Fixed Wireless—Do The Numbers Really Work?

Bart Stuck and Michael Weingarten

A couple of years ago, we wrote an article on high-frequency fixed wireless in which we concluded that the technology looked to be a viable alternative to fiber connections for a nontrivial fraction of buildings (“Going the Distance,” in *Telephony,* June 1998). We were right in at least one respect—the valuation for companies such as Teligent (www.teligent.com), Winstar (www.winstar.com) and Advanced Radio Telecom (ART—www.artelecom.com) have tripled and/or quadrupled since we wrote the article—at least until the mid-April high-tech massacre; the valuations since then are a work in progress (Figure 1).

In addition, WNP Communications was one of the major winners in the FCC auction of local multipoint distribution system (LMDS) spectrum allocation, bidding $186 million for 105 million population coverage. Within a year, they sold out to Nextlink (www.nextlink.com) for $695 million. Not a bad return on investment.

Two years have now gone by, which is a long time in both dog and Internet years. So what’s new on the fixed-wireless front? More specifically, how do different types of wireless LAN and local-loop technologies compare to their wireline equivalents? (There’s also plenty going on with mobile wireless, but we’ll leave that for some other time.) What’s changed since mid-1998, and what’s on the horizon?

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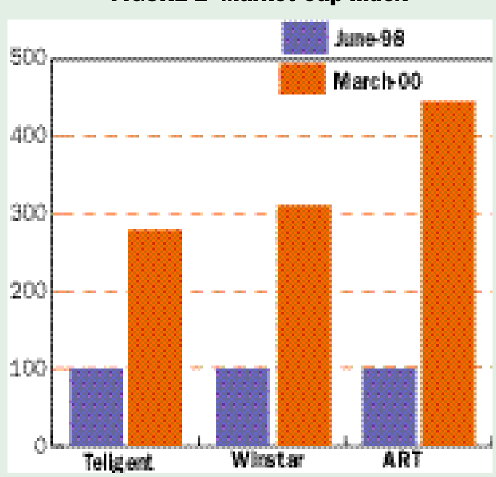
FIGURE 1 Market Cap Index



(Source: Author analysis from public data)

To deal with these questions, we consider three potential fixed-wireless applications:

- **RF OC-Rate WAN:** LMDS and other high frequency point-to-multipoint technologies.
- **RF Medium Bitrate WAN:** Back in 1998, 2G digital was a hot new technology. Now 3G is about to appear, and it offers the prospect of data transmissions up to 2 Mbps (this also may be possible with proprietary systems such as the upgraded AT&T Project Angel). What does this suggest for the attractiveness of fixed wireless?
- **Free-space optical technologies:** Free space is based on point-to-point and/or point-to-multipoint laser connections transmitted over the air without the use of fiber (hence the designation “free space”). A leading example is Terabeam Corp. (www.terabeam.com), which recruited Dan Hesse of AT&T Wireless as CEO and then negotiated an equity investment/joint venture with Lucent (www.lucent.com) in April. In principle, free-space optics could be a substitute for RF transmission, and this past March, George Gilder called free space optics a “disruptive technology,” that will make obsolete LMDS point-to-multipoint technology. How disruptive is it really?

Point to Multipoint (OC-Rate WAN)

In our June 1998 review, we commented that point-to-multipoint (PTMP) had the potential to offer substantially lower cost than fiber on a cost-per-building basis. In particular, we emphasized the importance of moving from point-to-point (PTP) technology to PTMP, because it lowered unit cost per subscriber substantially by sharing bandwidth at the RF base stations.

So what’s happened? To date, very little:

- Winstar’s 1999 10K suggests that of 2,500 buildings “on net” at the end of 1999, only 1,000 were fixed wireless, with the rest being leased wireline connections. Almost none were PTMP, although Winstar claims to have “recently accomplished the initial rollout of point-to-multipoint technology in Oakland, Phoenix, Salt Lake City, San Jose, Seattle and Washington, DC.”
- Teligent’s 10K states that it is expecting delivery of PTMP equipment from Hughes “before the end of 2000.” Teligent initially planned to have Nortel’s Broadband Network Inc. (BNI) subsidiary (which Nortel purchased for $700 million) as its primary PTMP supplier. But when BNI’s

TABLE 1 Major PTMP Customers and Suppliers

End Customer	Equipment Integrator	RF Provider
Winstar	Lucent	Netro
Teligent	Nortel	Hughes
ART	Cisco	Not available
Nextlink	Nortel	Broadband Networks (acquired by Nortel)
Adelphia	Not available	Ensemble

(Source: 10Ks and author interviews)

technology apparently did not work properly, Teligent turned to Hughes. Not exactly confidence-building *vis a vis* PTMP

- Nextlink's 10K says that it concluded tests of first-generation PTMP equipment in January 2000, and concluded that "improvement in the price, features and functionality of the point-to-multipoint equipment must be made before we undertake a broader commercial launch of services using this technology." Nextlink then expressed confidence that the next-generation equipment it expects to have installed by the end of the year would work OK.

Table 1 lists key vendors for selected major PTMP customers, and it shows four primary technology originators: Netro (www.netro-corp.com), Hughes (www.hns.com), BNI/Nortel (www.nortelnetworks.com and Ensemble (www.EnsembleCom.com. PTMP appears to be one of those businesses where technology has been driven by startups, not the majors; Netro, with a market cap of around $2 billion, has been the market leader, providing PTMP equipment to Lucent, Siemens (www.icn.siemens.com) and Motorola (www.motorola.com) among others.

But the question of whether any of these services is ready for prime time depends upon two underlying drivers. The first is *performance* and, in particular, quality assurance under different atmospheric conditions. High-frequency RF is subject to high attenuation, particularly under fog/rain conditions, leading to the frequent observation that with LMDS, "you can't make a call when it rains."

To cure these problems, the PTMP vendors have been working on next-generation technologies such as adaptive TDD, adaptive TDMA and adaptive modulation. Some of this equipment is in field trials, and we hear that the suppliers are "real confident" based on beta tests to date. If all continues to go well, PTMP could be ready for prime time, probably starting in 4Q00.

A second barrier to PTMP adoption is *cost*. Table 2 summarizes what we were saying in June 1998 versus what actually happened and what we anticipate for 2002. Essentially, we were overly bullish—by a factor of two—on the number of bits that could be transmitted by a base station, as well as on the unit costs per base station and receiver (off by 30 percent for business receivers). The net result is that today's unit cost per T1 is more than twice as high as we'd forecast for 2000.

Despite this track record, our understanding is that these issues are being addressed successfully and we believe that by 2002, the cost per building connected will drop to $3,000 and the cost per-T1 will drop to $45. At these levels, PTMP will be attractive for smaller-to-mid-sized buildings that are off-fiber net and/or cannot afford the higher cost for direct fiber hookups (roughly $50,000 marginal cost per building for an OC-3 mux, dropping to $20,000–$25,000 in two years; excluding fiber amortization/construction costs.)

However, it won't be the only option. For example, Quantum Bridge's (www.quantumbridge.com) passive optical networking solution, in which a single high-speed optical connection is muxed to multiple lower-speed end-user connections, is an alternative for 1–100-Mbps rates, and has a prospective base price of $7,000.

Point-to-multipoint adoption is still hampered by questions about performance and cost

Fixed Wireless (RF Medium Bitrate WAN)

The term "fixed wireless" often refers to a 1:1 substitution for POTS—i.e. 64-kbps voice-only service (no data except via analog modem). Back in 1992, George Calhoun wrote a classic book (*Wireless Access and the Local Telephone Network)* in which he presented the following economic reasons for substituting a wireless local loop for wireline:

- Copper loop is expensive to install. You need to dig up the streets, which means a high fixed-capital cost is incurred in advance of signing up the first customer.

TABLE 2 PTMP Capacities and Costs Over Time

	1998	2000 (per 1998 est.)	2000 (current est.)	2002 (est.)
Base Station Capacity (Mbps)	1,600	6,400	2,952	6,000
Base Station Costs	$300,000	$190,000	$190,000	$140,000
Business Receiver Costs	$5,230	$4,150	$5,300	$2,850
Blended Cost Per Building Connected (25 Mbps base; 125 Mbps burst @50% utilization)	$6,371	$4,348	$5,712	$3,001
Blended Cost Per T1	$135	$63	$91	$45

(Source: Author analysis)

The presumed value proposition for wireless local loop is flawed

TABLE 3 RBOC Capital Plant Per Access Line

	1995	1996	1997	1998
RBOC Gross Plant	$1,635	$1,585	$1,515	$1,515
Depreciation	$736	$745	$735	$764
RBOC Net Plant	$899	$840	$780	$751

(Source: *FCC Statistics of Communications Common Carriers*)

TABLE 4 RBOC 1998 Net Plant Per Access Line

Local Loop/Network Interface Units	**$318**
Cable & Wire	$318
Other ILEC Capital Items	**$433**
Central Office Transmission	$158
Switching	$144
Land & Support	$102
Information Orig/Term	$12
Plant Not In Service	$10
Amortizable Tangible Assets	$5
Operator Systems	$2
Total	**$751**

(Source: *FCC Statistics of Communications Common Carriers*)

- Copper loop is expensive to maintain.
- In contrast, while wireless RF transmitters cost more than wireline CPE, no streets need to be dug up and costs are incurred only after someone becomes a subscriber. In other words, with wireless, you "pay as you grow."
- Wireless has lower maintenance costs (there aren't any cable cuts) and can be deployed faster (no digging up the streets) than copper.
- The economics are particularly favorable for difficult terrain (areas with lots of hills and/or water) and for areas where the "teledensity" is low.

Despite these advantages, however, there has not been much fixed wireless installed within the U.S. A few years ago, AT&T announced, with a great deal of fanfare, Project Angel, which would use PCS spectrum and proprietary radio technology to deliver POTS service to residential users. Unfortunately for AT&T, Angel's costs proved far higher than anticipated and the rollout was deferred.

At least that was the official explanation. And while it undoubtedly was true, we think fixed wireless has a more fundamental problem: The value proposition as espoused by Calhoun and the original Project Angel was flawed, for several reasons:

First, fixed wireless in the U.S. must compete with the heavily depreciated RBOC plant, using fresh "greenfield" capital. Since the RBOCs' accumulated depreciation is roughly 50 percent of gross plant, the fixed wireless plant must be very low in cost versus RBOC gross plant.

Second, fixed wireless is chasing a moving target. In the mid-90s, when Project Angel was developed, the RBOC gross plant per access line was $1,635 and net plant (net of depreciation) was $900. So, if Project Angel could be developed at $400–$500 capital cost per sub, AT&T arguably could compete with the RBOCs.

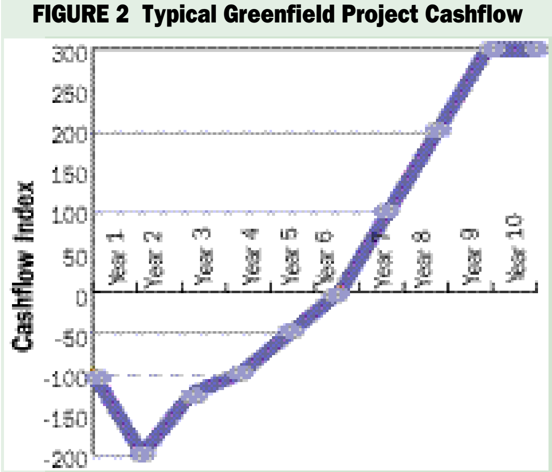
However, the RBOCs, benefiting from price cap-based pricing and therefore less dependent on maintaining large rate bases, wrote off a substantial portion of their gross plant. The result, as shown in Table 3, is that from 1995 to 1998 (the latest year data was available from the FCC), RBOC net plant per line *dropped* by 30 percent—from $900 to $750—a drop of 17 percent. This meant that roughly half of the anticipated differential was eliminated.

Beyond this, fixed wireless arguably was chasing an overly aggregated target. The 1998 cost per net-plant-access-line of $751 includes a number of items that are not local-loop related (for example, transmission equipment, Table 4) and, arguably, not replaced with a fixed-wireless network.

A final contributing factor was technological obsolescence. Building a greenfield network such as Project Angel involves a cashflow curve that looks something like the one shown in Figure 2, with *a.)* substantial cashflow losses in years 1–5, when the plant is being built out and customer penetration is in ramp-up mode; *b.*) breakeven cashflows beginning in year 6–8; and *c.*) substantial terminal value in year 10, as the system is mature and does not require major reinvestment going forward. We have observed many such cashflow curves and, in general, something like 80–90 percent of total net present value (NPV) comes from terminal value.

This has important implications for fixed-wireless investments. Assuming a fixed wireless

FIGURE 2 Typical Greenfield Project Cashflow



(Source: Authors' estimates)

Fixed wireless needs to become low cost versus wireless. This actually could happen

TABLE 5 Fixed Wireless Versus RBOC Wireline Capital Costs	Wireless (5 year cum; Greenfield basis)	Wireless (5 year cum; Greenfield basis)	Wireline (RBOC 1998, net of depreciation)
	Per Subscriber	Per 64 kbps equivalent (assume 2 lines plus 768 kbps burst data)	Per Access Line
Local Loop/Network Interface Units	**$381**	**$27**	**$318**
Cable & Wire	Not applicable	Not applicable	$318
RF Base Station	$183	$13	Not applicable
RF End Customer	$199	$14	Not applicable
Switching	**$13**	**$1**	**$144**
Class 5 Switch	Not applicable	Not applicable	$144
POP Router & Gateway	$13	$1	Not applicable
Total	**$394**	**$44**	**$462**

(Source: *FCC Statistics of Communications Common Carriers;* fixed wireless estimates from SOMA Networks)

greenfield plant comes in at no more than $318 per interface unit for local loop (Table 4), and assuming the technology is stable, then an investor can rationally decide to make the investment, *provided* that the RBOCs continue to price in a way that generates a return on full cost investment—i.e., that they don't start pricing on a marginal cost basis.

However, if we recognize that *a*.) technology is changing rapidly, and *b*.) consumer demand will shift dramatically in the direction of higher bandwidth, then any rational investor should be profoundly concerned about making this investment. Why? Just around the time that the year-10 terminal value payoff finally occurs, the entire POTS-equivalent plant is likely to be obsolete—that antiquated, POTS-only, fixed-wireless plant will be competing with lots of residential/small business subscribers using DSL and/or cable modem service, with far superior functionality.

So fixed wireless needs to become low-cost versus wireline (e.g., under $318 per line for local loop) and provide high bandwidth connectivity. And, as shown in Table 5, this actually could happen. The table shows prospective capital costs for one proposed fixed-wireless system utilizing third-generation (3G) technology—i.e., it can handle broadband data communications—and compares it to the average RBOC access line for equivalent functionality (the 3G fixed-wireless vendor has bundled Class 5 circuit-switched functionality inside its RF base stations, so we include RBOC switching costs as part of our comparison). On a per-subscriber basis, the wireless system only lowers the cost by about 15 percent if we attribute equal transport and other costs.

However, instead of supporting only one 64-kbps line, the 3G-based fixed-wireless system

TABLE 6 Wireline DSL Versus Fixed Wireless Capital Costs	Wireline Including DSL	Wireline Including DSL	Wireless (5 year cumulative; Greenfield basis)
	Per Subscriber	Per 64-kbps equivalent (assume 2 lines plus 768 kbps burst data)	Per 64-kbps equivalent (assume 2 lines plus 768 kbps burst data)
Local Loop/Network Interface Units	**$568**	**$41**	**$27**
Cable & Wire	$318	$23	Not applicable
DSL Modems (customer paid)	$250	$18	Not applicable
RF Base Station	Not applicable	Not applicable	$13
RF End Customer	Not applicable	Not applicable	$14
Switching	**$557**	**$40**	**$1**
Class 5 Switch	$144	$10	Not applicable
DSLAM/Co-Location	$400	$29	Not applicable
POP Router & Gateway	$13	$1	$1
Total	**$1,125**	**$80**	**$44**

(Source: *FCC Statistics of Communications Common Carriers;* fixed wireless estimates from SOMA Networks; DSL cost estimates by authors) will support 2–4 phone lines, as well as high-speed data. If we assume that the average subscriber has two phone lines and a 768-kbps burst data speed, the cost per-equivalent 64-kbps line drops to about 6 percent of the cost of an RBOC POTS line.

Even if we compare fixed wireless to the cost of a line that uses DSL as well as voice over DSL (Table 6), the greenfield, fixed-wireless approach is about half the cost of DSL (and perhaps more, given that independent DSL providers such as Covad (www.covad.com), Northpoint (www.northpointcom.com) and Rhythms (www.rhythms.com) must pay for an additional layer of transport cost from RBOC central office to their own CLEC office, and they also must pay for office space in both locations). So net-net, fixed wireless can be substantially lower- cost for equivalent throughput.

So that's the good news. The bad news—perhaps "troublesome" is more appropriate—is that capacity remains a very real issue for 3G fixed wireless. Unlike the 1150 MHz of spectrum available for LMDS licenses, the government may only set aside 10–20 MHz for 3G. If the 10-MHz level gets adopted, capacity for a single-sector, microcell base station would be around 10 Mbps (10 MHz × 1 sector × 1 bit/Hz; larger cells employ sectorization but net of frequency reuse also work at 1 bit/Hz; the system would operate at 5 MHz in duplex, but we assume that asynchronous transmission would be deployed). If that 10 Mbps were shared among 300 subscribers, each would get 33.3 kbps on average, enough for voice or fax at 6 kbps plus lots more for data.

And if 10 percent of the 300 subs were active in a peak busy hour (most ISPs provision one modem for every 10–20 customers), each of the 30 active users would get 333.3 kbps allocated asynchonously. Assuming peak burst traffic among active data users would be only around 5–10 percent of this, 2-Mbps data rates could be supported (except during peak fractal usage spikes, which can be handled via router queuing protocols). Of course, if *everyone* wants to download simultaneously, the available capacity drops to a maximum 333.3 kbps non-duplex—not all that fast.

Over time, 3G capacity will rise substantially. Like 2G, it will initially deliver product at a design point of 1 bit/Hz/sector. But going forward, 3G is designed for software upgrades, so moving to 2 bits/Hz/sector—effectively doubling capacity—in 2002–2003 is a real possibility.

So, are these capacities enough? The answer is yes, assuming above usage patterns. Given that a 3G microcell would cover an area of one square mile or less, and likely CLEC penetration is probably below 10 percent, there shouldn't be a serious capacity problem except for fractal spikes.

Free-Space Optics

As noted earlier, the buzz on free-space optics (FSO) is that it is a "disruptive" technology that will supplant RF fixed wireless. Here's some of what's been said:

- "*TeraBeam [one of the leading FSO companies] commands at once the most disruptive and most redemptive technology in all communications—cheap, cellular, wireless multigigabit optics…It's a revelation. It's the fulfillment of the spectronic paradigm.… It blows open the last mile bottleneck into shards of light.*"—George Gilder
- "*My hunch is that TeraBeam is the next meteoric rise in the emerging telecom space. This is the first example of revolutionary technology I've seen in 23 years.*"—Jack Grubman, managing director, Salomon Smith Barney
- "*Periodically, technology is developed that has the power to significantly change the landscape…TeraBeam's Fiberless Optical Network system is such a disruptive technology.*"—Rich McGinn, chairman and CEO, Lucent

Whenever something gets this much hype, our

Whenever something gets as much hype as free-space optics has, our natural cynicism comes to the fore

TABLE 7 Current Free Space Optics Competitive Products

Company	Product	Bandwidth	Range	Price $U.S.
fSONA , Vancouver, Canada	SONAbeam	155Mbps–1.2Gbps	2–4 km	$18,000–60,000
Lucent/TeraBeam	Wavestar - Opticair	2.5–10 Gbps	5 km	Not available
Canon, Japan	Canobeam II	155 Mbps	4 km	$120,000
Jolt Communications, Israel	LACE Omnibeam	34–155 Mbps	1.2 km	$20,000
Astroterra, San Diego	Terralink	155 Mbps	8 km	$80,000
Astroterra, San Diego	Terralink	622 Mbps	4 km	$120,000
SilCom Mfg, Ontario, Canada	FreeSpace Turbo Laser	155 Mbps	0.3 km	$17,000
KMH Communications, UK	Skynet 500	100 Mbps	0.5 km	$15,000–17,000
Eagle Optics, Colorado	Lightstream	155 Mbps	1 km	$20,000
Eagle Optics, Colorado	Lightstream	20 Mbps	to 4 km	$27,000
AirFiber, San Diego	OptiMesh	622 Mbps	200–500 m	Not available

(Source: Industry sources)

Free-space optics service providers talk about needing a wireless system for backup

natural cynicism comes to the fore. Is free-space for real or is PR hyperbole running amok?

We begin by considering what it means to be a "disruptive technology." Disruptive technologies start out by being high-cost relative to existing technologies but, over time, they experience significantly faster cost/functionality improvements. The net result is that disruptive technologies soon offer significantly lower cost/higher functionality than the existing technology, and make it obsolete. In this context, which of these characteristics are true of FSO?

- **Performance under different atmospheric conditions:** Unless something works acceptably, nothing else really matters. For better or worse, POTS has set an uptime standard that presents competing systems with a high hurdle.

A couple of years ago, one of the authors had an opportunity to drive to the top of a hill on a rainy day to view a free-space trial. The equipment failed but, in fairness, it's our understanding that FSO works well for limited distances (up to 5 km) and with reasonable atmospherics.

However, the faster the bit rate, the lower the effective distance. Moreover, FSO will not work well in heavy rain/snow, and could suffer attenuation in foggy or dusty conditions. Also, atmospheric turbulence (seen when looking at objects near a hot asphalt highway) can significantly distort signals received across the aperture of an optical receiver, typically 10 centimeters or less. Turbulence is not a problem for microwave because those signals have much longer wavelengths than the turbulence in the air.

As a result, FSO service providers talk about having to install two local-access systems for their end customers—a high-bandwidth FSO system for acceptable atmospheric conditions and a lower bandwidth *wireline* system to be used as backup during poor atmospheric conditions—at a non-trivial capital cost and service penalty.

One additional issue: eye safety. Lasers that transmit at certain frequencies and above threshold power levels can injure people's eyesight. (When FSO first came on the scene, people used to make jokes about blinding flocks of birds and using the lasers as crude missile defense systems.)

That having been said, fSONA's (www.fsona.com) unit—and reportedly, Terabeam's—operates at 1550 nm, a level that's on the edge of the visible optical spectrum. In addition, operating at 1550 conveniently taps into most commercially available optical equipment (e.g., erbium doped fiber amplifiers).

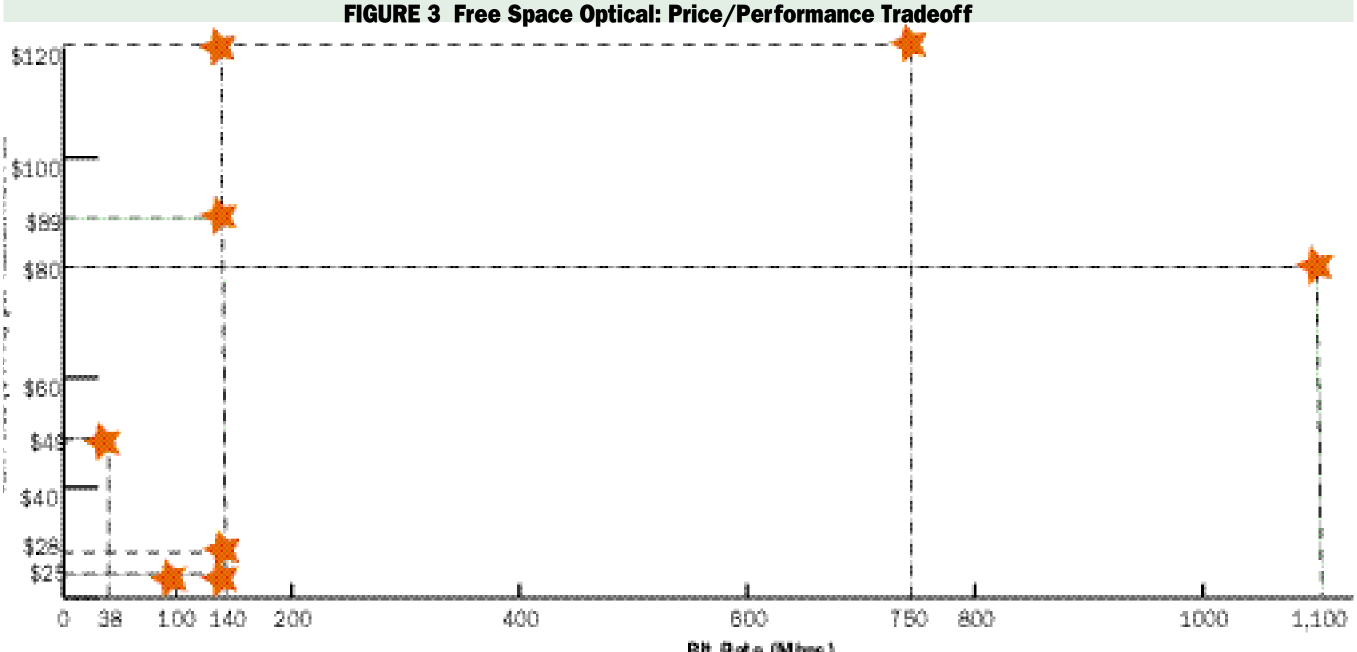
- **Capacity:** FSO can provide gigabits of bandwidth to individual buildings, as opposed to megabits for RF. However, as shown in Table 7, only two of the eight point-to-point products currently being offered deliver in the gigabit range, and they're both expensive.

A related issue is how much capacity is needed? For many buildings, a 622-Mbps line would provide more than enough capacity, at least for now. Giving these buildings a 10-Gbps connection is overkill.

- **Unit Cost—Today:** As shown in Table 7, the cost for point-to-point FSO equipment ranges from $15,000 to $120,000. If we plot peak bit-rate against price (Figure 3), bit-rates above 155 Mbps get pricey—in the $100,000–$120,000 range. Of course, the price-per-Mbps drops with overall scale.

This suggests that FSO may make sense for buildings with large aggregate bit-rate

FIGURE 3 Free Space Optical: Price/Performance Tradeoff



Source: Industry sources; author analysis)

The "disruptiveness" of FSO depends on the true rate of optical improvements

requirements. However, buying a $100,000 system and then only using 155 Mbps could result in a high-priced local access alternative.

Since pricing details for Lucent/Terabeam are not available, for Table 8 we "guesstimated" the economics of two plausible PTMP FSO systems compared to two equivalent PTP systems:

- 100-Mbps/1-km system for four sites linked via PTMP to a single transmitter location (compared to four PTP systems of the same capability).
- 1-Gbps/0.5-km system for four sites linked via PTMP to a single transmitter location (compared to four PTP systems of the same capability).

As seen in Table 8, PTMP FSO benefits from savings in the base optics and lasers/detectors, but requires additional cost for erbium doped fiber amplifiers (EDFAs) and wavelength division multiplexers (WDMs). This means that the savings for PTMP really kick in for higher-bandwidth systems that can amortize the EDFA/WDM cost. So we estimate around a 12-percent savings for PTMP at 1 Gbps and a 15-percent cost *disadvantage* at 100 Mbps. The 1 Gbps savings for PTMP versus PTP is less significant than the equivalent for RF, because in the latter case, common aggregate bit-rate capacity is shared among multiple users; with FSO, optical bandwidth is not shared.

In addition, one needs to include the cost for a backup wireline system during periods of poor atmospheric conditions. To minimize cost, a 10-Mbps PTP microwave link in the unlicensed spectrum could run $3,000 or less, but would cause substantial performance degradation.

- **Unit Costs—Future:** This is the key issue with respect to whether FSO is a "disruptive technology." To what extent do we expect current costs to come down, and at what pace relative to the RF alternatives? Put another way: Will the current article of faith—that all things optical (and particularly DWDM) are going down a cost curve roughly double Moore's Law—hold?

Table 9 is our best estimate of PTMP FSO unit

TABLE 8 Prospective Costs for Equivalent PTP and PTMP Free-Space Optical Systems (2000)

Subsystem Category	PTP 100 Mbps/1km	4 sites/PTMP 100 Mbps/1 km	PTP 1 Gbps/0.5 km	4 sites/PTMP 1 Gbps/0.5km
Optics	$5,000	$15,000	$15,000	$45,000
Lasers, detectors	$3,000	$8,000	$10,000	$ 20,000
EDFA	Not applicable	$15,000	Not applicable	$15,000
WDM, filters	Not applicable	$10,000	Not applicable	$10,000
Electronics	$500	$1,500	$1,000	$2,000
10 Mbps link backup	$5,000	$15,000	$5,000	$15,000
Chasis, power	$1,000	$2,000	$1,000	$2,000
Total costs	**$14,000**	**$66,500**	**$32,000**	**$109,000**
Per subscriber	**$14,500**	**$16,625**	**$32,000**	**$27,250**
PTMP discount versus PTP		-14.7%		14.8%

(Source: Authors' estimates)

TABLE 9 Prospective Costs for Equivalent PTMP Free-Space Optical Systems

Subsystem Category	2000 4 sites/PTMP 100 Mbps/1 km	2002 4 sites/PTMP 100 Mbps/1 km	2000 4 sites/PTMP 1 Gbps/0.5 km	2002 4 sites/PTMP 1 Gbps/0.5 km
Optics	$15,000	$10,500	$45,000	$20,000
Lasers, detectors	$8,000	$4,000	$20,000	$10,000
EDFA	$15,000	$10,000	$15,000	$10,000
WDM, filters	$10,000	$ 7,000	$10,000	$7,000
Electronics	$1,500	$ 1,000	$2,000	$1,000
10 Mbps link backup	$15,000	$10,000	$15,000	$10,000
Chasis, power	$2,000	$1,500	$2,000	$1,500
Total costs	**$66,500**	**$44,000**	**$109,000**	**$59,500**
Per subscriber	**$16,625**	**$11,000**	**$27,250**	**$14,875**
2002 cost reduction %		34%		45%

(Source: Authors' estimates)

costs in 2002. We believe that unit costs for 1-Gbps systems are likely to decline by 45 percent, or an amount roughly equal to the cost reductions anticipated for RF.

Essentially, the greater-than-Moore's Law rates seen in DWDM come from the ability to multiplex ever greater numbers of *lamdbas* onto equipment, as opposed to direct massive cost reductions in the individual components. Since FSO systems will be using a number of non-multiplexed components, we don't anticipate 2× Moore's Law rates.

The bottom line? We aren't technological troglodytes, and we think that free space optics is exciting technology, particularly for buildings with high bandwidth requirements that are close to a fiber ring. We also are keenly aware that not all of the technological underpinnings of offerings such as Terabeam's have been disclosed. That said, we don't see FSO as the all-encompassing "disruptive" technology that its proponents make it out to be.

TABLE 10 Optimal Local Access Choice By Building Charactistic

Distance From Existing Network	Low	Medium	High
High	3G Fixed Wireless	PTMP	PTMP
Medium	3G Fixed Wireless/DSL	PTMP/DSL	Free Space Optics
Low	DSL/3G Fixed Wireless	DSL/PTMP	Fiber

Aggregate Building Bandwidth Requirement

Conclusion

There are three prospectively attractive wireless, local-access technologies. And as shown in Table 10, each has a potential space in the topology depending on aggregate building bandwidth requirement and distance from the network originating point.

The low-cost solution for high bandwidth/short distance applications is *optical fiber*. For buildings with high-bandwidth requirements that are "off-fiber-net" but relatively nearby (e.g., within a kilometer), *free-space optics* offers a logical solution. Such buildings can utilize FSO's high bandwidth and can amortize the high connection cost per building. However, FSO's distance limitation makes it non-feasible for buildings located far from central transmitters.

Buildings with moderate bandwidth requirements are in the realm of *DSL and PTMP*. DSLis distance-constrained to conditioned loops within a specific number of feet from a central office; beyond this, PTMP is a good alternative. Also, the higher the bandwidth requirement, the greater the advantage for PTMP, because it can deliver OC-level bit rates, while DSL cannot.

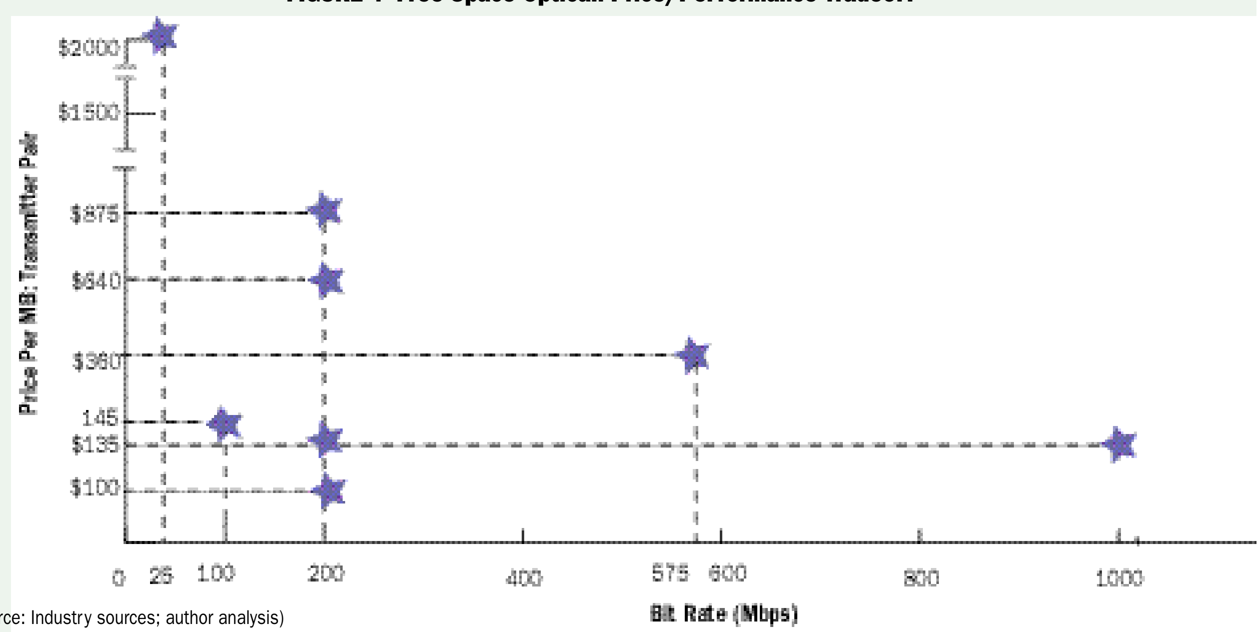
Buildings with bandwidth requirements of 2 Mbps or less can choose between *DSL* and *3G fixed wireless*. Again, DSL is distance constrained, and it may have a cost disadvantage, particularly where there is a separate collocation/DSL office architecture.

So, relative to the overall question of the wireless local loop we have reached two fundamental conclusions:

1. Wireless access has an important role to play in next-generation networks

2. There is no "magic bullet;" different forms of wireless access are appropriate for different building situations□

FIGURE 4 Free Space Optical: Price/Performance Tradeoff



(Source: Industry sources; author analysis)