WHITE PAPER

STRATEGIES FOR LOWERING LTE/4G BACKHAUL COSTS

EXECUTIVE SUMMARY

The Total Cost of Ownership (TCO) for LTE/4G backhaul is looming as a cost prohibitive business model that will have mobile network operators at the mercy of tower operators, as they seek to install equipment to satiate the tsunami of mobile data devices that are expected to accompany the coming Fourth Generation wireless telecommunications wave.

This white paper will dispel the erroneous notion that LTE/4G basestations present an infinite demand problem for backhaul that can never be met and offer an analysis of the relative TCO advantages of microwave, fiber and leased line technologies to meet it. Techniques for leveraging technology to further reduce TCO for backhaul will also be examined.

JULY 2012

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Fiber can cost $500,000 per mile or more. There is a real danger for operators to overpay for their backhaul requirements—and not just by a little—but by billions of dollars.

STRATEGIES FOR LOWERING LTE/4G BACKHAUL COSTS

"Legacy backhaul has generally consisted of leased TDM T1 lines that work fine for low bandwidth voice traffic but are too narrow to handle wideband video and other Internet applications now running over cell networks. There's a lot of work and a lot of innovation in terms of packet-based microwave to run native packet as well as TDM traffic and beef up the bandwidth to microwave links of 800 megabits to a gigabit and moving up to 3-plus gigs. You're definitely going to see a lot of microwave backhaul."

— Jim Barthold, *FierceWireless*, June 9, 2009

INTRODUCTION

The fourth generation of wireless communications technologies is well underway as denoted by the growing usage of "4G" terminology in popular media. It looks inevitable that 4G wireless will primarily consist of Long Term Evolution (LTE) cellular technology. With 4G/LTE traffic ready to spike to heretofore-unimaginable levels, backhaul for mobile operators and other wireless networks faces an impending traffic jam unless something is done to dramatically boost throughput levels—at least that is how many industry pundits see it. The first answer that springs to many minds is fiber optic technology, with some announced fiber optic projects possessing capability for 1 Gigabit/sec. throughput.[1]

But fiber can cost US$500,000 per mile or more.[2] And does anyone really know what the throughput requirements for LTE are going to be? There is a real danger for operators to overpay for their backhaul requirements—and not just by a little—but by billions of dollars. So it is very crucial to examine the realistic needs for 4G wireless backhaul throughput and which technologies, such as microwave, can help meet those requirements in addition to that of fiber optics. Even more important, it is highly critical to analyze the total cost of ownership for these alternative 4G backhaul technologies and determine which is the most cost effective for typical U.S.-based mobile network operators.

THE PROBLEM

With the run up to 4G/LTE wireless networks, the emphasis has been placed on how much data capacity will be eaten up by seemingly endless numbers of intelligent mobile devices—e.g., smartphones, tablet computers, machine-to-machine (M2M) embedded devices. The sky is the limit for these devices, and their voracious appetites for digital information could cripple 4G networks in a capacity crunch that would make the 3G backhaul bottlenecks of 2007-2009 seem mild in comparison.[3] Often, this backhaul discussion is held in terms of hundreds of megabits up to gigabits of capacity requirements. Seemingly, the default decision to deal with this deluge of data feeding into the backhaul network is to resort to fiber optic technology. However, only one out of four mobile network operators (MNOs) say they understand or feel they understand what the real requirements for LTE backhaul are going to be.[4] Choosing the default option of fiber technology without fully understanding the backhaul requirements for LTE could be a costly one. There needs to be more focus on the total cost of ownership (TCO) of LTE backhaul in conjunction with the capabilities of fiber, microwave and leased line alternatives to adequately service those requirements.

In addition, the TCO of 4G/LTE backhaul is not homogeneous. It comprises elements of both capital expenditure (capex) and operations expenditure (opex). Far too much of the focus on cost has remained on initial capex at the expense of opex. MNOs must examine initial opex and ongoing opex as well as look at ongoing capex. Also, what technological solutions are available to further reduce the TCO of 4G/LTE backhaul? There are several possibilities that have to be surveyed.

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THE SOLUTION

First, only so much data is likely or even possible to move through a 4G basestation and onto the backhaul network in a given amount of time. According to an Aviat Networks' bottoms-up technology analysis of what data throughput an LTE basestation can support, after a steep increase in throughput

[1] Jones, A., "Kansas City Selected for Google Ultra High-speed Network," *IT Business Edge,* 30 March 2011, retrieved from www.itbusinessedge.com.

[2] Goldman, A., et al, "The Price of Laying Fiber," *ISP-Planet,* retrieved 29 March 2011 from www.isp-planet.com.

[3] Wortham, J., "Customers Angered as iPhones Overload AT&T," *New York Times,* 02 Sept. 2009, retrieved from www.nytimes.com.

[4] Donegan, P., "Ethernet Backhaul Quarterly Market Tracker" *Heavy Reading,* December 2010.

There are three main factors to consider in 4G/LTE backhaul: capacity, cost and reliability. It is not advisable to look at any of these in isolation when making a decision regarding backhaul.

capability from that of the level of 3G basestations, it quickly plateaus out at approximately 200 Mbps. This is for a three-sector LTE basestation independent of the number of users in the sector or the amount of content they are attempting to download to their smartphones or tablets.

Today's microwave radio solutions are more than capable of delivering 200Mbps backhaul throughput to 4G/LTE basestations (Figure 1). Far from being less deployable in support of 4G wireless networks than they were for 3G, microwave radio backhaul has an important role to play in providing a cost-effective, high-capacity LTE network.

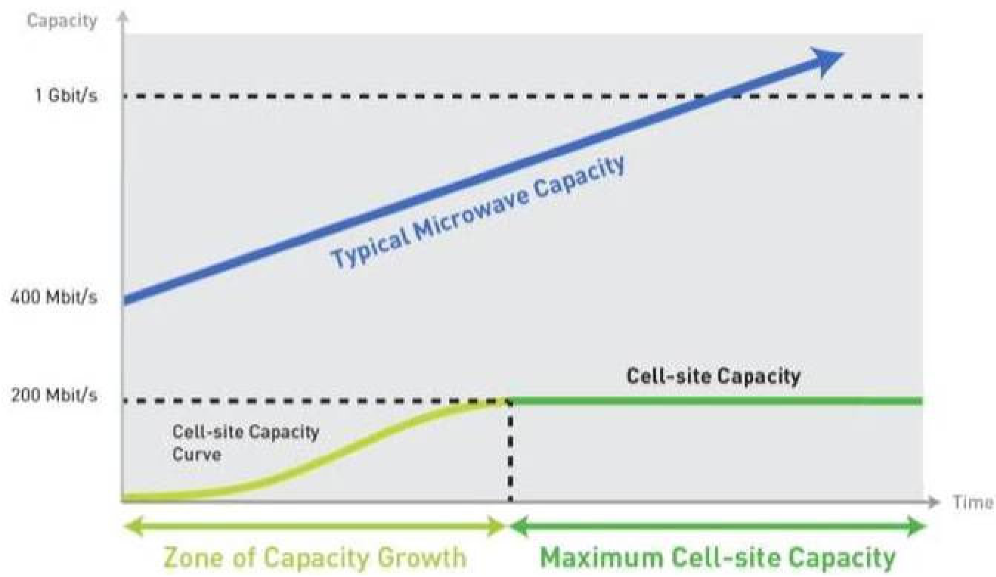

Figure 1. Far from lacking the scalability to support throughput levels needed by the next generation of 4G/LTE basestations, microwave radio backhaul can deliver double the capacity. 4G/LTE basestation traffic quickly tops out at about 200 Mbps, whereas microwave backhaul supports 400 Mbps initially and projects to deliver more than 1 Gbps bandwidth over time.

FOCUS ON COST

While TCO of wireless backhaul for 4G/LTE networks is very important, it would be an error to consider it in isolation from other factors. There are three main factors to consider in 4G/LTE backhaul: capacity, cost and reliability. It is not advisable to look at any of these in isolation when making a decision regarding backhaul. Multiple technologies can meet the backhaul demands of 4G /LTE wireless. The ones we will look at are microwave, fiber optics and leased line. The two questions that should be answered are: "What is the lowest cost backhaul solution to meet LTE capacity requirements?" and "How can these costs be reduced even further based on some recently introduced technological innovations?".

TCO models vary greatly depending on the market and geography on which they are based. The model presented here is specific to MNOs in the United States of America and is typical for operators who lease towers.

TOTAL COST OF OWNERSHIP MODEL: ASSUMPTIONS

TCO models vary greatly depending on the market and geography on which they are based. The model presented here is specific to MNOs in the United States of America and is typical for operators who lease towers. The model would be very different for private markets, utilities, public safety and others who own their own towers. The model for international-based MNOs would also be different. Macro cell backhaul applications are its focus, and the model is not applicable for small cell or pico cell backhaul. Some assumptions about the typical US MNO case are that the backhaul network consists of all single non-redundant links, has an all-IP architecture and that capacity requirements start at 50 Mbps in year 1, increase to 100 Mbps in year 3 and then are 200 Mbps from years 5 through 10.

Over 10 years, the largest component of TCO is tower leasing, which includes leasing indoor and outdoor tower space. Tower leases are very complicated and highly variable based on a number of factors. The most variable part is the antenna site.

In the TCO model under consideration, there are a number of components (Figure 2). Key contributors to TCO are microwave equipment,[5] which includes antennas, waveguides and all other hardware, design (including FCC fees for licensing and coordination), site development (including application fees and structural studies) and tower leasing. Over 10 years, the largest component of TCO is tower leasing, which includes leasing indoor and outdoor tower space.

TCO Component	Year 1	Year 10
MW Equipment Price (incl. antenna, waveguide, etc)	20,000	20,000
Spares	750	750
Upgrades and Expansion	0	9,000
Design (engineering, site and path surveys, FCC fees, freq coord))	8,000	8,000
Site Development (permits, struct. analysis, upgrades)	8,000	8,000
Installation & commissioning	12,000	12,000
Field corrective maintenance	1,154	11,538
Repair and return (MLA fees)	600	6,000
Tower lease (3' antenna)	12,000	120,000
Microwave Cumulative Cost	**62,504**	**195,288**

Figure 2. Total cost of ownership (TCO) for a microwave backhaul solution involves many components, of which the microwave solution is only one part. TCO models can also vary greatly depending on the market and geography and whether the operator owns its towers. The TCO model represented here is designed to provide insight for a typical mobile network operator in the United States of America.

Tower leases are very complicated and highly variable based on a number of factors: tower location, tower space available, changes and additions to the contract and more. The most variable part is the antenna site. Calculations are based on US$200 per site and US$100 per antenna-foot for each site. In the case of this model, a single link is considered, resulting in a cost of US$500 per site for a monthly lease, which equals US$12,000 per year. This is the context of this TCO model.

10-YEAR MICROWAVE TCO

Looking at TCO of microwave backhaul over 10 years, the largest component cost turns out to be tower costs—this is the key takeaway (Figure 3). MNOs are at the mercy of tower owners. As the largest cost component, any effort to reduce microwave TCO has to take tower leasing under serious analysis for ways reduce its cost. Tower leases are the largest part of ongoing opex, which is the most important part of microwave TCO. Anecdotally, this goes against the grain of conventional wisdom in the wireless industry, with its emphasis on initial capex as the most important determinant when choosing a microwave backhaul solution.

Focusing on initial capex of microwave equipment when making a purchase decision can be the wrong way to look at backhaul solutions, given that it is such a small percentage of the total cost. Units can vary by a few hundred dollars more or less in initial cost. Perhaps, even spending marginally more on microwave solutions with specific features, software licenses and capabilities that allow MNOs to lower opex in the long run is appropriate. That is why the TCO model is important to examine over the life of the solution to determine which is the most cost-effective alternative overall. And there are technology approaches that make it possible to lower ongoing opex.

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[5]Of the key contributors, microwave equipment figure is the most arbitrary. It can range up or down based on selected options, volume discounts and other factors. The number here represents a middle-of-the-road figure.

Adaptive Coding and Modulation (ACM) is a proven technology with more than 2000 licensed and coordinated links in the US. ACM varies the coding and modulation of the radio based on path conditions.

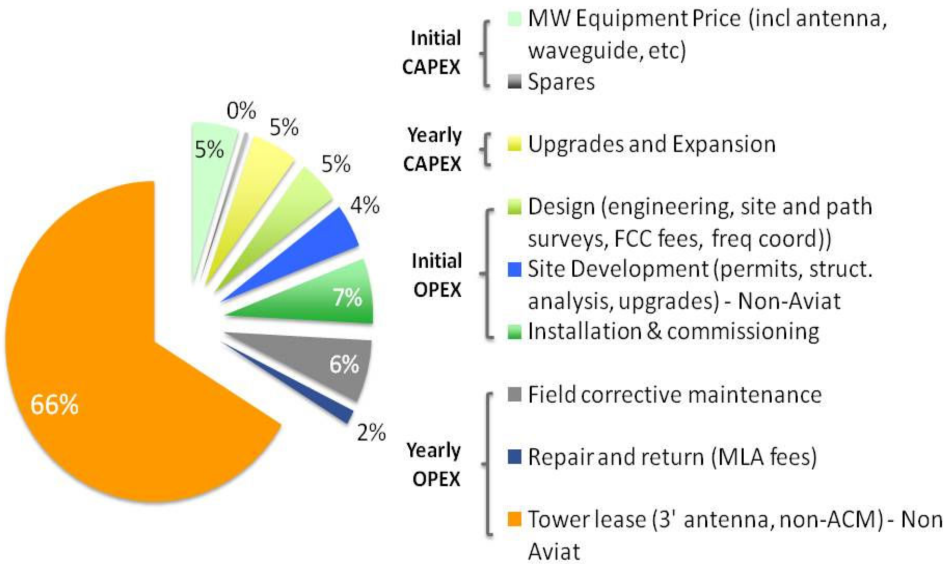

Figure 3. Based on a 10-year cost analysis of the backhaul of a typical US-based mobile network operator, Aviat Networks' results show that the tower leasing component has the lion's share of both the ongoing opex and total cost of ownership. This runs counter to the conventional thinking in the industry, which tends to emphasizes initial capex of equipment.

TECHNOLOGY APPROACHES TO REDUCING TCO

There are several approaches to reducing TCO for microwave backhaul, such as performing more diligent contract negotiations with tower owners. The approach taken here is based on leveraing the technology of microwave radio. Four technology approaches that can be used to reduce microwave backhaul TCO include:

- High system gain radios—system gain is the single biggest factor in enabling the smallest possible antenna to be used (which is the biggest factor in TCO reduction)
- Adaptive Coding and Modulation (ACM)—a proven technology with more than 2000 licensed and coordinated links in the US, ACM varies coding and modulation of the radio based on path conditions
- Diverse network topologies—instead of each link having "five nines" reliability (99.999 percent uptime) the network design provides five nines via Carrier Ethernet ring protection, protected VLANs or MPLS fast reroute allowing for lower level reliability on each hop and smaller, less costly antennas
- Zero-fooprint radios—next-generation basestations are moving to true all-outdoor, multi-radio solutions and microwave backhaul radios are accompanying them with all-outdoor designs

HIGH SYSTEM GAIN RADIOS

A radio with high system gain does not require large size antennas to achieve the desired system reliability. Smaller size antennas are less costly than larger antennas. And with smaller size antennas, tower wind loading is reduced, resulting in savings on costly tower strengthening. Plus, most tower leases are tied to the size of the antennas—bigger antennas, higher lease charges. So using smaller antennas results in lower monthly lease charges. Lastly, maximum system gain enables longer paths. Longer paths allow for fewer sites and lower outlay for equipment. High system gain is the surest way to achieving lowest TCO—even if you have to pay more capex upfront to get it!

ADAPTIVE CODING AND MODULATION

With the ability of ACM to switch modulations based on path conditions between hops, an MNO is spared making a one-time choice that locks it into a tradeoff of throughput vs. reliability. Without ACM, the operator has to make a design decision where it receives high throughput using a high microwave modulation at the expense of radio link reliability or choosing high reliability using a lower, more robust modulation for the cost of reduced throughput. However, with ACM, MNOs get the benefits of high throughput and high reliability (Figure 4). The modulation of the radio link is adjusted dynamically and

In the past, wireless backhaul paths were typically designed to implement five nines reliability on each separate link. With IP networking, higher level redundancy schemes enable the design of lower reliability links on a per-hop basis but still have overall five nines.

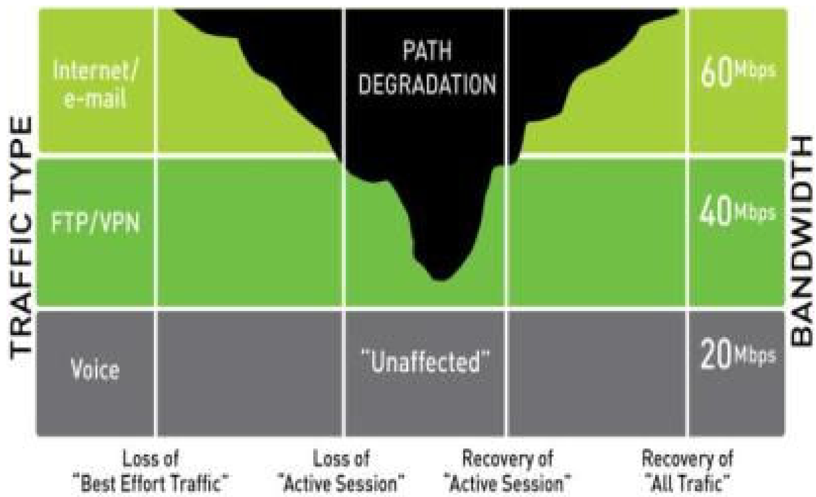

Figure 4. Adaptive Coding and Modulation dynamically varies link frequency to lower modulation when path conditions degrade to maintain priority traffic such as voice, then rise to higher modulation as they improve to carry all traffic including "best effort" applications such as email. ACM enables higher modulations with smaller antennas for higher throughput and lower TCO without reducing reliability.

predictably based on monitoring signal-to-noise ratio (SNR) and received signal level (RSL), switching automatically before an outage takes place, ensuring a hitless recovery. Able to design links with lower modulations, MNOs can use smaller antennas, which results in lower cost, while maintaining five nines uptime in a poor transmission environment yet benefiting from increased capacity via higher modulations under normal operating conditions. Thus, links can be designed with higher modulations and smaller antennas for higher throughput without sacrificing reliability while reducing overall TCO.

DIVERSE NETWORK TOPOLOGIES

In the past, wireless backhaul paths were typically designed to implement five-nines availability on each separate link. Basically, it was a link-by-link network plan. Now with IP networking, higher level redundancy schemes such as Carrier Ethernet ring protection, protected VLANs (Figure 5) and MPLS fast reroute enable the design of lower reliability links on a per-hop basis but still have overall five nines service reliability. Not needing as high level reliability, MNOs may design in a smaller antenna, which is a major driver for reducing TCO.

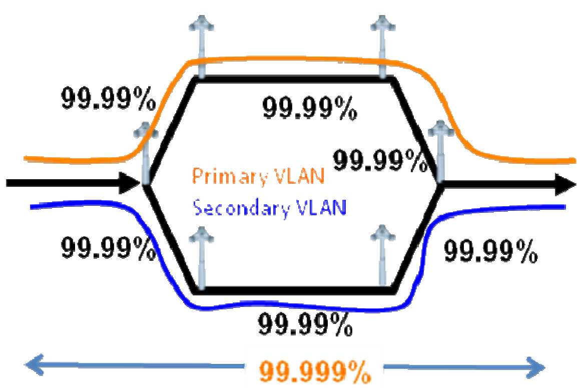

Figure 5. Diverse network topologies such as the use of protected VLANs allows operators to achieve overall 99.999 percent network availability (i.e., five nines), even though individual links may only be designed to 99.99 percent availability (i.e., four nines). Because single links meet a lower threshold for reliability, they use smaller, less costly antennas, contributing to lower overall TCO.

ZERO-FOOTPRINT RADIOS

Next-generation basestation technology is moving to all-outdoor basestation technology. But unless the basestation is completely all-outdoor, then having all-outdoor microwave backhaul technology generally does not make sense because it actually increases TCO over and above what would result

In addition to providing a lower cost basis with a smaller antenna, the ACM design provides five times more throughput than the fixed design over a year—1034 terabytes vs. 197 terabytes.

from using a split-mount design. If you have requirements for TDM, protection, ring network architecture, XPIC or advanced QoS, you will likely need another box to support those functionalities with all-outdoor microwave. At that point, split-mount radios bear a lower TCO. True all-outdoor microwave backhaul solutions do not have *any* indoor components for power, ACM, XPIC, etc.

ACM DESIGN COST SAVINGS

To demonstrate the cost savings ability of ACM, the following example takes into consideration a plausible implementation scenario for an MNO customer. Here we will compare a fixed modulation design to an ACM design (Figure 6). In this example, the design requirements are to establish 99.999 percent link reliability for a 10-mile communications path.

ACM Design, 18GHz, 2' Antenna				
Link State	Uptime %	Uptime Minutes	Capacity (Mbps)	Total Per Year (TB)
256QAM	99.5613%	523,294	263	1,032
64QAM	99.7784%	1,141	155	1.33
16QAM	99.9299%	796	100	0.60
QPSK	99.9995%	366	50	0.14
Out of Service		3	0	
Total		525,600		1,034

Fixed Modulation Design, 11GHz, 4' Antenna				
Link State	Uptime %	Uptime Minutes	Capacity (Mbps)	Total Per Year (TB)
64QAM	99.9994%	525,597	50	197
Out of Service		3	0	
Total		525,600		197

Figure 6. Uptime comparison of fixed vs. ACM modulation link design.

For a fixed modulation path of 10 miles to have 99.999 percent reliability for 50 Mbps throughput, an 11GHz frequency band at 64QAM modulation will be used. This would provide uptime over the course of a year of 525,597 minutes—leaving only 3 minutes of no service availability. In this implementation, a costly 4-foot antenna must be employed.

In an ACM implementation providing the save uptime characteristics, a higher 18GHz frequency can be used with a smaller, less costly 2-foot antenna. The design will be able to utilize a robust QPSK modulation to ensure 99.999 percent operation availability during poor transmission conditions, but for the vast majority of the time, it will utilize 256QAM modulation. In addition to providing a lower cost basis with a smaller antenna, the ACM design provides five times more throughput than the fixed design over a year—1034 terabytes vs. 197 terabytes. The effect alone of using ACM instead of fixed modulation in this design example saves the MNO $4800 in a year.

DIVERSE NETWORK TOPOLOGIES COST SAVINGS

The ring configuration TCO is 30 percent less than TCO for the hub-and-spoke design for the same six sites.

To compare how different network topologies perform under the same operating scenario, let's analyze how a traditional hub-and-spoke and a ring configuration compare in connecting the same six sites (Figure 7). For the hub-and-spoke configuration, each cell site is provided 50 Mbps capacity in 1+1 protection. With five links and no path diversity, full protection is the only way to achieve five nines reliability. In this configuration, 10 antennas are employed, which average a large and costly 5.2 feet in diameter. Total cost of ownership for this six-site network is close to $700,000 for five years.

For a ring design for the same six sites, throughput of 200 Mbps is established to carry the traffic for each specific hop and any traffic coming in that direction from farther up the network. Designed to take advantage of the higher-level redundancy schemes already discussed, the ring configuration only requires antennas that average 2.3 feet in diameter, which are much lower in cost compared to the antennas in the hub-and-spoke configuration. And even though the ring configuration requires 12 antennas and six links, its overall TCO amounts to a little under $500,000 over five years—30 percent less than TCO for the hub-and-spoke design for the same six sites.

Overall, the relative cost curve for microwave backhaul compares very favorably to those of leased line and fiber. It is clearly a much better strategy to pursue long-term TCO reduction, especially given technological cost reduction techniques.

TCO Comparison by Topology

	Hub – Spoke	Ring
Sites	6	6
Links	5 (1+1)	6
Antennas	10	12
Average Antenna Size	5.2	2.3
Reliability (per link)	99.999%	99.95% (average)
Capacity (per link)	50Mbps	200Mbps
CAPEX	$176k	$119k
Yearly Tower Lease	$77k	$48k
5 Year TCO	**$676k**	**$478k**

Figure 7. Hub-and-spoke topologies require more costly equipment to maintain five nines reliability, highlighted in this example by an average antenna size more than twice as large as the network laid out in a ring design. Over five years lower lease costs are attributable primarily to smaller antennas, lowering TCO by more than 30 percent.

RELATIVE COST OF BACKHAUL ALTERNATIVES

As the three main alternatives for backhaul, microwave, fiber and leased-line solutions all have different cost curves. You can look at these as leased and owned alternatives: leased line TDM, leased Ethernet over fiber, owned fiber (i.e., trenched fiber) and owned microwave (Figure 8).

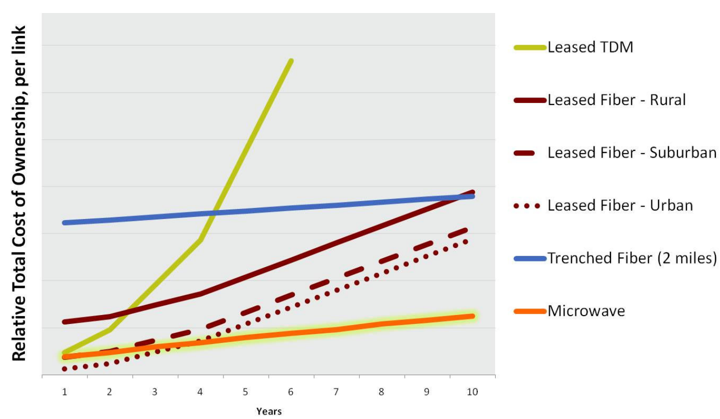

Figure 8. As the three main alternatives for backhaul, microwave, fiber and leased-line solutions all have different cost curves. You can look at these as leased and owned alternatives: leased line TDM, leased Ethernet over fiber, owned fiber (i.e., trenched fiber) and owned microwave.

In this relative comparison of costs over time, the backhaul alternatives change. Leased line TDM has the steepest cost curve, but can vary by region of the country and whether the terrain is urban or rural. For example, a T1 line can cost from $100 in urban areas up to $800 in many rural areas. For leased Ethernet over fiber from a wholesale fiber provider or multiple system operator (i.e. cable television company) rates are typically $600 to $800 per 10 Mbps/month of service, moving up over time. Leased Ethernet over fiber service may also entail special construction fees depending on the location and degree of difficulty to bring fiber to the backhaul site. Most often, these apply to special construction in rural areas (these fees are usually waived in urban areas). Fees range from $25,000 per site for rural locations to as high as $50,000 per site in suburban settings. Represented by the blue line, owned (trenched) fiber endures highly variable costs, again depending where the trenching takes place. Costs range from $30 to $100 per foot, with a small opex component, as well.

Overall, the relative cost curve for microwave backhaul compares very favorably to those of leased line and fiber. It is clearly a much better strategy to pursue long-term TCO reduction, especially given the technological cost reduction techniques that were discussed earlier.

All-indoor microwave radio solutions offer the lowest TCO for LTE backhaul among the three possible configuration options when extrapolated over a five-year period.

ALL-INDOOR RADIOS: LOWEST TCO OVER FIVE YEARS FOR LTE

Despite its higher initial cost, all-indoor microwave radio actually offers lowest the TCO for a high-capacity LTE backhaul solution when extrapolated over a five-year period (Figure 9). This may surprise those who have not gone through an LTE deployment, but based on our experience deploying LTE

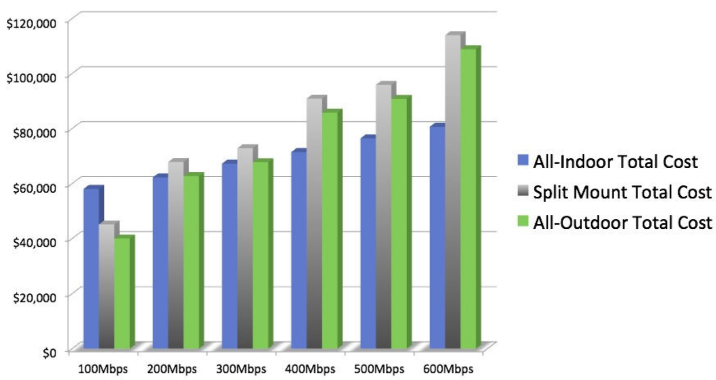

Figure 9. All-indoor microwave radio solutions offer the lowest TCO for LTE backhaul among the three possible configuration options when extrapolated over a five-year period.

backhaul for some of the world's largest LTE networks, all-indoor radios are actually the best microwave architecture for the job. With new advances in LTE technology, the need for capacity will only grow over time. This means that microwave radios providing LTE backhaul will have to be upgraded as time progresses. And the most proven way to expand backhaul capacity for microwave radios lies in adding radio channels because it represents real usable bandwidth independent of packet size, traffic mix and the RF propagation environment.

Although, all-indoor radios are more expensive initially in terms of capex, they are less costly to expand and are easier to service because all their electronics are accessible from ground level, negating cost-prohibitive tower climbs. For example, indoor radios usually need a waveguide, which can be pricey, to carry the RF signal from the radio to the antenna, but they are less costly to upgrade, as only one tower climb is required to install the waveguide and antenna on the tower. To add more radio channels in the future, the cabinet at ground level is simply accessed and the needed RF units are installed. On the other hand, when additional RF units are added to an all-outdoor radio configuration, a tower climb is required for each upgrade. Tower climbs can cost up to as much as US$10,000 per climb! Not to mention, outdoor radios may need to have their antennas swapped out for larger ones due to extra losses incurred when radio channels are combined on the tower—remember larger antennas equal larger tower lease costs.

When additional RF units are added to an all-outdoor radio configuration, a tower climb is required for each upgrade. Tower climbs can cost up to as much as US$10,000 per climb!

These additional tower climbs to upgrade all-outdoor radio capacity are important to note because no LTE network planners really know how much bandwidth they will need in the future. They may deploy one radio channel today at 150 Mbps and need to add another 150 Mbps in six months. What these planners really want is a "futureproof" LTE system. They get that with all-indoor radios because multiple radio channels can be run over the same waveguide and antenna without incurring extra losses. Adding more channels to outdoor radios require couplers, which incur losses and then larger antennas to compensate for the losses. Again, larger antennas mean larger tower lease costs, which typically bill based on $100 per antenna-foot per month.

TCO AND OTHER ADVANTAGES OF ALL-INDOOR RADIOS

According to an Aviat Networks' analysis of TCO, for most MNOs tower leases comprise 55 percent of the cost of an LTE deployment over 10 years. Upgrading an outdoor radio increases these lease costs even more, whereas an indoor radio can be expanded without having to touch equipment installed on the tower, leaving lease costs unchanged.

Another advantage of all-indoor radios is that they can be accessed regardless of the weather conditions. This is especially critical during rainy or snowy conditions when climbing a tower can very dangerous; another problem to be confronted when using outdoor radios.

Not every implementation scenario is appropriate for fiber, such as when the relative costs rise too sharply.

Also, some radio engineers have yet to realize that indoor radios have become very compact, and their impact on cabinet space has been reduced considerably since the 1990s when one radio occupied an entire telco rack. Today, an indoor radio requires less than 10 inches of vertical rack-space.

CONCLUSION

Backhaul costs are an area that requires careful scrutiny. If not watched carefully, they can quickly spiral out of control. However, this white paper has disclosed multiple approaches and techniques to contain and reduce TCO. The focus of any serious TCO reduction effort has to be on operations expenditures (opex). The initial capital expenditures (capex) of a backhaul project are easy to see in black and white on the pages of a purchase order or invoice. Opex—especially ongoing opex—is harder to see as it is not entered as a clearly defined ledger entry each quarter. And many variables can affect its overall impact on TCO.

Variables such as the relative cost advantage of microwave backhaul to fiber are some of the most important ones. Clearly, fiber has a major place in the wireless backhaul infrastructure. But not every implementation scenario is appropriate for fiber, such as when the relative costs rise too sharply. In those instances, microwave offers an attractive complementary solution for backhaul, especially where cost is a prime driver.

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