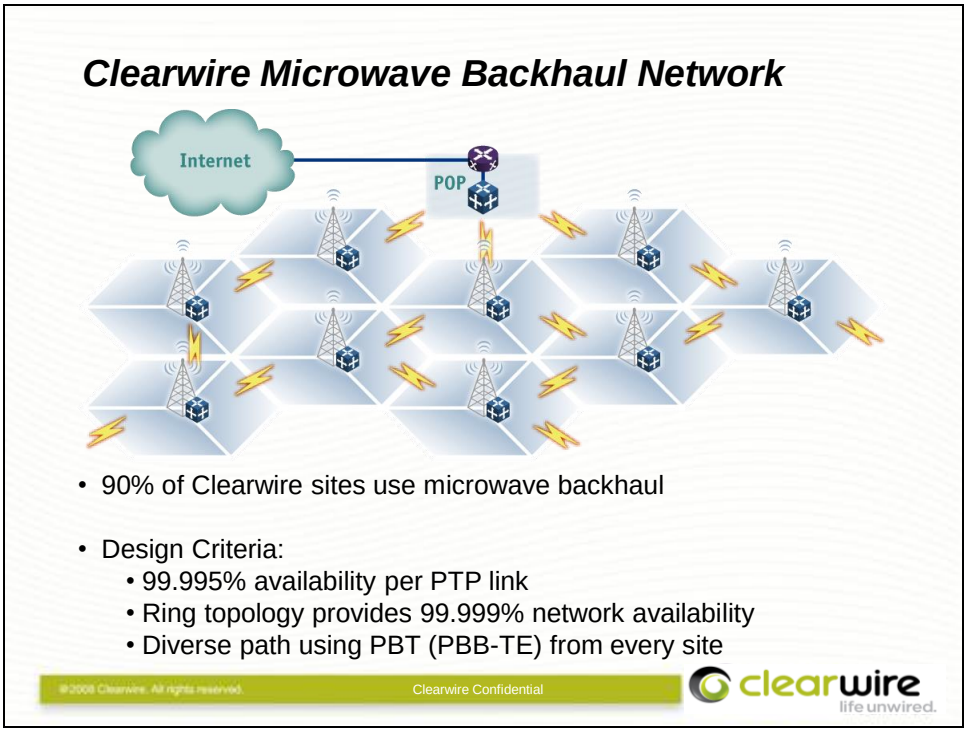
BACKHAUL: THE BACKBONE OF THE NEW NETWORK

Though its funding comes in chunks of billions of dollars, in the world of telecom Clearwire is a scrappy startup -- an underfunded underdog that is forced to improvise and invent new rules to play against the telecom titans whose advertising budgets alone dwarf Clearwire's yearly captial expenses. On Clearwire's side, however, is an impressive swath of wireless spectrum, and the power of using open, standards-based Internet Protocol (IP) technology at its base to produce economies of scale and to promote competition among its suppliers.

"When you have no money, and you're a small company, and you are desperate to differentiate yourself, you'd be amazed at what you can come up with," said Dr. John Saw, Clearwire's Chief Technical Officer who has been with the company since its inception -- his bio notes that he was the company's second employee hired. "The nice thing about Clearwire is that the first day on the job, I had no legacy network to worry about," said Saw, a veteran of AT&T's wireless operations before joining Clearwire. "Craig [McCaw] told me let's not make the same mistakes that were made before."

One of the places Saw and Clearwire started innovating right away -- and this was starting when the company was launched in 2004 -- was to figure out a better way to do "backhaul," the term associated with bringing bandwidth from the Internet to the radio towers. "From the first day we built the company we started asking what we were going to do with backhaul," Saw said. In the buildout of previous cellular infrastructures, most carriers used a pair of T-1 lines -- about 1.5 Mbps of bandwidth in each -- to provide connectivity to their towers.

"That's enough [backhaul] to carry narrowband voice traffic, but we know that a couple of T-1s is insufficient when you have a lot of bandwidth needs," Saw said. "If your iPhone is slow, it might be the fact that AT&T's backhaul is completely full." Indeed, AT&T announced in January of 2010 that it had spent the past year putting in an additional 13,500 T-1 lines into just San Francisco and New York -- among the most congested of its 3G markets -- along with 238 new optical backhaul lines.



Clearwire microwave backhaul network design (credit: Clearwire)

Clearwire's early calculations on user demand, Saw said, led the company to believe that it would need conservatively to provide 30 Mbps to 50 Mbps bandwidth to each of its towers -- "That's 20 T-1s, or else you are going to need to bring optical fiber to the sites," Saw said. While optical fiber connections could certainly support such bandwidth needs, Clearwire had two expensive problems in the way of using that approach: The

cost of trenching the physical fiber to each tower location (which typically involves digging up streets) and the cost of metro fiber facilities and fiber-based services. Instead, the newest wireless broadband provider looked to the air when it came to its own backhaul needs -- using technologies based on microwaves, which have long been used to transmit television programs, long-distance phone calls and other communications traffic.

"We didn't do this because we wanted to be different, we did it because we had to," Saw said. "Clearwire does not own any fiber facilities, so **we put a strong and heavy emphasis on microwave backhaul**."

A big problem, especially in 2004 when Clearwire started its initial buildout, was that there were no vendors in sight with the equipment Saw wanted -- a microwave radio that spoke Ethernet, so that the company could keep its flat, IP-based architecture intact.

"When we asked for an Ethernet-based microwave radio, 5 years ago nobody even knew how to spell that," Saw said. After many frustrating meetings, Saw and Clearwire finally found the Canadian firm Dragonwave, whose Ethernet microwave radios fit the bill. Saw and Clearwire used those radios to build what he describes as a "flat Layer 2 mesh network," where cheap Ethernet switches at each tower site help establish a network that doesn't have a single point of failure.

Microwave antennas on a Clearwire light pole tower site, Portland, Ore.

"What we do is basically switch those microwave packets around, so that every cell site has more than one path back to the data center," Saw said. "They are very low cost Layer 2 Ethernet switches, but they are very intelligent and will automatically switch traffic around with intelligent failover. It's far cheaper than any cell site switches used for 3G today."

Though Clearwire hasn't yet launched enough networks or attracted enough users to know how the microwave setup will really perform under strain, Saw said its implementation seems to be a harbinger of the future, since now many vendors are offering Ethernet microwave radios.

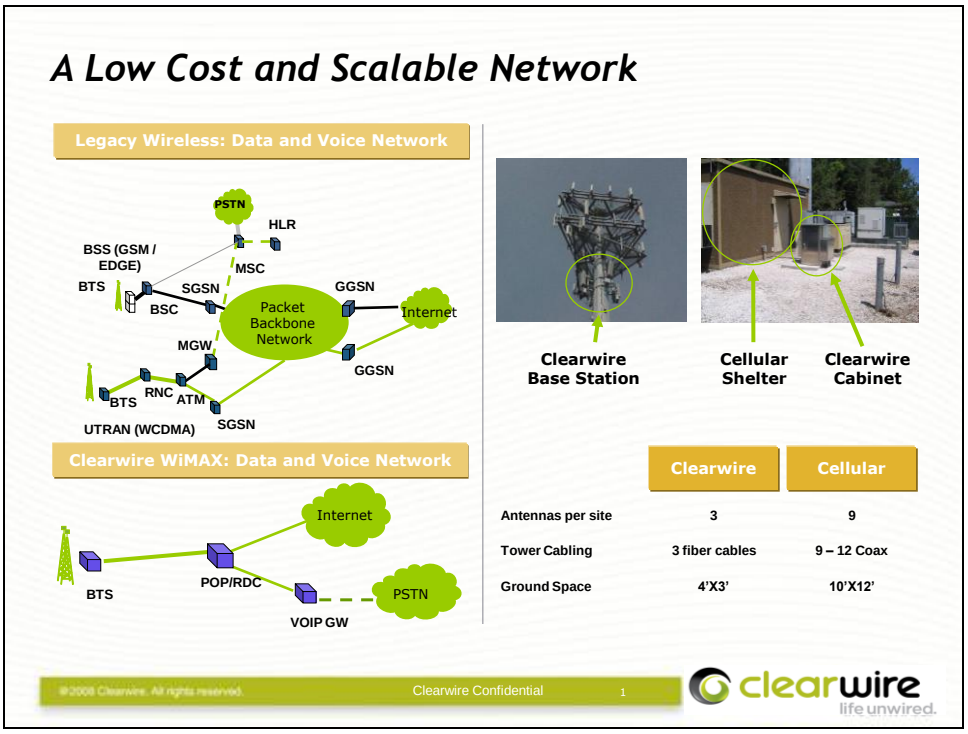
"What nobody knows is that by being a wholesale backhaul service provider to ourselves, we're probably one the the largest in the world on microwave," Saw said.

OPEN IN THE CORE MEANS COMPETITION AND SAVINGS

If you follow the cables down from the antennas on a typical "3G" cellular tower, they almost always end up leading into a building the size of a largish tool shed or a small garage -- typically a 10-foot by 12-foot (or larger) enclosure that houses all the complex gear necessary to process, separate, administer and manage the phone companies' mix of voice calls and data traffic.

Since Clearwire is building a data-only network, its tower-site infrastructure needs are much simpler than cellular. To house a typical Clearwire tower site's power needs, microwave backhaul, WiMAX antenna gear and an Ethernet switch takes merely an enclosure the size of a large refrigerator, sitting on a 3-foot-by-5-foot space.

With far less gear than a comparable cellular site, Clearwire's Saw said his network is



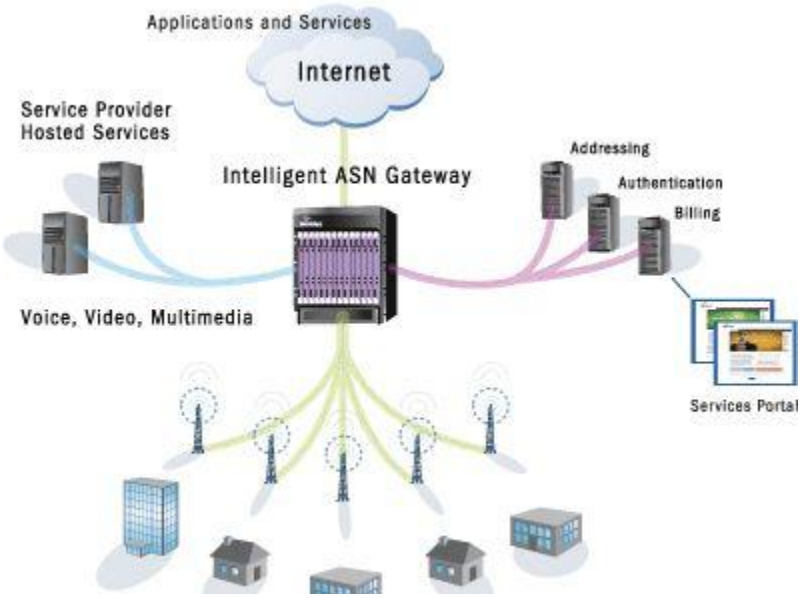
Clearwire network layout compared to a "legacy" wireless data/voice network. (Credit:Clearwire)

not only obviously cheaper to operate but also more flexible, allowing for quicker and closer deployment toward its customer base. "Where cellular providers get in trouble is trying to shoehorn a packet network into a network built for another purpose," said Saw. "That's why you have to put in boxes like a GGSN [a Gateway GPRS Support Node,

which supports traffic conversion between the cellular network and the packet networks of the Internet], which cost an arm and a leg -- and they also impair performance. Nokia and Ericsson make a killing selling those boxes. Those are very expensive boxes."

According to both Saw and Barry West, Clearwire's president of International operations (and the former head of WiMAX operations at Sprint Nextel before its merger with Clearwire), a typical WiMAX network is about eight to 10 times cheaper to build than a 3G cellular network covering the same area.

"Our average cost number per cell site, when you add in all the backhaul access, zoning costs and everything else, is less than $150,000 per site -- and the real number is actually much lower than that," Saw said. "You'll never get a cell site at that cost for 3G. What we have done on the network side is the lowest cost approach we could get to." The small costs and size of Clearwire's tower deployments also help the company in putting its network closer to where its users are.



Where an ASN Gateway sits in a wireless network. (Credit: WiChorus)

According to Saw, early lessons Clearwire learned from active WiMAX networks shows customers "using more bandwidth than I've ever seen in my years of working with wireless networks" and that they are using these mobile services primarily indoors, where they work or or live. "No longer is mobile broadband limited to what you would call the road warriors," Saw said. "So I need to be very accurate in where I put my cell sites, to cover the right demographics, the right neighborhoods."

Clearwire's lean tower site infrastructure, Saw said, allows the company to "piggyback" on existing cellular installations -- "since we use fiber to the antennas, not coax, we don't weigh down the towers," Saw said. "I can go to tower guys who say they have no more ground space and show them that we can just squeeze our cabinet in the corner. Same for rooftops. Our implementation allows us to site in a lot of creative places, where you might not otherwise be able to get a cell site in."

Inside its network, Clearwire also embraces an openness that will allow it to reduce costs by introducing a competitiveness not typically found in cellular networks. In the latest implementation of the WiMAX standard, **there is a model that calls for true open interfaces between infrastructure gear, like base stations, radios, and administrative equipment** like the Access Service Network (ASN) gateway, the workhorse box of a WiMAX network that aggregates and distributes a wide range of subscriber-related data, from session management information, billing data, traffic and mobility management, quality of service and other administrative functions.

In cellular 2G or 3G data implementations, Clearwire's Saw said that a single vendor almost always provided all the different pieces of gear needed, often at a premium cost. "What we wanted to do with Clearwire was break the monopoly between the base station provider and the gateway provider," Saw said. "**In a 3G network these are always supplied by the same vendor**, making you beholden to a Nokia or an Ericsson. Even though the spec says they are supposed to talk to other companies' products, they do not interact."

Clearwire tower site equipment cabinet, front; Cellular provider equipment building, rear. (Credit: Sidecut Reports)

To win a contract for Clearwire's new IP-based network, however, means that vendors must comply with the open interfaces requirements. "What that really means to Clearwire is that we can buy base stations from Motorola, Samsung or Huawei, and we don't have to be beholden to also buy their ASN gateway," Saw said. "I can go find a really low-cost ASN gateway from someone who makes ASN gateways for a living and get a really good price -- say from WiChorus, Starent or some Taiwanese company in the future who wants to build one as cheaply as possible. What this means is that the cost of my core network is going to drop considerably."

Bruce Brda, senior vice president and general manager of the wireless networks business at Motorola, said that opening up such internal interfaces inside a cellular network allows Clearwire to act as its own system integrator, which could produce cost savings and spur product innovation.

"These interfaces have never been open before -- now the carriers like Clearwire have the ability to mix and match," Motorola's Brda said. "It's great to have a clean slate, and to have the flexibility to pick the best vendors for the best elements. The downside is control, in how you manage and debug a disparate network. That's a challenge."

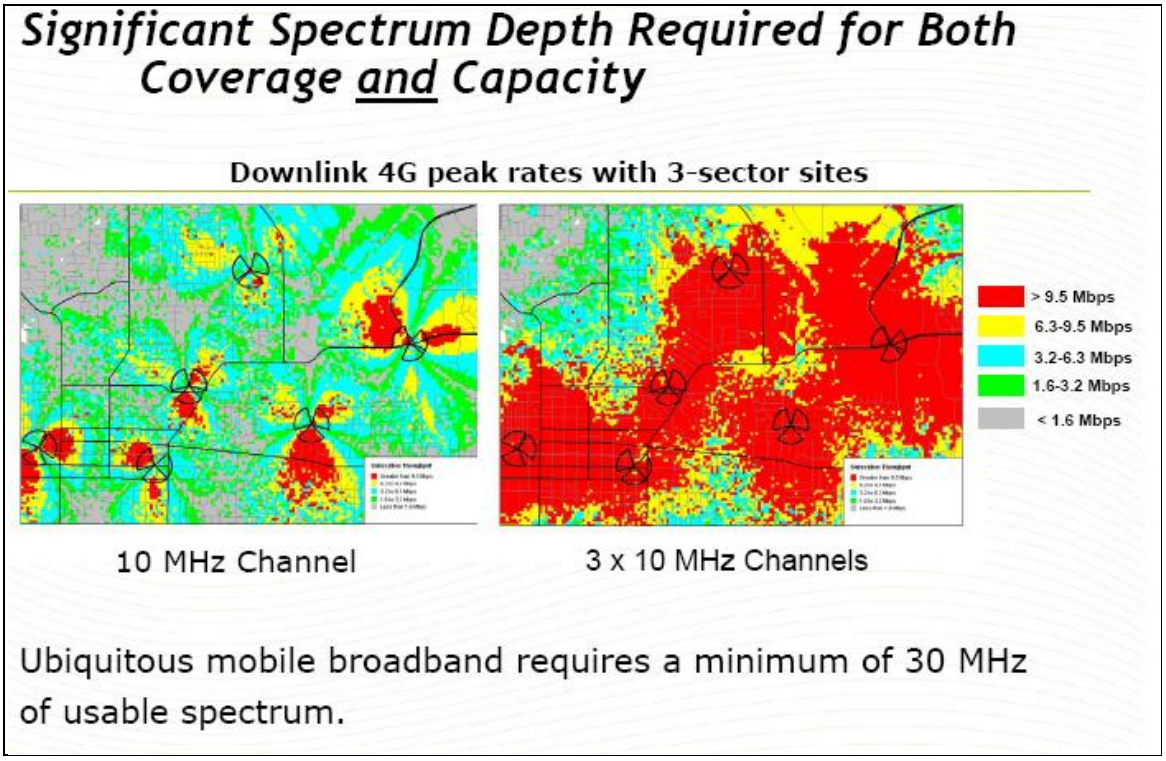
But Kittur Nagesh, director of service provider marketing at Cisco, said the positives outweigh the negatives when it comes to combining gear from different vendors. "**In some sense you can say Clearwire is now able to pick the best of breed to meet their specific needs**," Nagesh said. "Right now they have transport and Layer 4 to 7 gear from Cisco, and ASN gateways from WiChorus. When it's done right you can actually combine the best of breed from multiple companies."

"It's a big step for us to open up the interfaces, but I really believe we have to have an open network, open in many ways," Clearwire's Saw said. "Vendors like Ericsson have been very successful, charging carriers a lot of money for gear. But I think you will start to see a lot more of what we're doing in the 4G world."

MORE SPECTRUM MEANS MORE BANDWIDTH

For wireless network providers, there may be no more important asset than broadcast spectrum -- the airwaves used to transmit signals from tower to user. While Wi-Fi networks in the U.S. are typically run over "unlicensed" spectrum in a sort of free-for-all, cellular providers and WiMAX providers like Clearwire use licensed spectrum bands, reserved parts of the ether gained either via government auctions or through licensing agreements with spectrum holders like schools, universities or other entities.

Though there are many complex nuances regarding wireless spectrum and data networks, a simple rule of thumb for carriers is that the more licensed spectrum depth



Clearwire map showing how spectrum depth affects coverage and capacity. (Credit: Clearwire)

you have, the more bandwidth you can provide. And when it comes to spectrum holdings, Clearwire currently has almost twice the total spectrum depth of either AT&T or Verizon, and has as much as five to seven times more depth than the larger carriers in the spectrum bands that each will use to carry its so-called "4G' network traffic.

Some quick caveats and explanations: Comparing wireless spectrum assets is not exactly apples to apples, since the spectrum AT&T and Verizon plan to use for their Long-Term Evolution (LTE) networks is in the 700 MHz band, while Clearwire's entire spectrum portfolio is in the 2.5 GHz band. An entire research paper discussion could take place arguing the merits and flaws of each band -- the 700 MHz spectrum, for example, is regarded as being able to support better in-building reception than the 2.5GHz band, but its power may also make it harder and more expensive to manage when it comes to interference issues. For the purpose of this paper, we will assume an even comparison of spectrum slices since the main concern here -- providing bandwidth to end users -- is roughly the same for both technologies, LTE and WiMAX, and for the 700 MHz and 2.5 GHz bands.

The most-often overlooked or misunderstood element of the spectrum discussion is the idea of spectrum "depth," which like frequency is measured in megahertz. The "depth" of a provider's spectrum holdings comes from the fact that the shorthand used to

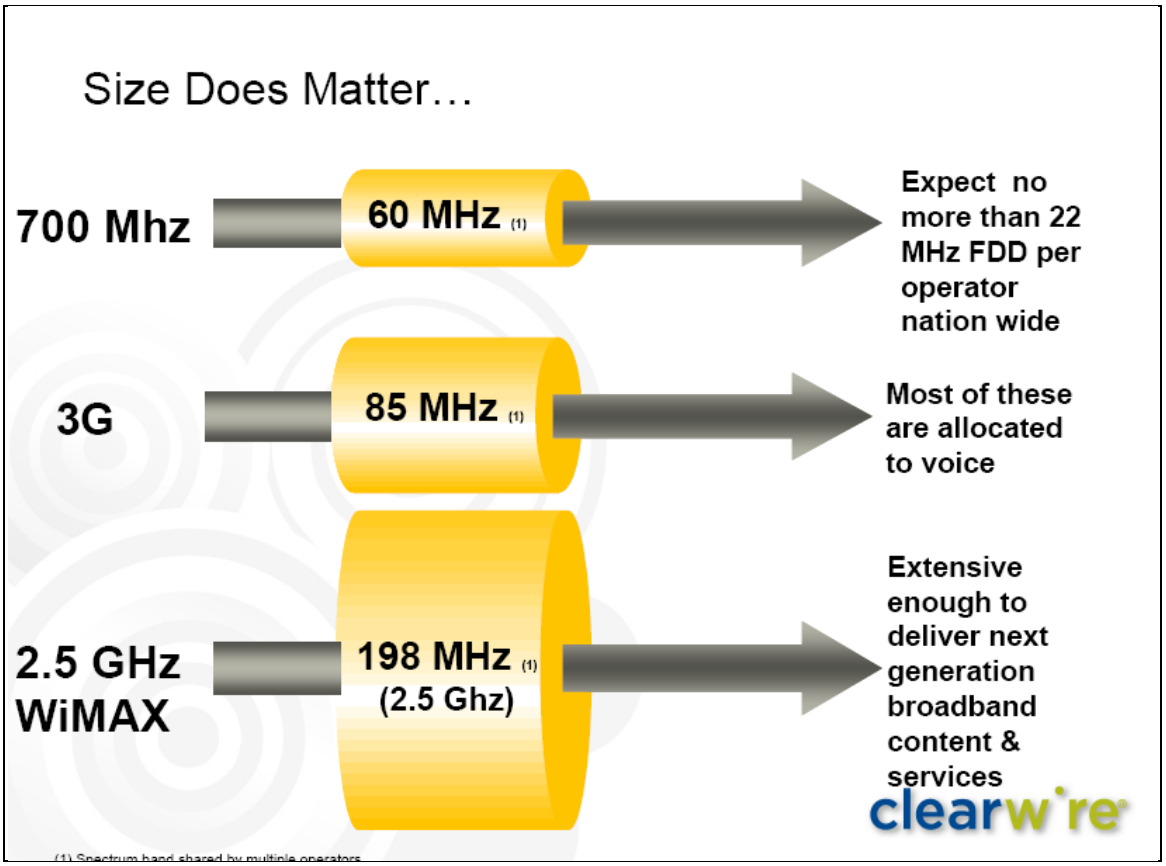


Diagram showing the relative amount of spectrum depth for different frequencies. (Credit:Clearwire)

describe the different "bands" -- as in 700 MHz or 2.5 GHz -- doesn't fully explain that each "band" contains many different frequency channels; the 2.5 GHz band, for example, actually includes frequencies from 2496 MHz to 2690 MHz, while the recently auctioned bandwidth in the 700 MHz band includes frequencies from 696 MHz to 806 MHz. Depending on how the spectrum was sliced for distribution, companies can compile spectrum "depth" -- as in chunks of those frequencies -- for their delivery portfolio.

Clearwire, which built its spectrum assets through direct license acquisitions and also via its 2008 merger of WiMAX assets with Sprint Nextel (which had a large license portfolio at 2.5 GHz), **has approximately 150 MHz of spectrum "depth" in most U.S. markets**. AT&T and Verizon, the biggest spenders in the government's auction at 700 MHz, have between 24 MHz to 30 MHz nationwide depth each in the 700 MHz band, a figure somewhat murky since neither company provides exact details of its spectrum holdings. AT&T and Verizon also hold spectrum at other frequencies for cellular, but both have said that 700 MHz will be their primary frequency for "4G" LTE services.

The spectrum depth matters most when it comes time to bring bandwidth to users -- simply put, **the more spectrum you have, the bigger "pipes" you can provide to potential customers**. Called "channels" in the wireless industry, both WiMAX and LTE can use channels of 5 MHz or 10 MHz in size, with the bigger number offering more bandwidth and support for more users per tower. By having such a large spectrum portfolio, Saw said that Clearwire can easily add capacity by just adding more frequency "channels" in any given market -- something Verizon or AT&T won't be able to do given their more-limited portfolio.

"Right now I assign a 10 MHz channel on each of three sectors per tower, which provides a very good ratio for reducing interference," said Saw. "So that's 30 MHz being used already. But I have up to 12 channels of 10 MHz each that I could deploy in any given market -- so if I need to add capacity in a given area, I can just keep adding channels. This is something Verizon will never be able to do."

Since neither Verizon nor AT&T has an operating LTE network yet, it remains to be seen how the companies will manage performance versus spectrum availability -- one way to conserve spectrum is to slow down the bandwidth speed per user. Another way to manage spectrum is to "split" cell sites, which means adding more towers closer together so that users aren't competing for the same antenna. However -- if you remember the earlier discussion of the costs of building, siting and supporting towers -- splitting cells isn't for the weak of wallet.

"Clearwire has enough spectrum to let me stack new channels all day long on our existing towers, without having to split my cells," Saw said. "When you start splitting cells, capital expenditures go through the roof because you are bringing in new towers and everything else that goes with them."

Motorola's Brda said that the relatively small slices of spectrum AT&T and Verizon have at 700 MHz may force the big carriers to be more creative with their 4G deployments.

"I don’t think the traditional mobile carriers have enough spectrum to meet all their needs," Brda said. "They're going to have to mix and match spectrum for solutions."

Both AT&T and Verizon have said publicly that they plan to use their currently dormant AWS (Advanced Wireless Services) spectrum (at around 1700 MHz and 2100 MHz) to "help" with LTE services; however, such solutions also introduce more radios and more power consumption to user devices, for added costs and performance drain.

Clearwire, on the other hand, has been reportedly contemplating "renting" some of its spectrum to another provider (the most-repeated rumor involves T-Mobile USA), and has publicly said that it has the ability -- should the need or demand arise -- to build a separate network for LTE side-by-side with its WiMAX network.

"Some people miss the fact that Clearwire has 150 MHz in most markets and they're only using 20 or 30 MHz right now," Cisco's Nagesh said. "With their next generation mobile architecture and core, they're not limited to just having WiMAX."

FUTURE: MORE OPEN, MORE POSSIBILITIES

For the rest of 2010, Clearwire's operational focus will no doubt still be centered around launching new markets (including San Francisco, New York, Boston and Los Angeles), and increasing adoption by users in its existing coverage areas. But internally, its networking operations are building hooks for a potentially even more open future, one that might include support for independent, off-the-shelf WiMAX devices as well as third-party applications that make use of Clearwire network attributes like location, presence and quality of service.

Sprint's "Overdrive" hybrid 3G/4G portable Wi-Fi hotspot. (Credit:Sprint)

The open-to-any-device theme is one often repeated in theory by WiMAX promoters and marketing groups like the WiMAX Forum: Basically it says that since WiMAX is an open, published set of standards, manufacturers could theoretically build network-ready devices, test them in a certification lab and allow them to connect to Clearwire's network -- without Clearwire having to do any certification, testing or approval of its own. While such devices are probably a year or so away from delivery, Clearwire's Saw said the network will be ready for the devices if and when they arrive.

"This is something the wireless industry has never seen before -- a device that you certify through a lab, and sell through a Walmart," said Clearwire's Saw. "That requires a very robust activation and provisioning ability on our networks. We do have the capability, but we haven't seen a lot of devices yet."

Some of the device drought has to do with the fact that Clearwire simply doesn't have the millions-strong kind of market-coverage or user numbers to get consumer device manufacturers extremely interested. Yet.

"The example everyone gives [of a potential WiMAX-ready device] is a camera," Saw said. "But you don't build a camera specifically to get onto a WiMAX network." However, should a camera manufacturer so desire, it could perhaps "strike a small deal" with Clearwire to support instant uploads of pictures or videos that could be shared instantly. Amazon's Kindle operates under such a fashion, with the cost for connectivity built into

the price of the content downloads. "It's a challenge for us to ensure such devices can be authenticated and authorized," said Saw. "But in the name of trying to open up the network to the mobile Internet, we think we need to do things like that."

Also in the yet-to-be-tested category are Clearwire's proposed open network application programming interfaces, programming hooks into network features like user location, user activity or quality of service -- which could theoretically allow third parties to offer network-aware services and applications (say, the ability to order a pizza from a restaurant that knows you are nearby) in concert with Clearwire's WiMAX network.

Cisco's Nagesh, whose company is one of Clearwire's core-network suppliers, said such open APIs could be the fuel for much future innovation, once developers start realizing that mobile Internet users could be part of their new market base.

"The creativity of the mobile Internet has not yet been unleashed -- all we've really seen is the tip of the iceberg," Nagesh said. "Once you have true open networks, with open APIs into attributes like location and security, developers will be confident they are writing for networks, and not just a single device. Clearwire has shown a lot of leadership here, because they have thought well beyond a WiMAX-only device. Their network will eventually support a lot more capabilities than just pure transport."

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