Microwave Backhaul Radios Meet the Evolving Traffic Challenge

Alan Solheim

Article

February 4, 2013

Smart phones and tablets are driving the insatiable demand for bandwidth in mobile networks. End users expect content-rich applications such as Web browsing, gaming, video streaming, and interactive maps to be available on any wireless device, transforming and often overwhelming today's mobile networks.

The mobile network capacity gap keeps increasing despite the adoption of LTE with more bandwidth and improved spectral efficiency.

The mobile network capacity gap keeps increasing despite the adoption of LTE with more bandwidth and improved spectral efficiency.

Much of the industry's focus has been on radio access technology, with the expectation that the evolution from 3G to HSPA+ to LTE will satisfy the demand. But advances in spectral efficiency, coupled with aggressive liberalization of new spectrum for mobile applications, still fall short of meeting capacity demands (Fig. 1).

Spectrum limitations in the radio access network (RAN) mean that the maximum capacity per cell site is limited, and the only way to further increase the bandwidth supplied to each user is to increase the density of cell sites. This approach reduces the number of users per cell site and allows each user access to a larger portion of a cell site's capacity. To achieve this, operators are adopting Wi-Fi offload and small-cell deployment strategies.

The new network realities of higher cell-site capacity and higher cell-site density are dramatically changing backhaul requirements. First, the data format has changed from T1/E1 interfaces on 2G and 3G basestations to Ethernet interfaces, forcing a move to all-IP (Internet protocol) backhaul technologies. Second, the capacity per site is increased to several hundred megabits per second, driving the need for higher-capacity radios or the move to fiber-based backhaul.

At the same time, the maximum-to-minimum bandwidth ratio has increased, allowing for the potential advantage of statistical multiplexing. To take advantage of this statistical multiplexing gain, however, traffic from several basestations first needs to be aggregated with multi-gigabit capacity in the aggregation layer.

The higher density of cell sites can lead to different deployment scenarios that could dramatically change the backhaul requirements. If a green field network were deployed with small cells, then a more uniform backhaul technology could be deployed. Typically, though, the macro layer is deployed first to achieve coverage in a given market (or an earlier generation of macro layer basestations already exists), and then the small-cell layer is deployed as a fill-in to increase network capacity.

This drives us to a tiered network architecture with some level of aggregation both at the street level and at the macro level. The requirements for backhaul are markedly different in these two tiers. In the macro layer, the capacity is foremost in importance. But at the street level, the form factor is the principal driver. Different products, then, are required to optimize the two layers.

Higher-Order Modulation

There is a lot of activity among vendors to extend the capacity and spectral efficiency of microwave systems by moving to higher-order modulations including 1024, 2048, and even 4096 quadrature amplitude modulation (QAM). Recent deployments using 2048 QAM technology produced a 37% capacity increase over existing 256 QAM systems with no incremental hardware or spectrum.

As with most technology enhancements, higher modulations come with performance tradeoffs in the form of reduced link budgets. This is mitigated with intelligent adaptive modulation technology, which allows the system to switch to lower modulation, at a reduced throughput, during a fade event such as heavy rain. Given that fade events generally only impact lower-priority traffic for a few hours per year, most operators welcome the opportunity to cost effectively add capacity to their network.

XPIC

Cross Polarization Interference Cancellation (XPIC) technology allows for vertical and horizontal transmission over the same channel, doubling the link's capacity without adding new spectrum. While XPIC requires additional hardware, it's particularly useful in regions with high spectrum costs and limited availability.

Multi-Carrier Radios

Another significant development in microwave technology is the introduction of multi-carrier radios, which can transmit multiple channels from a single radio and antenna. A two-channel system can therefore carry twice the traffic without adding additional hardware and with only a minor impact to link budget. This technology is most widely adopted in regions where spectrum is readily available and affordable.

The regulatory environment also drives adoption. For example, in places such as India where a carrier is given a certain number of frequency spots, dual-carrier operation can provide equivalent spectral efficiency to XPIC in ring structures (since you cannot reuse the same carrier frequency on adjacent legs of the ring with XPIC due to interference).

Data Optimization

Some microwave backhaul systems can employ a combination of white space suppression, wire-speed bulk compression, and header optimization technology to significantly enhance the efficiency of transmission. Compression algorithms used in these networks function much like those found in today's file compression tools, substituting patterns in the payload and header data with shorter symbols. Depending on the compressibility of the traffic mix, data optimization technologies typically result in a 40% increase in capacity with gains up to 100% possible under certain conditions.

Wider Channels

In regions like the U.S. where spectrum availability is good and new spectrum is being made available, particularly in bands above 24 GHz, operators have the opportunity to use wider channels up to 112 MHz. This provides double the capacity of 56-MHz channels without the need for additional hardware investment and with no impact on link budget. In the case of millimeter-wave technologies (60 to 80 GHz), much wider channels (up to 1 GHz) are possible, allowing for high-capacity (albeit shorter-range) links that are well suited to fiber extension and certain small-cell backhaul applications.

MIMO

Multiple-input multiple-output (MIMO) wireless technology, which is widely deployed in access networks, holds promise in point-to-point microwave systems. By using multiple transmitters and receivers, MIMO leverages multi-path transmission to increase overall throughput by combining multiple signals. This is accomplished without the need for new spectrum. MIMO systems do, however, require an additional antenna and radio per link end and must have sufficient space diversity on the tower to achieve the desired multi-path effect.

A Combined Solution

Multiple technology improvements can be used to greatly boost microwave backhaul capacity.

Multiple technology improvements can be used to greatly boost microwave backhaul capacity.

The combination of these technologies can deliver the link capacities required (Fig. 2). However, the added cost and complexity means they will only be added when and where they are required. Increased capacity also usually comes at the expense of signal-to-noise ratio (SNR), though, which implies shorter path lengths. Here, we have a couple of factors that can mitigate (but not remove) this consideration.

Mobile sites in different regions face various levels of capacity challenges.

Mobile sites in different regions face various levels of capacity challenges.

Not all the sites have the same capacity requirements, as can be seen in the results from a recent network design for a North American metro (Fig. 3). Most of the sites that need the increase in capacity are located in the urban core, where the average path length for the radios is shorter than in the suburban and rural areas. What's more, with the move to IP-based backhaul, the links can take advantage of adaptive modulation to deliver the highest capacity possible under all environmental conditions.

Small-Cell Considerations

Now consider the small-cell network requirements. A closer look at microcell requirements illuminates that what's needed for deployment at the pole very much depends upon the type of network being built. For example, the use of fiber is assumed in many of the microcell or distributed antenna product designs, yet the reality is that very little fiber is available at the light pole or lamp post for backhaul. Hence, a wireless backhaul option is required in the vast majority of situations.

As a result, hardware is needed to convert the Ethernet signal from the basestation to the wireless frequency, as well as some sort of antenna structure. The hardware and antenna need to be packaged in something that is visually pleasing and, preferably, looks nothing like a microwave radio.

Another consideration is network topology. For star configurations, where each pole-mounted microsite is connected directly back to a macrosite or fiber point of presence, the equipment required at the pole is quite simple: a basestation, either a wireless or fiber backhaul link, a battery backup (if required by the operator), and an aesthetically pleasing environmental enclosure that meets municipal zoning requirements.

The problem with this network topology is that the hub site can become a point of congestion, and visibility (also known as line-of-sight) between the hub site and the micro site limits the deployed network's size. A much more flexible network topology would include some level of interconnectivity between microsites at the street level to enable aggregation of traffic prior to connecting back to hub sites. Rings with spurs or add/drop chains are among these topologies.

In addition to significantly reducing the number of hub sites required, these types of networks offer higher reliability by providing alternate paths for traffic in case of equipment failure or a power outage. The implication of these network topologies is that the number of backhaul links per site and the capacity per link must be increased to carry the traffic from multiple microsites. Additionally, the microsite needs to include packet-switching capability to route traffic between the local site and various backhaul links.

The number of backhaul links required per site is naturally limited by street-level topologies, too. With most cities laid out on some sort of grid, on any given street corner only four possible paths are available. Since the pole or light standard usually blocks one of the directions, most microsites will require two or three backhaul links—all of which need to be housed within the same volume and weight restraints imposed by municipal requirements and be designed for simple and quick installation to keep the cost per site in control.

High-frequency, high-capacity radios will be required to deliver capacity to support the aggregated traffic from multiple microsites. These higher-frequency radios also have the advantage of reducing self-interference due to higher propagation losses and narrower beam widths compared to lower-frequency radios. But due to street-level clutter such as trees and signage, microsites can also take advantage of lower-frequency wireless technologies that can cope with reduced line-of-sight propagation and will be required in some instances, meaning a mixture of radio technologies will be required in most networks.

The Wi-Fi extensions that are commonly considered for small-cell backhaul application do have some limited non-line-of-sight capability. This is certainly advantageous, as achieving a clear line-of-sight on all the links is made difficult by trees and other obstructions that line city streets. Yet to deliver this non-line-of-sight performance, they use a modulation technology called time-division duplex orthogonal frequency division multiplexing (TDD-OFDM).

TDD-OFDM's latency is significantly higher than that of the frequency division duplex (FDD) QAM modulation employed in higher-frequency microwave radios. This becomes a very serious issue for LTE, effectively limiting these types of radio links to a single hop before the traffic must be delivered to the fiber network for transport to the core network.

What's more, the total capacity is limited due to the smaller channel sizes available in the sub-6-GHz bands (10- or 20-MHz channels that must be shared between upstream and downstream traffic versus the 50-MHz+ channel sizes dedicated to either upstream or downstream traffic that are available with the higher-frequency radios). Finally, since the spectrum is not licensed, there is a very real possibility that some other device operating in the same spectrum could interfere with the backhaul radio, either reducing the throughput still further or disrupting the signal altogether.

While sub-6-GHz radios don't deliver the cost per site performance and don't have the latency, capacity, or reliability required for the entire network, are the higher-frequency radios (6 to 80 GHz) any better? As one might expect, they are not without their own problems.

Higher-frequency radios have lower latency and higher throughput, allowing the aggregation of multiple small cells before handing off to the fiber network. But they also require clear line-of-sight, and many of the frequency bands need larger parabolic antennas that cannot be packaged for street lamp deployments.

For some of these frequencies, the spectrum licensing is done on a link-by-link basis, driving up the cost and increasing the paperwork required to get a link on air. Clearly, operators must choose a subset of these frequency options that do not require link-by-link licensing and can use specialized mini-antennas.

Capacity demands must always be balanced with the capability of the network operators to spend the capital expenditures (CAPEX) required to meet the demand. If the new investment is not sufficient, capacity demand will not be met and the networks will become congested, resulting in a poor user experience. How realistic is it to expect enough CAPEX to solve the problem?

One way to look at this is to assume that the CAPEX is roughly constant and the network capacity increase must come entirely from cost reduction in the equipment. Now the cost reduction that matters here is the cost per bit reduction, not necessarily the absolute cost per network element. It is also helpful to remember that only a portion of the network will require capacity upgrades to meet the demand. (In the instance of the North American metro network example above, approximately 50% of the cell sites required an upgrade.)

Next, one can look at the network trends in capacity per link growing tenfold over the past few years while the cost per network element has remained constant. Finally, when considering small-cell economics, a cost per bit reduction of a factor of three to five is expected when compared to the macro network, primarily from the reduction in ancillary costs such as tower rental, HVAC, and power.

Even though it is beyond the scope of this article to go into an in-depth economic analysis of each of the technology options above, it seems clear that achieving a 20-fold cost per bit reduction consistent with a 20-fold increase in capacity demand, while challenging, is not inconsistent with recent trends.

Summary

Backhaul technologies and network architectures continue to evolve, driven by the need to adapt to the tsunami of smart-phone traffic and the economic imperatives of network operators. As is often the case with technology, limits that once seemed insuperable yield to the relentless onslaught of innovation. The evolutionary path for macro-cell backhaul products is clearly different from that of small cells, even if some of the technology building blocks are similar. It is clear that this area of the network remains very dynamic and that one should continue to expect innovation and clever engineering to continue to drive the necessary evolution forward.

View this Article Online

http://mobiledevdesign.com/learning-resources/microwave-backhaul-radios-meet-evolving-traffic-challenge