LEHMAN BROTHERS

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Telecom Services

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EMERGING NETWORK COMPANIES: EXPLOITING INDUSTRY PARADIGM SHIFTS

- The emerging network companies are positioned to exploit the explosive growth (100%-plus per year) in Internet and data traffic and the paradigm shift from voice to high bandwidth data networks.
- We believe that the growth of the new network providers will also be driven by current capacity shortages and the proliferation of new competitors, including CLECs, Internet Service Providers, and RBOCs, which is driving 15% annual revenue growth in the wholesale market.
- Capacity glut concerns are overblown, in our opinion.

  First, we expect high incremental capital and operating costs to light the new fiber and grow revenue to mitigate pricing pressures. We estimate it would cost 5-10 times the initial network construction investment to completely light the new networks with 8 windows of OC-192. Qwest has only lit about 1% of its total potential capacity to date.

  Second, new entrants with low share and low cost position, we believe, have attackers advantages (i.e., they can outrun pricing pressure.)

  Third, Internet, data and video, which requires 10-1,000 times the capacity of voice, with growth rates of 100%-plus per year, should fill potential capacity over time.

  Finally, we believe that pricing pressure will mainly be focused in network-intensive, commodity-like wholesale and private line markets.
- We view the RBOCs as potentially large customers, partners and perhaps acquirers of the new network companies. We believe that the likelihood of an RBOC buyout increases in 12-24 months as the RBOCs begin to enter the long distance market.
- We see the window of opportunity in the wholesale market beginning to close, as new entrants lock in long-term deals. Combined, Qwest, IXC and Williams' wholesale revenue forecasts for the year 2001 equal 50% of our bottom-up wholesale market forecasts.
- Retail distribution, service assets, and speed to market are key points of differentiation, especially given the increasing competition in the wholesale market. Qwest's acquisition of LCI was motivated by the need to accelerate the development of strong distribution assets and we expect more consolidation that pairs distribution and network assets in the future. We believe that strong distribution assets would enhance the likelihood and price of an RBOC acquisition.
- We reiterate our 1 Buy rating on Qwest. Qwest is currently trading at 17 times 1999 EBITDA, 11 times 2000 EBITDA and 3.9 times 1999 revenue. At 17 times, Qwest is trading at just 0.41 times expected three-year EBITDA growth of 42%. Telecom EBITDA multiples have typically traded at 0.4-0.5 times expected growth. We would expect Qwest to trade at the upper end of the range given its state of the art network, strong distribution channels, time to market advantages, strong balance sheet, and strong brand name.

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VALUATION

We have valued Qwest Communications International using 10-year DCF valuations and near-term EBITDA multiples. Our 10-year DCF assumes that the new network entrants take 15%-20% share of the long distance market by 2008 (Second tier long-distance competitors were able to take 10%-15% of the market in the last 10 years despite owning very little network). We believe that EBITDA returns on fixed assets will be 25%-30%, in line with historic long distance returns (see Figure 1). We estimate fixed asset turnover at 0.8-1.3 times and EBITDA margins in the low-high 20% range – both in line with historic averages. We have used a discount rate of 14% and terminal EBITDA multiplier of 10 times with a 25% public market discount.

Figure 1: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Long Distance Returns

	EBITDA Margin	Fixed Asset Turnover	EBITDA/ Fixed Asset	Return On Net Assets	Return on Equity
ATT (1996)	23%	1.3X	30%	15%	29%
MCI (1995)	21%	1.0X	24%	8%	12%
WCOM (1994)	20%	2.4X	46%	7%	10%
WCOM (1995)	27%	1.8X	48%	9%	19%
LCI (93-97 avg)	19%	1.5X	28%	11%	23%
Sprint (95-97)	27%	0.6X	17%	11%	20%
LD Only	22%				

Unlevered return = Operating Income less taxes
Source: Lehman Brothers estimates.

High growth telecommunications stocks have historically traded at firm value/EBITDA multiples between 0.4-0.5 times expected EBITDA growth. Figure 2 compares EBITDA and revenue growth, and firm value/EBITDA and firm value/revenue based on current stock price and projected net debt at the beginning of the year.

Figure 2: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Valuations Comparables ($ in Millions)

	Ticker	Rating	Price	FD Shares	Net Debt YE '98	Firm Value	'99 Revenue	'99 EBITDA	Firm Value / '99 Revenue	Firm Value / '99 EBITDA
Qwest	QWST	1-Buy	$35 1/4	346.1	$1,369	$13,569	$3,514	$798	3.9x	17.0x
MCI-WorldCom	WCOM	1-Buy	$51 13/16	1,819.0	$17,200	$111,447	$37,601	$11,625	3.0x	9.6x
AT&T	T	2 - Outperform	$63 13/16	2,252.0	$22,757	$166,463	$62,481	$19,494	2.7x	8.5x
Sprint	FON	1-Buy	$75 3/16	440.0	$4,429	$37,512	$17,467	$4,306	2.1x	8.7x
Frontier	FRO	3 - Neutral	$28 9/16	174.0	$834	$5,804	$2,803	$669	2.1x	8.7x
WorldCom 9/97 (1)		n/a	n/a	n/a	n/a	$41,400	$9,425	$2,785	4.4x	14.9x
Intermedia	ICIX	3 - Neutral	$24 1/16	57.8	$2,475	$3,866	$1,056	$170	3.7x	22.7x
ICG	ICGX	1-Buy	$22 1/4	46.8	$1,483	$2,524	$790	$90	3.2x	28.0x
McLeod	MCLD	2 - Outperform	$34 3/4	69.8	$553	$2,979	$755	$45	3.9x	66.2x
Electric Lightwave	ELIX	1-Buy	$6 5/8	49.7	$470	$799	$170	($54)	4.7x	n/a

(1) Based on Fwd 12 Months Revenue, EBITDA, and Growth Rates at 9/97

Based on closing prices 10/23/98
Source: Lehman Brothers estimates.

Figure 3: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Network Companies Valuation

	FV / REVENUE		FV / EBITDA		'99 - '02 GROWTH			
	'99	'00	'99	'00	REV	EBITDA	FV/'99 Rev to Growth	FV/'99 EBITDA to Growth
Qwest	3.9x	2.9x	17.0x	11.0x	27.2%	41.7%	0.14X	0.41X
IXC (1)	2.7x	n/a	13.1x	n/a	n/a	n/a	n/a	n/a

	FV / Route Miles (000s)		FV / Fiber Miles (000s)		FV / PP&E
	Current	Planned	Current	Planned	'98
Qwest	$1,542K	$733K	$32K	$15K	6.2x
IXC	$275K	$170K	$13K	$5K	2.0x
Level 3 (1) (2)	n/a	$468K	n/a	$5K	n/a

(1) Based on 1999 consensus estimates and company guidance
(2) Firm Value is estimated value for network division only excluding PKS Info systems, coal mining, and holdings of RCN, Cable Michigan, Commonwealth Tel
Source: Consensus estimates, company guidance and Lehman Brothers estimates.

CATALYSTS

We see three catalysts for Qwest over the next few quarters: (1) network mileage should double over this time period which should help to accelerate revenue growth and increase gross and EBITDA margins; (2) we expect Qwest to announce another major partnership within the next few weeks similar to the Netscape deal; and (3) we believe Qwest will announce a venture, partnership, or acquisition that expands its business into Europe. Qwest 's sequential third quarter 1998 telecom services revenue growth rate hit 11% and is on target to meet our 1999 revenue estimate of $3.5 billion.

INVESTMENT THESIS

We believe there are four key factors that will drive the success of the new long distance network providers. First, these network providers have built high capacity networks to take advantage of the shortage in incumbent network capacity exacerbated by an explosion in the demand for bandwidth driven by data and the Internet. Second, the new network providers are targeting the highest growth market segments: the $25 billion Internet and data markets, where volumes are growing 100%-plus annually, and the $8 billion wholesale market. Third, the new network providers are well positioned to serve, partner with, and perhaps be acquired by the powerful RBOCs who will enter the long distance business over the next couple years. Finally, advances in processing power and network technology have driven down the costs of capacity.

Capacity Shortages

The incumbent providers have had a shortage of high bandwidth capacity to sell to wholesale customers over the past three years. In fact, we understand that a couple of the major carriers have had bandwidth rationing review committees to allocate high bandwidth capacity to large customers. We believe this is a function of three things: (1) capacity additions in the industry have historically followed demand increases fairly closely and have been constrained by capital spending limitations. We believe that incumbent carriers have been using scarce network capital to satisfy retail demand rather than wholesale demand; (2) there is getting to be some real shortages of capacity at current technology levels. This requires even higher levels of capital spending to increase from OC12 to OC48 (or higher) or to add dense wave division multiplexing (DWDM). We believe that a couple of the large wholesale deals announced by the new network providers are sales to incumbents which confirms our view that capacity has been in short supply; and (3) the incumbents may have underestimated the demand from new entrants like CLECs and ISPs.

The bottom line for the new network providers is that this shortage is allowing new entrants into the market and giving them the opportunity to develop customer relationships and profitable revenue streams.

Targeting High Growth Segments

The new network providers are targeting the high growth Internet/data and wholesale markets. We believe that data and Internet traffic comprises about 40% of all traffic today and is growing at over 100% per year. We believe that growth in residential and business use of the Internet and demand for higher speeds, increasing use of electronic commerce and video applications, will drive orders of magnitude increases in demand for bandwidth. Data, Internet and video require 10–1000 times more bandwidth than voice traffic.

Historically, new telecom entrants have had better success taking share in new markets versus taking share from the base. MCI, WorldCom and AT&T's other competitors historically have captured as much as 60%-70% share in new markets (800, virtual networks and frame relay) versus just 30%-40% in traditional voice networks. It's easier to get new business from a customer than displace a competitor, especially where new technology reduces the incumbents' advantages.

Wholesale Opportunity

Deregulation and the rise of the Internet has driven a dramatic increase in the number of new entrants including CLECs, new long distance companies and Internet service providers. Deregulation will eventually allow the RBOCs into long distance. This proliferation of new entrants has created increasing needs for wholesale capacity which, we believe, will drive 15% annual revenue growth over the next fourth years in the $8 billion wholesale market. The new network providers already have signed $3.5 billion in multiyear contracts.

RBOC Opportunity

RBOC entry provides these new entrants with key partners, customers and perhaps acquirers. We view the RBOC – network provider relationship the same as the CLEC - long distance relationship. Teleport and MFS sold services to the large long distance companies and eventually were acquired by AT&T and WorldCom. We believe that the RBOCs could be acquirers of these network companies in 12-24 months as they move closer to long distance entry.

Technology Changes and Cost Advantages

Dramatic improvements in processing power and network technology have pushed down transmission costs. In 1986, fiber electronics provided for 4 DS3's of capacity per fiber pair, in the mid 1990s you could put 48 DS3s on a fiber with OC48 optronics – today you can put 192 DS3's on a fiber and with dense wave division multiplexing (DWDM) can increase this by a factor of 8 today and technology is being developed for up to 96 – 128 window DWDM. OC768 technology is in the lab and could be ready in three years.

This improvement in technology as well as the shift from circuit switching to ATM and packet switching are allowing the new entrants to build higher capacity networks for less than the incumbents spent on their lower capacity networks. In addition, the change in technology is reducing the experience edge of the incumbents.

In our opinion, these advantages give the new entrants a window of opportunity in entering the market dominated by the three large long distance companies – AT&T, MCI/WorldCom and Sprint. Each of these incumbents has, or is building, its own Internet and data capabilities and they are all in the process of expanding capacity and migrating to packet switching technologies. However, we think that the edge the new entrants have is enough to allow them to capture 15%-20% of the market over the next 10 years. The second tier long-distance providers were able to take over 20% share in the small and mid-sized business market and 10%-15% overall share over the past 10 years.

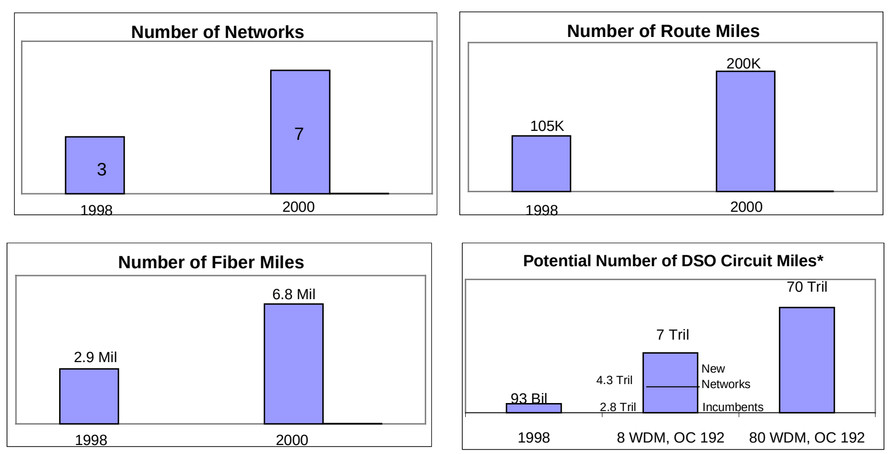
SUPPLY AND DEMAND

Supply

Supply will increase over the next two years as the new providers build out their networks. The number of long distance networks is expected to increase from three to at least seven and potential capacity could increase to levels of 70--700 times today's capacity — potential capacity assumes that all fiber in the ground is fully equipped with the maximum SONET electronics and DWDM (see Figure 4). Total fiber miles will almost triple to 6.9 million fiber miles when the planned networks are complete in 2000. Potential capacity will increase to between 7 trillion and 70 trillion DS0 circuit miles assuming that all new entrant and incumbent networks upgraded all fibers to OC192 with 8 window DWDM (7 trillion) or 80 DWDM (70 trillion). We estimate that the three incumbent carriers currently average about an OC48 worth of capacity on their networks. This results in 94 billion DS0 equivalent circuit miles (2.9 million fiber miles x 48 DS3s x 672 DS0/DS3). In the same period, we expect bandwidth needs to grow 30%-60% per year to about 3-6 times today's levels which means that in the near-term demand will not come close to filling potential capacity (see Figure 6).

However, we believe that capacity glut concerns are overblown. There are shortages of capacity today and it takes time and capital to light the fiber. Also, over time, we expect demand to expand to fill capacity (see Figure 6). In addition there are high additional incremental costs to drive revenue growth that will mitigate competitors' ability to cut prices, and we believe new entrants with low share and lower cost networks can outrun pricing pressure. We discuss these factors in more detail later in this report.

Figure 4: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Industry Capacity and Competition Are Increasing



Source: Lehman Brothers estimates.

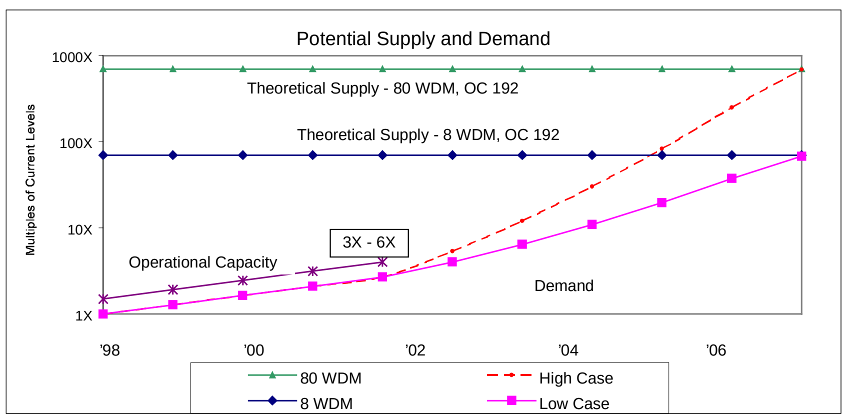
Figure 5: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Network Capacity

	Current					Theoretical Potential		
	Route Miles *(000s)*	Retained Fiber Miles *(000s)*	Speeds	WDM	DSO Circuit Miles *Billions*	Speeds	WDM	DSO Circuit Miles *Billions*
Current Incumbent Capacity								
AT&T	41.0	1,385.0						
MCI-WorldCom	40.0	1,060.0						
Sprint	24.0	480.0						
Subtotal	105.0	2,925.0	OC 48 or Equivalent		94	OC192	8.0	3,019
New Networks Potential Capacity								
QWEST	18.5	888.0				OC192	8.0	917
Williams	32.0	512.0				OC192	8.0	528
IXC	15.0	465.0				OC192	8.0	480
Total - Qwest, Williams, IXC	65.5	1,865.0				OC192	8.0	1,925
GTE (1)	13.0	312.0				OC192	8.0	322
Frontier (2)	16.0	345.0				OC192	8.0	356
Level 3 (3)	15.0	1,440.0				OC192	8.0	1,486
Subtotal	80.5	3,962.0						4,090
Total	185.5	6,887.0			94	OC192	8.0	7,109
Theoretical max as a multiple of todays incumbents capacity								76x

(1) GTE bought 24 fibers on original Qwest network of 13K miles
(2) Frontier bought 24 fibers on original Qwest network of 13K miles, and bought 3K miles, 11 fibers, from Williams
(3) Level 3 estimates are for US long haul network only

Source: Lehman Brothers estimates.

Figure 6: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Supply and Demand



Source: Lehman Brothers estimates.

In addition to IXC, Qwest, Level 3 and Williams, there are now two new plans to build national networks. Enron and Digital Teleport have both announced plans to build 18,000-20,000 national fiber networks. These national networks are also supplemented by regional fiber networks including Metromedia Fiber, McLeod and ITC DeltaCom, and Pathnet, which plans to build digital microwave networks to second tier markets.

Incumbent Network Supply and Upgrades

We believe the incumbents are currently using a mix of OC12 and OC48 optronics and are installing DWDM in their networks. Sprint has installed DWDM equipment throughout its network using anywhere from 4 window to 40 in some places. We believe that very little of the DWDM for the incumbents is lit at this point.

There is some debate within the industry on the ability of the incumbents to upgrade their networks to higher speeds and DWDM (see Appendix F). Some of the older fiber does have limitations, but in general the incumbents can reach OC48 speeds and use DWDM up to 80 windows. Older single mode fibers require additional amplifiers in order to reach OC192 speeds. Corning (a fiber manufacturer) estimates it cost 30% more to light single model fiber (which most incumbents use) with OC192 than with non-zero dispersion shifted fiber (which is what new network companies use).

Capacity Glut Concerns Are Overblown

We believe that concerns related to the overcapacity issue and resultant competitive pressure are overblown. 1) There are high incremental costs to light the fiber and to acquire and service customers that, in our opinion, will mitigate any competitor's ability to slash prices to gain market share. Potential capacity does not equal operational capacity. It costs about $1 billion to fully light 8 windows on just 1 fiber pair over a 20,000 mile fiber network AFTER the initial $1.5 billion-$2 billion investment has been made in right of way, conduit and burying the fiber in the ground. If all the new networks are fully built out, it will take $86-$172 billion in capital (see Figure 7) – In comparison, it costs roughly $8 billion in initial construction investment for the four networks ($172 billion is at today's cost; $86 billion builds in expected 50%-70% cost decline over the next several years). Even if only 20% of capacity is used, it still costs more to light the network than it costs in initial construction. In addition, routers, switches, multiplex equipment, and other infrastructure expenses drive the cost of adding capacity even higher.

Figure 7: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Cost to Light Networks to Full Capacity

	Investment to Light OC192 8DWM		
	Construction	Optronics	Total
IXC	$1.5B	$10B	$11.5B
Level 3	$2B	$41B	$43B
Qwest	$2B	$25B	$27B
Williams	$2B	$15B	$17B
New Networks	$7.5B	$91B	$98.5B
Incumbents (AT&T, MCI WCOM, Sprint)		$81B	$81B
Total	$7.5B	$172B	$179.5B

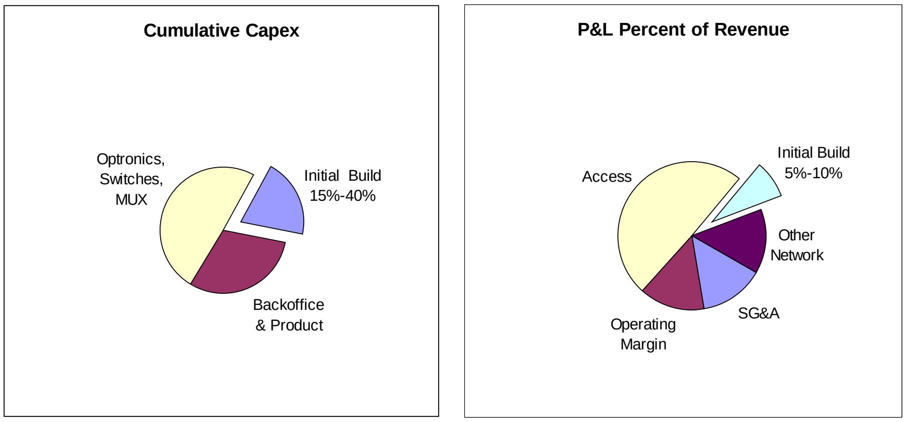
* Based on current market prices of $5K-$6K/mile/fiber strand for first window and $3K - $3.5K/window for additional windows.
(Translates to $0.025 / voice grade equivalent / per mile)
These costs could fall 50%-70% over the next 10 years.

Source: Lehman Brothers estimates.

The high costs of lighting fiber is the reason why potential capacity has always exceeded demand. Capital spending constraints, controlled by the financial markets, has historically kept supply in closer step with demand. Today, for example, Qwest has just 1% of its 384 windows lit.

We estimate that the upfront capital costs to install the fiber will represent just 15%-40% of the total long-term capital structure of the new network providers and only about 10% of the operating costs structure (see Figure 8). SG&A, access costs, and the depreciation and operating costs of the other network elements make up a much larger portion of the overall costs structure.

Figure 8: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Capital and Operating Cost Structure



Source: Lehman Brothers estimates.

2) The new network providers have low share (not much embedded base at higher prices) and a lower cost structure, which should allow them to outrun industry pricing pressures. This is similar to the experience of MCI, WorldCom and Sprint which all were able to successfully take share from AT&T despite the pricing pressures of the first 10 years.

3) Over time we believe that demand will expand to fill unused capacity. This expansion will be fueled by data and the Internet which is currently growing 100%-plus per year and which requires 10-1000 times the capacity of a voice call. The expansion will also be enabled by the availability of cheap high bandwidth capacity.

4) We believe that most pricing pressure will be focused in the more commodity-like wholesale and private line markets. These are the most highly network intensive segments and are generally more price elastic. As shown in Figure 9, network depreciation and operating costs run about 50% of revenue for wholesale and private line versus just 15% for retail switched services. We believe that the wholesale segment will, and already has, seen pricing pressure due to the increase in number of network wholesale providers. We believe that wholesale prices for DS3s have fallen from the $0.04/DS0-mile level of a couple years ago to $0.03-$0.04 currently with prices for OC level service below $0.03. We note that Qwest, IXC, and Williams are insulated from any additional pricing pressure based on the contracts they have locked in to date.

Figure 9: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Product Cost Structure (Percent of Revenue)

	Switched Business Products (Outbound, 800)	Private Line	Frame Relay	Business Internet	Wholesale Private Line	Total Business
Access/Int'l.	60%	15%	37%	15%	15%	52%
SG&A	13%	14%	13%	13%	6%	14%
Network Ops	6%	12%	15%	11%	8%	9%
Depreciation	9%	39%	23%	28%	39%	11%
Network + Depreciation	15%	51%	38%	39%	47%	20%
Market Size	$40B	$8B	$3.5B	$3.7B	$4B	$60B

Source: Lehman Brothers estimates.

Demand Growth and the Shift to High Bandwidth Data

We expect demand for bandwidth to grow dramatically over the next 10 years enabled by the greater availability and lower cost of bandwidth and driven by the power of the Internet and customer demand for transport of data and video to the home and desktop.

While the increase in potential capacity looks huge, it is important to look at the order of magnitude difference in speed and bandwidth required for data, Internet and video versus voice. A 5-minute voice call requires a speed of 64,000 bits/second and transmits 38 million bits. This is just a fraction of the speed and data transmitted in LAN communications or required for video.

Figure 10: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Bits Transported

	Speed/Bandwidth	Bits Transported
5 Minute Voice Call	64 kbps	38 million
Sell Side Research Report Sent Via Internet	28 kbps – 1.5 mbps	10 - 20 million
5 Minute Video Clip	100 mbps	30 billion
Lan to Lan Communication	100 mbps	

Source: Lehman Brothers estimates.

We estimate that packetized data (frame relay and ATM) and the Internet volumes (as expressed in bits per year) will grow at least 100% per year for the next several years (we base this estimate on analyses done by IDC, Dataquest, and Kagan research reports as well as from discussions with industry executives.) Based on the research reports, we expect access bandwidth (the total size of all circuits from the customer to the long-haul network) to double over the next four years growing 20% per year (see Figure 11). (The detailed IDC circuit forecast is presented in Appendix C). We believe the number of bits will grow faster, perhaps much faster, as usage per customer increases. If Internet usage per customer increases four-fold over this period, total Internet demand (measured by bits) would increase 30 fold or over 135% per year (compared to estimates from MCI WorldCom and others that Internet usage is doubling every three-four months). At these levels total demand would increase 6 times today's levels. If Internet usage just doubles, then total demand will grow to 3 times current demand levels.

Figure 11: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Demand Forecast 1998-2002

	Users / Minutes / Lines		Average Connection Speed		Total Access Bandwidth (In Terabits (10^12))			Total Demand (Bits/Yr * 10^{15})		
	'98	'02	'98	'02	'98	'02	CAGR	'98	'02	CAGR
Voice (Access Lines)	580B Minutes	850B Minutes	64 KBPS	64 KBPS	10.2	12.4	5%	4,454	6,521	10%
Retail Private Lines (1)	600k Lines	750k Lines	561 KBPS	650 KBPS	0.3	0.5	14%	2,455	4,000	13%
Residential Internet (2) (3)	22.6M Users	37.6M Users	14.4 KBPS	167 KBPS	0.3	6.3	114%	97	3,500 - 7,000	145% - 191%
Business Internet (4)	2.8M Connections	7.0M Connections	167 KBPS	505 KBPS	0.5	3.5	63%	636-1,133	8,900-31,800	93% - 130%
Frame/ATM/SMDS/X.25 (4)	955K Ports	2.1M Ports	736 KBPS	1.3 MBPS	0.7	2.7	40%	664	2,579	40%
Total					12.0	25.4	21%	8,550	25,500 - 51,900	31% - 57%

SOURCES / NOTES:

(1) AT&T Labs study by A.M. Odlyzko and K.G. Coffman
(2) Res. Internet Users from Paul Kagan Associates
(3) Assumes avg. connection speed is 14.4 KBPS in 1998. 10% of users on cable or DSL using 1.5 MBPS in '02.
(4) Users/Ports & Speeds from IDC
Access bandwidth = Number of lines or users X connection speed. (There are 160 million voice lines)

1998 BIT ASSUMPTIONS:

Voice	580 Bil minutes/yr * 64 KBPS * 2 way * 60 Sec/Minute = 4454 * 10^15
Private Line	5K minutes/line/month * 12 months * 60 sec * 561 KBPS/64kbps per line * 64kbps * 2 * 600k lines = 2455 x 10^15
Frame/ATM	955K Ports * 736 KBPS * 3% usage * 31.5M sec/yr = 664 * 10^15
Res. Internet	22.6M users * 23 hrs/month * 3600 sec/hr * 14.4 KBPS * 30% download time/hr * 12 months = 97 * 10^15
Bus. Internet	Based on total Internet (see below) less residential.
Total Internet estimate:	MCI said its Internet backbone carried 740 terabytes of data in November 1997. Assuming MCI carried 25% of Internet traffic, then toal annual traffic was 284 X 10^15 (740 X 10^12 X 8 bits X 12 months X 1/25%). This was about 4% of total traffic. If we assume that traffic quadrupled in the past year (double every 6 months), then total Internet traffic would have averaged 726 X 10^15 bits/year in 1998. Doubling every 4 months, Internet traffic would be 8X higher today, and would average 1225 X 10^15 bits/year in 1998.

Ranges shown for Internet traffic (bits) in 2002 assumes usage/user ranges between doubling or quadrupling.

Source: Lehman Brothers estimates.

Figure 12: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Revenue Forecast

	Revenue				
	1998	2002	CAGR	Volume CAGR	Drivers
Voice (1)	$79.1B	$92.5B	4%	10%	10% volume growth
Private Line (1)	$12.3B	$15.5B	6%	11%	10% - 12% volume growth
Residential Internet (2)	$5.5B	$11.5B	20%	108%	Penetration increases from 23M to 36M users.
Web Hosting / Value Add (3)	$1.1B	$4.9B	45%		
Dial Access	$0.8B	$1.6B	19%		
Dedicated Acess	$1.8B	$12.2B	61%	66%	Penetration increases from 3M connections to 7M (35% - 80% penetration)
Business Internet (3)	$3.7B	$18.7B	50%		
Frame Relay/ATM (3)	$5.1B	$12.5B	25%	40%	LAN and Internet Growth, SNA to LAN migration
Total	$109.4B	$169.4B	12%	29%	
Wholesale (1)	$8.0B	$12.0B	11%		

(1) Lehman Brothers Estimates
(2) Paul Kagan & Associates Estimate
(3) IDC Estimate

The key driver of bandwidth growth is clearly Internet traffic. In the short term, we see increasing penetration of Internet services in the home and office driving up demand. We believe that Internet traffic is growing at least 100% per year. IDC estimates that currently 35% of all businesses (over 50% when weighted by number of employees) and 20%-25% of homes (23 million homes) are connected to the Internet. Driving volume beyond these levels will come from (1) increased penetration to the 40% range for the homes and 80% for business by 2002, (2) the demand for higher bandwidth services that will allow faster response time and (3) increased usage. We have assumed that 10% of all homes will have T1 level (1.5 Mbps) Internet service by 2002 using either ADSL (asynchronous digital subscriber line) or cable modems, both of which have theoretical one-way capacity of 4.5 – 9 Mbps. Using the IDC and other forecasts we predict that the average speed of a business connection will increase from 167 Kbps today to over 500 Kbps by 2002.

We have shown growth sensitivities assuming that usage/user either doubles or quadruples. We expect that business usage to expand significantly over the next three-five years.

The second key driver is frame relay and ATM packet data services. We estimate that these services will increase in volume at 40% per year over the next four years. This growth is being driven by the need to connect client server PC networks and to convert old SNA private line data networks to client server technology, as well as by the Internet that uses frame relay as one way for businesses to access the network.

Long Range Demand Forecast

In order to drive a 70 times increase in capacity, bandwidth demand must increase 53% per year for 10 years. In order to begin to fill the potential capacity, bandwidth needs per user, number of users and usage/month has to increase. If every phone line in the country were upgraded to a T1, then network capacity would have to increase just 24 times (at constant usage levels). Therefore, in order arrive at 70 times increases even higher speeds and greater usage is required.

Figure 13 illustrates the combination of bandwidth speeds per user and usage per month required to drive various increases in network capacity, assuming a total of 140 million users (70 million homes and 70 million employee PCs). In order to reach these levels we think video usage has to start to play a larger role. Full motion, uncompressed video requires speeds of 100 Mbps. Currently ADSL and cable modem technology appears to be able to deliver speeds up to 9-10 Mbps.

Figure 13: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Demand Sensitivity

Increase In Capacity Required
By 2008 *
(Multiples of Current Capacity)

Usage Hours Per Month / PC	Internet Connection Speed			
	1.0 MBPS	1.5 MBPS (T1)	4.5 MBPS	9 MBPS
20	15X	23X	68X	138X
40	30X	46X	136X	276X
100	75X	115X	340X	690X

* Assumes PC grows to 70M households (70% penetration) and 70M business users (80% penetration). Also constant data flow during the 20 hours per month (I.e, not occasional bursts).

Source: Lehman Brothers estimates.

We also believe that electronic commerce will grow exponentially helping to drive demand for higher bandwidth for Internet and data services. PC industry pundits see the day when every person has electronic agents constantly in the network pulling down data to the PC that is customized to the individual user. In addition, there is potential for connecting virtually every appliance with a chip to the Internet to increase the usefulness of the appliance and communicate information to users and manufacturers.

The Shift From Voice to Data

The higher growth in data and the Internet versus voice is clearly driving data volumes toward those of voice. As shown in Figure 11 we estimate the volume of bits/year for each type of service. Our estimate is that 10% of voice is fax traffic while perhaps as much as 50% of private line is voice. Using this math, data is currently about 40% of total traffic but could grow to 70%-80% by the year 2002.

Network Deployment and Capital Costs

We expect Qwest to be the first company to complete its network in mid 1999. IXC will largely be complete by year-end 1999. Williams will be largely complete by year-end 2001 and Level 3 is expected to complete its network in 2001. (see Figure 14). Qwest built a 96 fiber network and will retain 48 fibers. The Williams network is a composite of its 11,000-mile single fiber that it retained from Wiltel/WorldCom and new builds and swaps (see Williams section for more information). On the large volume segments the company is installing as many as 96 fibers with the intention of retaining 24 for its own use. IXC also plans to retain 31 fibers for its own use. Level 3 is planning to build a 96+ fiber system and to retain 96 fibers. Level 3 has already sold 24 fibers to Craig McCaw and Nextlink/Nextel.

Figure 14: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Network Deployment

	Current	YE '98	YE '99	YE '00	Total Planned	When Completed
Route Miles						
IXC	9,300	11,500	15,000	15,000	15,000	1999
Level 3	-	-	5,000	10,000	15,000	2001
Qwest	8,800	13,000	18,500	18,500	18,500	1999
Williams	15,170	18,414	25,000	28,000	32,000	2001
GTE	5,000	8,000	13,000	13,000	13,000	1999
Frontier	5,000	8,000	13,000	16,000	16,000	2000
Total	33,270	42,914	63,500	71,500	80,500	

Retained Fiber Miles	Current	YE '98	YE '99	YE '00	Total Fibers Retained	Total Fibers Built
IXC	204,000	312,000	410,000	465,000	31	48
Level 3	-	-	480,000	960,000	96	144
Qwest	422,400	624,000	888,000	888,000	48	96
Williams	75,000	117,094	207,500	250,000	9	48
GTE	120,000	192,000	312,000	312,000	24	N/A
Frontier	120,000	192,000	312,000	345,000	22	N/A
Total	941,400	1,437,094	2,609,500	3,220,000		

Source: Company reports and Lehman Brothers estimates.

It costs roughly $80,000- $100,000 per route mile for right-of-way, fiber and construction. In total, this drives almost $2 billion in capital for the initial construction of these 17,000-20,000 mile networks (Williams will have 32,000 mile when its network is complete including the 11,000-mile single fiber). Figure 15 compares the capital costs for each of these companies over the next three years. IXC's initial capital costs are below $2 billion because it is building 15,000 miles and swapping for 4,000 miles so it is just constructing 11,000 miles.

Offsetting the capital costs for Qwest and Williams are dark fiber sales. Williams does not recognize any of its dark fiber sales as revenue but instead reduces its gross fixed assets by the amount of each dark fiber sale. IXC recognizes all dark fiber sales as revenue and amortizes it over a 20-year period on the P&L and doesn't adjust gross fixed assets. Qwest does a little of both. It recognizes the revenue from the sale in the period it turns the fiber over to the customer but it also recognizes the amortized capital costs as operating costs on the P&L when it recognizes the revenue. It simultaneously reduces the gross fixed assets by the cost basis of the plant. The end result is that Williams is reducing it book assets the most – by the amount it sells dark fiber for – while Qwest is reducing assets by the actual cost.

Figure 15: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Capital Costs

Cumulative Capital Spending - 2001 $M

	Fiber & Construction	Optronics, Switches, Backoffice, Other	Gross Capex	Adjustments *	2001 Reported Gross Fixed Assets
IXC	$1,275	$1,075	$2,350	$0	$2,350
Qwest	$2,000	$3,334	$5,334	($1,085)	$4,249
Williams Network	$1,870	$995	$2,865	($600)	$2,265

		Capital Expenditures						
	1997 Gross Plant	1998	1999	2000	2001	2001 Gross Plant Pre Adjustments	Adjustments *	2001 Gross Plant
IXC	$725	$575	$400	$350	$300	$2,350	$0	$2,350
Qwest	$1,534	$1,100	$800	$900	$1,000	$5,334	($1,085)	$4,249
Williams Network	$0	$765	$800	$800	$500	$2,865	($600)	$2,265

* Qwest and Williams are netting portions of dark fiber sales against gross fixed assets

Source: Lehman Brothers estimates.

WHOLESALE WINDOW OF OPPORTUNITY

We believe that the wholesale window of opportunity is starting to close as the new entrants battle to lock in large long-term contracts. Our bottom-up forecast shows that the market should expand enough to support Qwest's, IXC's, and Williams' plans, provided that the RBOCs become significant customers (U.S. West is currently a customer of Williams). Our bottom-up forecast of the wholesale segment points that Qwest, IXC and Williams need to capture 75%-80% of the unsigned opportunity and about half the total growth in the segment in order to meet their forecasts. Qwest, IXC and Williams have all been very active signing long-term contracts with the new entrants – CLECs, Internet service providers and RBOCs. In total they have signed over $3.5 billion in long-term wholesale deals (see Figure 16) that will bill approximately $500-$800 million per year (usually five to seven-year contracts).

Figure 16: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Wholesale Contracts

Network Company	Deal With	Wholesale	Retail	Total
IXC				
	PSINet	$470M		
	Excel	$156M		
	Unnamed ISP	$265M		
	Others	$109M		
Subtotal - IXC		$1,000M		$1,000M
Qwest				
	Star Telecom	$70M		
	Electric Lightwave	$122M		
	CAIS	$100M		
	US Gov't		$430M	
	Verio	$100M		
	Sungard		$10M	
	Cable & Wireless	$107M		
	Unnamed Carrier	$60M		
	AGIS	$575M		
	MiCTA		$38M	
	Nortel			
	Digital Broadcast Sys.	$60M		
	Facilicom	$25M		
	Others	$300M		
Subtotal - Qwest		$1,519M	$478M	$1,997M
Williams				
	US West	$400M		
	Intermedia	$400M		
	Concentric	$200M		
Subtotal - Williams		$1,000M		$1,000M
TOTAL		$3,519M	$478M	$3,997M

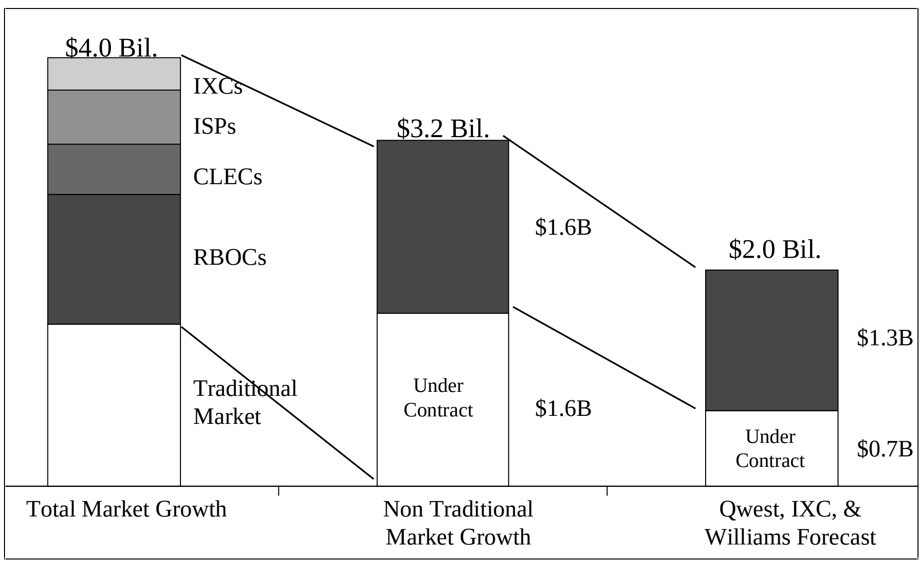
Source: Company reports and Lehman Brothers estimates.

We estimate the wholesale market at roughly $8-$10 billion market today. MCI WorldCom is the leading wholesale carrier with $3-$4 billion in wholesale revenue. 1998 wholesale revenue is estimated at over $500 million for IXC and at over $100 million for Qwest. We note that the largest traditional wholesale customers, WorldCom, LCI, and Frontier are all moving traffic to their own facilities.

Our bottom-up wholesale market growth are shown in Figure 17 and 18 (we forecast growth by assuming that long distance capacity costs are 15% of all long distance, data and Internet revenues from these non-network based providers). We expect the $8 billion market to grow to $12 billion over the next three years with $3.2 billion of this growth coming from the new entrants (CLECs, ISPs, RBOCs) where we think the new network providers will gain the lion's share of the business. We think that almost $1.6 billion of this new $3.2 billion is currently under contract. This leaves a market opportunity of approximate $1.6 billion from these new sources.

The key sensitivity to this forecast appears to be the RBOCs (no surprise). If the RBOCs push into long distance faster than we expect ($6 billion in revenue by 2002) then the opportunity increases (our forecast assumes that Bell Atlantic uses the GTE capacity that GTE bought dark from Qwest and that USWest is taken care of with the Williams contract). We point out that $6 billion would be about 6% share of the long distance business. GTE still had 3% share in its region after two years.

Figure 17: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Wholesale Growth 1998-2001E



Source: Lehman Brothers estimates.

Figure 18: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Wholesale Market Growth Forecast, 1998-2001 ($ in Millions)

	1998					2001		
	LD/Data Revenue	Carrier	Deal Size	Years	Network Cost @ 15% *	LD/Data Revenue	Network Cost @ 15% *	Growth in Network Costs
CLECs								
ICG/Netcom	170.0				25.5	250.0	37.5	12.0
ICIX/Digex	450.0	Williams	420.0	20.0	67.5	1,000.0	150.0	82.5
MCLD	130.0				19.5	450.0	67.5	48.0
ELI	25.0	Qwest	122.0	9.0	3.8	150.0	22.5	18.8
TW	0.0				0.0	0.0	0.0	0.0
NextLink	0.0	Level 3	700.0		0.0	200.0	30.0	30.0
Hyperion	0.0				0.0	40.0	6.0	6.0
ACNS	0.0				0.0	270.0	40.5	40.5
GST	0.0				0.0	100.0	15.0	15.0
Teligent	0.0				0.0	100.0	15.0	15.0
WCII	100.0				15.0	600.0	90.0	75.0
ITCD	150.0				22.5	300.0	45.0	22.5
Other CLECs	0.0				0.0	600.0	90.0	90.0
Subtotal	**1,025.0**				**153.8**	**4,060.0**	**609.0**	455.3
ISPs								
Earthlink	130.0	Sprint			19.5	219.1	32.9	13.4
MindSpring	85.0				12.8	143.2	21.5	8.7
PSINet	185.0	IXC	240.0	20.0	27.8	274.1	41.1	13.4
AGIS	60.0	Qwest	575.0		9.0	93.7	14.0	5.0
CAIS	13.0	Qwest	100.0	10.0	2.0	20.3	3.0	1.1
Verio	85.0	Qwest	100.0	7.0	12.8	122.6	18.4	5.6
Concentric	75.0	Williams		20.0	11.3	117.1	17.6	6.3
Other Backbone	400.0				60.0	1,650.0	247.5	187.5
Small Dial Up	2,200.0				330.0	3,900.0	585.0	255.0
AOL	3,100.0	WorldCom			465.0	5,500.0	825.0	360.0
UUNet	1,700.0	WorldCom			255.0	4,000.0	600.0	345.0
Subtotal	**8,033.0**				**1,205.0**	**16,040.1**	**2,406.0**	1,201.1
Long Distance								
Current Users							825.0	825.0
Large IXCs							300.0	300.0
Subtotal	**0.0**				**0.0**	**0.0**	**1,125.0**	1,125.0
RBOCs								
US West	0.0	Williams	400.0	20.0	0.0		200.0	200.0
Other RBOCs	0.0				0.0	6,000.0	1,000.0	1,000.0
Subtotal	**0.0**				**0.0**	**6,000.0**	**1,200.0**	1,200.0
								3,981.3
Growth in Wholesale Opportunity							**3,981.3**	
Growth in Wholesale Opportunity - Excludes Growth Under Contract Today							**2,400.0**	

* Assumes carriers pay 15% of revenue in long haul charges to wholesale providers

Source: Lehman Brothers estimates.

IXC, Qwest and Williams should increase their annual wholesale revenue by $2 billion over the next three years (IXC could add $440 million, Qwest $748 million, and Williams about $600-$800 million). Of this amount, we estimate that almost $700 million is currently under contract. The bottom line is that together these three carriers need to take $1.3 billion of the $1.6 billion unsigned growth in order to meets their forecasts. It also means that they need to take half of the total growth in the market ($2 billion out of $4 billion).

Figure 19: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Wholesale Forecast by Carrier ($ in Millions)

	1998	2001	Growth	Growth From Current Contracts	Add'l Growth Required	% of Available
IXC	542	982	440	175	265	16%
Qwest	120	868	748	250	498	29%
Williams	123	700 - 900	600 - 800	270	400 - 600	24% - 35%
Total	785	2550 - 2650	1800 - 2000	695	1200 - 1400	70% - 80%

Source: Lehman Brothers estimates.

DISTRIBUTION ASSETS: KEY POINT OF DIFFERENTIATION

We believe that the key point of differentiation for these new network providers is strong distribution and service assets as well as speed to market advantages. We believe this is especially true given the increasing level of competition in the wholesale market. We also believe that distribution assets would greatly enhance the likelihood and price of an RBOC or other acquisition. We believe that the RBOCs will be able to acquire capacity through wholesale deals, cheaper than buying the companies. Wholesale fiber bought dark costs about $2,000/fiber mile versus the trading value of these companies which is currently between $4,000-$14,000 per planned fiber mile.

INDUSTRY CONSOLIDATION AND CONVERGENCE

We see three key forces driving continued industry consolidation: (1) the need for network-based companies to develop distribution channels; (2) the need to develop all the end-to-end pieces - local, long distance, data, international, and Internet; and (3) RBOC entry into long distance.

Distribution

As we mentioned in earlier reports, we believe that companies that are building key network assets and those with developed distribution channels would consolidate. We have seen Qwest buy LCI and WorldCom acquire MCI. Both of these deals were driven by the need to quickly gain access to strong distribution channels, customer bases, and back office systems. We believe this trend will continue.

Local, Long Distance, and Data Convergence

We also believe the convergence of local/long distance/data is driving competitors to load their quivers with all the necessary arrows - local, long distance, data, Internet, and international. MCI WorldCom is perhaps the best example of a company that has put all the pieces together. We believe that convergence will continue and we will increasingly witness: (1) CLEC-CLEC mergers that will add scale, trading liquidity, product breadth, and management talent; (2) CLEC-Long Distance consolidation with perhaps a company like Qwest buying, or merging with, a CLEC, (3) RBOC purchase of long distance network companies to acquire capacity and distribution;(4) U.S. long distance and international merger to build a global platform; and (5) continuing acquisitions of ISPs by all types of communication providers.

INDUSTRY GROWTH AND SHARE

We expect the traditional long distance and data telecom industry revenue to increase 7%-8% over the next 10 years from 4%-5% today, but below the bandwidth growth we forecast.. As shown in Figure 20, we forecast that the three largest IXCs, which today have almost 90% market share, could lose 20%-30% of market share over the 10 year period. (We note that these companies will have other significant sources of revenue growth including local and international). Given the high industry growth rate, these competitors will be able to grow long distance revenue 4%-5% per year while still losing share. We are forecasting the new network providers to pick up 12 percentage points of market share over the next 10 years. Also, we assume that the RBOCs will capture about 15% of the market, which corresponds to a 25%-30% share gain in the residential market and substantially lower gains in the business market.

Figure 20: Emerging Network Companies: Exploiting Industry Paradigm Shifts
Traditional Domestic Long Distance Market Share

	1998		*2001*			*2008*		
	Revenue	**Market Share**	**Revenue**	**Market Share**	**CAGR 2001/1998**	**Revenue**	**Market Share**	**CAGR 2008/1998**
Big 3 IXCs	$ 82.9B	88.2%	$ 94.2B	81.9%	4.4%	$ 132.0B	67.0%	4.8%
New Network Providers	$ 3.1B	3.3%	$ 9.2B	8.0%	43.3%	$ 30.0B	15.2%	25.4%
CLECs/RBOCs/Other LD	$ 8.0B	8.5%	$ 11.6B	10.1%	13.1%	$ 35.0B	17.8%	15.9%
Total	$ 94.0B	100.0%	$ 115.0B	100.0%	6.9%	$ 197.0B	100.0%	7.7%

Source: Lehman Brothers estimates.

APPENDIX A: WILLIAMS

OVERVIEW

Williams Communications is in the process of building a $2.8 billion, 32,000-mile high bandwidth long distance network connecting the 100 largest cities in the country. The company in some ways is repeating the strategy it undertook in the late 1980's when it built the Wiltel network using its gas pipeline right-of-way to give it a cost and reliability advantage. That network was eventually sold to LDDS, now WorldCom, for $2.5 billion and forms the basis of the WorldCom network. The company is also building its network largely on its pipeline right--of-way and is also swapping for additional capacity.

Williams has about 15,000 miles complete (including 11,000 miles with one fiber that can be used to carry Internet traffic only until July 2001 and then is free to carry voice) and expects to complete its buildout in 2001 or sooner, completing about 5000-7000 miles per year. The company's current strategy is to be a wholesale player in the market as it was for the most part with Wiltel. The company currently plans to sell high bandwidth private line services (T1, DS3, OC3, etc.) as well as frame relay and ATM. Williams plans to enter the wholesale switched voice business in 1999, which will cost about $200 million in capital for voice switches and infrastructure. The company recently made a $28 million investment in Unidial, one of the largest switchless resellers, and will get all incremental traffic until 2001 when Unidial can start switching over the current traffic from WorldCom.

In addition to its network long distance business, Williams owns a 70% stake in a $1.5 billion enterprise network equipment and services business. This company sells and services PBX's and other telecom equipment (Nortel owns the other 30%). The unit was formed in April 1997 when Williams and Nortel merged their network services businesses. It is now the second largest equipment servicing company in the country behind Lucent. This business is currently growing 10% per year with 10% EBITDA margins. We see increased value in this asset given the trend toward the need for more complex data networking and equipment and the entrée into commercial customers this sales force could provide for a retail telecom services company.

MARKET OPPORTUNITY AND INVESTMENT THESIS

We believe that Williams is well positioned to take advantage of the huge changes sweeping the industry. These changes include:(1) steep growth in data and Internet services and rapidly changing technology, which drive the demand for bandwidth; (2) proliferation of new long distance competitors, including the RBOCs, that pushes the demand for wholesale capacity; and (3) significant changes in regulation, technology and demand that should drive orders of magnitude increases in the demand for high speed capacity over the next several years.

Williams has some key advantages. The company has a state-of-the-art network and benefits from cost advantages from its pipeline right-of-way. Williams has also a very good reputation in the telecommunications area and good relationships with wholesale and large retail customers from its Wiltel relationships. Wiltel was widely considered as a cutting edge wholesaler and high-end retailer of high capacity bandwidth and data services. Through this relationship, Williams benefits from Wiltel's experienced management. In addition, the financial backing of Williams is a key advantage for Wiltel, especially in today's market.

We believe Williams is also well positioned to align itself with the RBOCs. It is just a matter of time before the RBOCs enter the long distance business and we believe that they will look to align themselves with strong partners. We believe that companies such as Williams and Qwest are to the RBOCs what MFS and Teleport were to AT&T and WorldCom – strategic assets for attacking the new opportunities that deregulation and changing technology are opening.

LONG DISTANCE NETWORK BUSINESS

Williams current plan is to be a high quality provider of wholesale services. To date, the company has sold around $300 million-fiber miles in dark fiber deals. One large sale of dark fiber was to Frontier, a 3,000-miles deal for $68 million. The company does not recognize dark fiber sales as revenue but reduces fixed assets by the sale amount. The company's investment is estimated at nearly $900 million at year-end 1998, offset by $300 million in dark fiber sales. By completion of the network in 2001, Williams plans to have spend a total of $2.8 billion offset by a total of $700-$800 million in dark fiber deals.

The company has also signed three large long-term indefeasible right of use (IRU) wholesale deals with a total present value of $1 billion. The large deals include Concentric Networks (an Internet service provider) for $200 million, US West for $400 million, and Intermedia (CLEC) for $400 million. We expect revenue from this backlog at $64 million in 1998, $109 million in 1999 and $141 million in 2000. The Intermedia deal currently generates about $15 million in revenue per quarter. This traffic is mostly carried on other networks but is managed by Williams and revenue is recognized by Williams. The traffic will be converted to Williams facilities over the next two years.

The company plans to roll out a switched wholesale service in mid-1999. The capital cost for this will be $200 million in capital for five switches and related investment. We estimate gross margins around 25%- low 30% for this business and 40%-45% for wholesale private line business.

The company believes its year 2000 revenue mix will be $100 million sub-T1 private line, $27 million frame, $2 million ATM, $50 million OC-X private line, $50 million T1 private line, and $300 million wholesale voice.

NETWORK DEPLOYMENT

Williams plans to build a $2.8 billion, 32,000 mile high capacity fiber network linking 100 cities that cover 80% of the long distance traffic in the country. The company currently has a single 11,000-mile fiber that it retained from the Wiltel sale and is allowed to use it for Internet and multimedia traffic but not for voice until the year 2001. The company has added an initial 4,000 miles including the Houston-Atlanta-Washington DC route and a swap with IXC covering the Los Angeles-New York route and has purchased a 350-mile route between Jacksonville and Miami.

The company is expected turn on another 3000 miles by year-end, covering Portland-Salt Lake-Los Angeles and New York-Washington DC. Currently, Williams has another 1680 miles under construction with 1,320 miles of fiber in the ground but not lit and another 360 miles of conduit in the ground. The network will connect 69 major cities by year-end 1998 and over 100 at the time of completion.

The plan is to turn on an additional 3,000-7,000 miles per year over the next few years for a total of 32,000 miles by year-end 2001 (including the 11,000-mile single fiber total built and retained by route). When the network is complete, Williams will add a total of 96 fibers along its high-density routes but retain just 24 fibers, selling the rest in dark fiber sales. In total, the company will add 512,00-fiber miles and retain about 302,000-fiber miles. On average, the company plans to retain about 14 fibers per route mile (not including the single fiber route).

CAPITAL SPENDING

The total capital cost to construct and light the initial capacity will be $2.8 billion through year-end 2001. Capital expenditures are estimated at $800 million in 1998 and 1999 and dropping to $600 million in 2000 and 2001. The construction cost is expected to run about $100,000 per mile for the 12,000 miles that Williams is building (the balance is swaps) or $1.2 billion. Lighting an initial 6 OC192 windows will cost about $5,000/mile or $650 million. The company expects it will have to light an OC192 window, costing about $75- $100 million, every 18 months. Williams believes it can reach 65% capacity utilization within three years. By 2001, we estimate that Williams will have lit just 3%-4% of total capacity (assuming that total is based on 8 window DWDM).

Capital for ATM routers, POPs, voice switches and related equipment ($200 million), and back-office systems will bring the total to $2.8 billion by 2001. The company has announced a $150 million agreement with Ascend to purchase its GX 550 ATM core switches, CBX 500 Multiservice ATM and B-STDX 9000 Multiservice frame relay switches.

Dark fiber sales should offset capital costs. in the company's dark fiber sales amounted to $290 million to date including $67 million to Frontier. Dark fiber pricing has typically been in the $1,500- $2,000 per fiber mile range. We estimate that Williams will have about 609,000 dark fiber miles to sell for a total cost of $800 billion. Williams does not recognize dark fiber sales as revenue but nets it against its fixed asset base. This would reduce the company's initial construction investment to just $500 million and its three-year investment to $1.6 billion.

SOLUTIONS BUSINESS

Fifteen months ago, Williams combined its customer premise equipment sales and service unit with Nortel's to form the largest independent and second largest, to Lucent, overall CPE provider, with revenue of $1.4 billion per year and a 15% market share. The company accounts for over 60% of Nortel's PBX and key system U.S sales. The company, 70% owned by Williams, services over 133,000 customer sites and 10 million ports (fewer RBOC lines dues to concentration in PBX). The company has 6200 employees and a field technical force of over 2,500 people. The company provides consulting, network operations and network management, enterprise network products sales and service, PBX, key systems sales and service, and call center products. The revenue mix is 60% equipment sales and upgrades, 20% maintenance, and 20% adds/moves/changes.

The strategy is to move the company into what we believe will be the high growth and higher margin enterprise networking and data product and consulting markets. LAN equipment represents 65% of total customer spending and is growing 35% per year. We forecast increasing demand for single source suppliers for network consulting and equipment, as complexity and convergence of the desktop and network accelerate.

In addition, we believe that the company has a hidden asset in the customer relationships and field sales force that can be leveraged in the retail long distance, data and local markets. We estimate that currently Williams Solutions business serves 5%-10% of the business market with total telecommunications services spending of $9 billion and has relationships with another 15%-20% of the market. This is a valuable asset, one that we know the CLECs have already seen and discussed with Williams. Williams' internal surveys indicate that its customers would select Williams as their service provider in front of all other service providers. At the very least we believe that Williams can act as a sales agent to extract value form this base. The more lucrative option would be to use this as a springboard into the retail market.

APPLICATIONS BUSINESS

The applications division is an international provider of fiber optic, satellite, and teleport video transmission services. The division is made up of six groups: (1) Vyvx services, the leading provider of transmission services to the media industry, carrying approximately 80% of professional sports broadcasts and 65% of all live televised events in the United States; (2) Williams Conferencing provides audio/video conferencing services on a global basis; ,(3) Global Access Services provides business television services for companies -- services include private broadcast networks, special video events, and distance learning; (4) Williams TeleServices is a call center operation; (5) Choice Seat is a new product targeted at providing sports fans in attendance at professional sporting events access to statistics, different views of the field, and information on other sporting events; and (6) Telemetry Services provides systems for utilities to monitor customer usage of gas and electricity.

APPENDIX B: THE INTERNET

At its most fundamental level, the Internet is a set of software protocols that allow the inter-networking of any network in the world. These protocols (TCP/IP standing for Transmission control protocol/ Internet protocol) define the rules by which packets of data are addressed and transmitted across physical fiber, copper, and wireless networks. The Internet is a software defined logical network carried on predominantly the same physical facilities (mostly fiber for the long distance portion) as voice calls — most long distance carriers have six or more different logical networks including Internet, frame relay, X.25, voice, dedicated private lines all riding on the same physical fiber, each engineered with different switching and routers and providing varying levels of service and reliability. One of the benefits of the Internet and high speed packet technology is the eventual ability to move all these separate networks to one, thereby cutting down on overhead capacity and support costs.

The physical Internet network is made up of: (1) fiber networks of a variety of carriers including all the major long distance carriers and other “backbone” providers that lease the physical fiber from these carriers; (2) the routers owned by the Internet service providers; (3) Network Access Points or NAPs, where all Internet service providers can connect their networks in order to exchange traffic; and (4) the host servers that hold the data and information content and access facilities, such as a dedicated T1 facility for larger business customers provided by an RBOC (although probably bundled in to the pricing and offering by your service provider) or a dial up 28.8 modem connection from your home.

Who runs the Internet? No one really runs the Internet. There is a standards setting body that administers the assignment of addressees. The public network access points are run by some of the large long distance companies and RBOCs.

Where did the Internet come from? The Internet began as a packet switching project at the Defense Advanced Research Project Agency’s ARAPNET during the late 1960s. The goal was to connect Department of Defense computers and other government agencies. TCP/IP was developed as a packet protocol to allow connections of different systems across a wide variety of physical mediums. It was included in a popular release of the Berkeley Standard UNIX and freely distributed throughout the university community. In 1985, the National Science Foundation funded several super computer centers and a project to hook them together in order to make them available to the university research community. The NSF linked five original supercomputer centers with a 56 Kbps link. Universities soon found that the network was useful for electronic mail, news groups and transferring files. Traffic grew and the universities started expanding their regional networks. In 1987, NSF funded an upgrade to T1 links and awarded contracts to MCI, and IBM among others to make the upgrade. This network included 13 sites, which interconnected the various regional networks.

In 1990, IBM and MCI spun off a nonprofit organization known as Advanced Network and Services (ANS which AOL later bought and then sold to WorldCom) to operate the NSFNet backbone. The backbone was expanded to 16 cities and upgraded to T3 speeds by late 1991.

In 1993, NSF issued a solicitation for proposals for private commercial operators to operate a series of network access points NAPs where commercial operators could interconnect with the backbone. In the early 1990s the traffic had become increasingly commercial and NSF wanted to exit the business. This would allow anyone to build a national backbone, sell access to customers and interconnect with all other backbones and customers. In 1995, the NFS network was shut down.

NAP and Peering – Today there are 11 major interconnection points – four original NAPS (San Francisco – PacBell/SBC, Chicago/Ameritech, NY/Sprint, Washington DC/MFS). The others are in Los Angeles, Dallas, Chicago, San Jose, another in

Washington DC all run by MFS (WorldCom) and two federal exchange points, one in Maryland and the other in California at the Ames Research Center. Most of the national service providers are connected to all four original NAPs plus some of the others and many of the larger providers connect at other convenient locations to reduce backhauling traffic.

Peering refers to the mutual interconnection of competitors' networks and exchange of traffic. There are presently no standards for this and carriers can agree or disagree to interconnect with whomever they wish. Generally, major national backbone providers with significant volume (either those that own the underlying fiber and those that don't), known loosely as Tier 1 providers, exchange traffic at the NAPs with no financial exchanges. Smaller companies must buy backbone access from the Tier 1 providers.

Internet Service Providers - The Internet providers can be divided into four groups: (1) national backbone providers that own their own network; (2) national backbone providers that lease capacity between their routers/switches; (3) regional backbone providers; and (4) retail-oriented Internet service providers that buy bulk access from any of the national or regional backbone providers and then sell high speed dedicated Internet access to large customers and dial up access to small residential and small business customers. The backbone providers both own and lease fiber optic capacity to hook their Internet routers together. The large long distance companies provide national backbone services predominantly over their own facilities-based networks. These carriers provide most of the services mentioned above to both retail and wholesale customers. These carriers include WorldCom/UUNet, GTE/BBN, Sprint, MCI (before the merger with WorldCom) and Qwest. AT&T is in the process of building a national backbone network. UUNet is the largest backbone provider with about 30%-40% share of the market by some estimates (combined with MCI some estimates placed total backbone share at 60% which is the reason why MCI was forced to sell its business to C&W as a condition for the merger). In the second group are companies such as Digex (owned by Intermedia), ICON CMT, which Qwest just announced it was purchasing, and Netcom owned by ICG. Regional networks include Colorado Supernet (owned by Qwest). Retail-oriented ISPs include AOL, Mindspring, and Earthlink. Both regional and national backbone companies generally offer dedicated access to business customers and, sometimes, operate retail dial up ISP businesses as well.

APPENDIX C: IDC FORECASTS

Frame Relay Ports (1)	1996	1997	1998	1999	2000	2001	2002	CAGR '98-'02
56 Kbps	177,059	295,888	444,131	598,369	736,847	844,991	929,472	20%
T1	82,395	165,357	299,931	433,604	568,821	692,022	813,112	28%
T3	571	1,870	5,548	8,464	19,663	40,397	72,715	90%
Total Frame Relay DS0 Equivalents	1,484,207	3,059,213	5,741,075	8,413,473	12,034,815	12,034,815	12,034,815	20%

ATM Ports (1)	1996	1997	1998	1999	2000	2001	2002	CAGR '98-'02
T1	179	557	1,095	2,220	4,499	8,419	14,312	90%
T3	718	1,955	3,647	5,960	9,883	13,999	18,199	49%
OC3	170	460	952	1,782	3,206	5,369	8,161	71%
Total ATM DS0 Equivalents	829,512	2,254,488	4,396,296	7,650,912	13,212,648	20,433,288	29,025,356	60%

SMDS Ports (1)	1996	1997	1998	1999	2000	2001	2002	CAGR '98-'02
56 Kbps	2,258	3,432	4,342	4,924	5,350	5,705	6,008	8%
T1	3,918	5,638	7,570	8,850	10,019	10,690	11,299	11%
T3	707	1,102	1,480	1,980	2,267	2,488	2,682	16%
Total SMDS DS0 Equivalents	333,842	509,016	683,302	882,604	1,007,518	1,098,233	1,178,337	15%

X.25 Ports (1)	1996	1997	1998	1999	2000	2001	2002	CAGR '98-'02
56 Kbps	145,628	166,785	182,692	196,385	204,485	207,767	210,150	4%
T1	2,624	3,120	3,590	4,247	4,599	4,806	4,974	8%
Total X.25 DS0 Equivalents	129,504	150,837	168,603	185,703	195,930	201,413	205,922	5%

Total Frame/ATM/SMDS/X.25 Ports								
56 Kbps	324,945	466,105	631,165	799,678	946,682	1,058,463	1,145,629	16%
T1	89,116	174,672	312,186	448,921	587,938	715,937	843,697	28%
T3	1,996	4,927	10,675	16,404	31,813	56,884	93,595	72%
OC3	170	460	952	1,782	3,206	5,369	8,161	71%
Total Ports	416,227	646,164	954,978	1,266,785	1,569,639	1,836,653	2,091,082	
			736				1,299	
Total Frame / ATM / SMDS / X.25 DS0 Equivalents	2,777,065	5,973,554	10,989,276	17,132,692	26,450,910	33,767,748	42,444,430	40%

Internet (1, 2)	1996	1997	1998	1999	2000	2001	2002	CAGR '98-'02
DIAL - Residential	16,250,000	19,500,000	22,600,000	25,900,000	29,300,000	33,700,000	37,600,000	14%
DIAL - Business	2,303,792	2,061,614	2,621,254	3,127,715	4,016,627	4,937,362	5,850,004	22%
56 Kbps	59,846	79,692	164,384	254,774	358,040	534,661	784,422	48%
T1	15,275	18,966	36,979	48,161	102,940	196,770	340,457	74%
T3	6,374	8,011	10,799	17,421	28,395	42,704	59,921	53%
Total Internet Residential DS0 Equivalents	16,250,000	19,500,000	22,600,000	25,900,000	29,300,000	33,700,000	37,600,000	14%
Total Internet Business DS0 Equivalents	4,895,160	5,347,665	7,412,878	10,528,232	19,771,688	34,397,276	55,467,891	65%
Total Internet DS0 Equivalents	21,145,160	24,847,665	30,012,878	36,428,232	49,071,688	68,097,276	93,067,891	33%

Total Business DS0 Equivalents								
Frame/ATM/SMDS/X.25	2,777,065	5,973,554	10,989,276	17,132,692	26,450,910	33,767,748	42,444,430	40%
Internet	4,895,160	5,347,665	7,412,878	10,528,232	19,771,688	34,397,276	55,467,891	65%
Total	7,672,224	11,321,219	18,402,154	27,660,924	46,222,598	68,165,025	97,912,321	52%
Total Residential DS0 Equivalents								
Internet	16,250,000	19,500,000	22,600,000	25,900,000	29,300,000	33,700,000	37,600,000	14%
Total Business + Residential DS0 Equivalents	23,922,224	30,821,219	41,002,154	53,560,924	75,522,598	101,865,025	135,512,321	35%

1) IDC Port forecasts through 2001; 2002 port forecasts are Lehman Brothers estimates. All conversions to DS0 equivalents are Lehman Estimates
2) Dial Residential forecasts through 2002 are from Paul Kagan Associates

APPENDIX D: DATA/INTERNET PRICING PER MONTH

Product/Service	Single Line / 64 KBPS	T1	DS3
Dial Up Internet	$20-$25	n/a	n/a
Dedicated Internet	$400 - $500	$1700 - $2500	$20K+
Frame Relay	$300 - $400	$1500 - $2000	n/a
ATM	n/a	n/a	$5K+
Private Lines	$0.15 - $0.20 / DSO mile	$0.08 - $0.10 / DSO mile	$0.03 - $0.05 / DSO mile

APPENDIX E: TRANSMISSION SPEED CONVERSION TABLE

Customer Circuit Speeds	Speed	Equivalents	Number of Voice Channels
56 KBPS Data / DS0	56 KBPS	1 DS0	1
Voice Circuit / DS0 / VGE	64 KBPS	1 DS0	1
T1 / DS1	1.5 MBPS	24 DS0s	24
DS3 / T3	45 MBPS	672 DS0s, 28 T1	672

SONET NETWORK SPEEDS (Per Fiber)	Speed	Equivalents	Number of Voice Channels
OC 3	155 MBPS	3 DS3	2,016
OC 12	622 MBPS	12 DS3	8,064
OC 48	2.5 GBPS	48 DS3	32,256
OC 192	10 GBPS	192 DS3	129,024
OC 192 / 8 DWDM	80 GBPS	1536 DS3	1,032,192

KEY:

KBPS = Kilo (Thousand) bits per second
MBPS = Mega (Million) bits per second
GBPS = Giga (Billion) bits per second
TBPS = Tera (Trillion) bits per second

DS = Digitial Signal
OC = Optical Carrier
VGE = Voice Grade Equivalent
DWDM = Dense Wave Division Multiplexing

APPENDIX F: THE EVOLUTION OF OPTICAL NETWORKS

The Evolution of Optical Networks is provided by our telecommunications equipment analysts Steven Levy, Sender Cohen and Andrea Green.

The Evolution of Carrier Networks

In the beginning . . . the original phone networks required dedicated physical connections between parties who wanted to talk to each other. It's not hard to imagine that with just a few dozen interested parties, the cities of the 1800s began to look like they were covered with spider webs. The advent of switches alleviated the problem of multiple access wires, and, for the first time, introduced the concept of dedicated access to public switched telephone networks (PSTNs).

The next major innovation in PSTN development occurred approximately 60 years ago when a Bell Labs engineer, named Harry Nyquist, devised a theorem stating that if an analog signal could be sampled at twice its frequency, a digital representation of "1s" and "0s" could characterize the signal accurately enough to transmit it across communications lines and reproduce it at the far end. The result of this sampling theory is that if a standard plain-old telephone service (POTS) line, which has an analog bandwidth, or frequency, of 4,000 hertz (hertz, a unit of bandwidth measurement in the analog world, equals cycles per second) is sampled at 8,000 times per second utilizing 8 bit bytes, the digital bandwidth of the uncompressed line is 64,000 bits per second, or 64 Kb/s. Thus was born the digital signal equivalent of a voice circuit.

The final step toward high-speed digital communications started in the early 1960s, when AT&T began installing T-carrier systems in its network. These T-1 systems took advantage of digital transmission technologies and allowed 24 simultaneous connections, using time-division multiplexing (TDM), over two pairs of wires that had previously only supported one connection. Time division multiplexing is a technique of combining several voice equivalent digital channels (64 Kb/s each) into one facility in which each channel is allotted a specific, fixed position in the signal stream based on time. The Bell System implemented T-carriers in order to avoid the expensive and lengthy construction jobs otherwise required to meet network growth. This 1.544 Mb/s service was initially used internally only on AT&T's network (then known as the Bell System) and was not offered to the general public until 1983 with the introduction of AT&T's High Capacity Terrestrial Digital Service (later renamed Accunet T1.5 service). Today, T-1 lines remain one of the highest margin and highest growth services offered by LECs.

LIGHTING UP THE PUBLIC NETWORK

Starting in the late 1970s, fiber optic cables began to be deployed in the PSTN. The enormous information carrying potential (a.k.a bandwidth) of fiber optic circuits was their main attraction to network operators and compared to traditional copper-based digital circuits (such as T-1s), which required repeaters to regenerate and amplify a signal roughly every mile, while fiber optic circuits required repeaters spaced at intervals of up to 75 miles. This characteristic alone was thought to be tremendously significant because it reduced the number of network elements, the number of points-of-failure, and the potential network maintenance costs. Transmissions over optical fiber also offered a number of other advantages over sending electrical signals on traditional copper cabling, including: (1) a very low transmission loss rate, i.e. better quality signals; (2) immunity to electromagnetic interference, again better quality signals; (3) fiber optic circuits do not radiate so one can not place a receiver next to it and figure out what's going down the line; and (4) fiber optic cables are fundamentally less expensive to maintain and more reliable than copper.

The initial cost to implement fiber optic circuits and their associated opto-electronic equipment was high, however, which therefore limited initial applications to high density routes such as those found in AT&T's or Sprint's long distance network. As the cost of implementing fiber optic circuits dropped, the installations began to rise and spread further out in the PSTN. Coincident with that rise was the beginnings of a dramatic increase in end user demand for bandwidth, led by rapidly falling long distance pricing and the ascendancy of data and image communications. Installing fiber optics for its cost advantages soon became secondary to its capacity for hauling tremendous loads of telephone traffic between two points.

And Then Came SONET

As fiber optic circuit deployments grew to a critical mass, two new issues surfaced that required industry cooperation: (1) how to ensure optical network reliability; and (2) multi-vendor systems interoperability. While failures used to stem predominantly from the electronics used in networks, now the electronics are extremely reliable and the majority of failures come from fiber cuts (typically perpetrated by a backhoe or other such machine) that occur more frequently on long-haul routes. With (1) so many "eggs in one basket"—most fiber optic circuits today are carrying the equivalent of 32,000 voice conversations simultaneously — the potential impact of a fiber optic circuit failure rose almost to catastrophic levels, and (2) little common experience in fiber optic transmissions in international standards bodies, Bellcore stepped in and began developing a new set of standards that would resolve these issues. Thus was born SONET, a set of Synchronous Optical NETworking standards. These standards defined the critical fundamental protocols that enable vendor interoperability, ease the transition from electrical signals to optical signals, and serve to foster increased deployment of optical transmission equipment. SONET transmission systems, and their non-North American standards' cousin, SDH (Synchronous Digital Hierarchy) also allowed telephone companies to eliminate costly asynchronous equipment that was previously necessary to build transmission networks above the T-1 (1.544 Mb/s) rate. Finally, and most recently, SONET "ring" architectures have been developed that dramatically increase the reliability and survivability of fiber optic transmission networks by creating a one-for-one backup in the case of a circuit failure. An interesting side effect of the implementation of SONET ring architectures is that it effectively doubles, or quadruples, the required amount of fiber in the network due to the need for redundant transmission paths. Over time, as more fibers are deployed, we expect to see an increasing number of SONET rings migrating to mesh topologies, resulting in triplicate and quadruplicate route options to protect from fiber cuts.

A BANDWIDTH BURP?

One of the axioms that we believe applies to the telecommunications world is that bandwidth demand is incredibly price and availability elastic. In other words, end-users constantly find ways to consume any additional capacity given to them, especially if the price of that bandwidth declines over time. In respect to its effect on current local and long distance networks, this seemingly insatiable desire for network capacity has led to a problem increasingly referred to in the industry as "fiber exhaust". One of the most interesting aspects of fiber exhaust is that it goes somewhat contrary to the general view that fiber circuits have virtually unlimited capacity. Our rationale for explaining it, however, is to focus on the current limitations of opto-electronic equipment rather than the inherent data carrying capabilities of the fiber cables. On a relative basis, the opto-electronic terminal equipment is years, and perhaps even decades, behind the capacity constraints of the fiber cables, which still appear to be close to limitless in their bandwidth capacity.

The explosive growth of data traffic, and in particular the use of on-line services such as America On-Line and the Internet, has undermined all of the traffic and network planning assumptions made by all telephone network engineers in their initial deployments of fiber through the 1980s, when the dominant form of network traffic was voice. This in turn has resulted in incumbent carriers scrambling to add capacity, new carriers scrambling to build networks, and equipment vendors scrambling to capitalize on demand for higher bandwidth systems. As a result, the introduction of new technologies such as DWDM (dense wave division multiplexing) and OC-192 (10 Gb/s), coupled with the build-out of high-capacity networks by upstarts such as Qwest, Level 3 and Williams clearly begs the question, are we suddenly going to find ourselves rapidly shifting from a capacity shortage to a capacity glut? The abbreviated answer, we believe, is short-term yes and long-term no. That is, as we mentioned above, one of the axioms that we believe applies to the telecommunications world is that bandwidth demand is incredibly price and availability elastic. In other words, end-users constantly find ways to consume any additional capacity given to them, especially if the price of that bandwidth declines over time. We do believe that we may see some short-term deployment slowdowns, "burps" if you will, as carriers digest the capacity they have put in place (as occurred earlier this year in the core of WorldCom's network), but the continued explosive growth of the Internet and other bandwidth hungry applications should fill up those empty pipes over time.

Supply and Demand Act Like a Perpetual Pendulum

In our opinion, the bandwidth bottleneck should migrate out to the edge of the network after a network's backbone capacity is increased (this is occurring already, and "NG"DSL and metropolitan DWDM systems are both being deployed to address this shift in the bottleneck). Then, as the access segment of a network is upgraded, the backbone's capacity should get filled, leading to a new cycle of upgrades at the backbone after which the bottleneck will again be the access segment. And so on. The critical issue is how long it takes for carriers to address the bottleneck as it shifts. Capacity increases in step functions, but demand grows linearly – clearly the linear demand is accelerating because of the Internet, but it is still linear nonetheless. We believe that breaking the access bottleneck could cause demand to grow in more of a step function because of increased xDSL deployments, thereby shortening any potential "bandwidth burp" periods.

Battling the Bandwidth Bottlenecks

Anyway, as carriers begin to battle their fiber exhaust situations, they have roughly three choices of solutions. The first and most obvious one is to physically lay more optical fibers along with all the necessary optical and electrical network line terminating equipment and signal regenerators. The second solution, which to date seems to have been the most popular, is to change out the transmission equipment, thereby increasing the speed, that is, data handling capability, of the circuit. The third choice, and one that is dramatically increasing in popularity, is to install optical wavelength division multiplexers (WDM) at each end of the fibers. Each of these three solutions is explained in more detail below.

Solution 1: New optical fibers

The key issues in determining if this is the right solution are the availability of space in existing conduits and the availability of rights-of-way coupled with the high cost of tearing up the ground and laying new optical fibers If a carrier, such as Qwest, has anticipated the need to further build out its fiber network and has constructed its network with easily accessible conduits, this is probably the preferred solution. Assuming that rights-of-way are available, the cost to lay new fiber cables is quite linear with distance, which also would indicate a preference to use this bandwidth expansion method for short-haul circuits. For example, one CLEC (competitive local exchange carrier) we spoke with pointed out that it was faced with a shortage of capacity in its transmission network within a particular city. After doing a cost analysis, the CLEC determined that spending $250,000 on WDM equipment for the existing short distance fiber link would free up capacity equivalent to eight OC-48, or 2.5 Gb/s, fibers, whereas installing a new cable with 38 OC-48 fibers would cost roughly $350,000. In this case, the economics clearly favor the new installation. However, on long haul stretches where the cost (approximately $70,000 per mile) of labor and materials for installing new fiber links is significantly higher, the cost advantage easily shifts toward an opto-electronics equipment solution. This clearly begs the question of the elasticity of demand for DWDM systems; as the price of the systems comes down, there should potentially be significant pent-up demand for short-haul applications.

Solution 2: Upgrading the speed of opto-electronics

The key factor in determining how much bandwidth each fiber cable can handle is clearly the opto-electronic equipment at the end points (although we note that there are certain types of fiber in the ground that cannot handle ultra high-speed transmissions). Simply described, these systems generally consist of lasers that operate at specific wavelengths (colors) and generate "0s" and "1s" by rapidly turning off and on. Optical amplifiers also play a significant role at the end points and along the fiber route where the digital signals need to be occasionally regenerated. These sets of equipment are typically measured by their optical circuit levels, for example, OC-3, or 155 Mb/s, OC-12, or 622 Mb/s, and OC-48, or 2.5 Gb/s. SONET Add-Drop Multiplexers (ADMs) are the terminals that operate within the SONET hierarchy, generating the actual pulses of light that constitute the optical transmission and grooming traffic. Currently, the prevalent speed of SONET ADMs is 2.5 Gb/s (OC-48) but 10 Gb/s OC-192 systems are starting to build momentum in certain segments of the market. While WDM systems aggregate multiple wavelengths of light onto a single fiber, TDM based (time division multiplexed) SONET systems instead work with a single wavelength of light, but turn it on and off at a higher rate. OC-192 signals cannot travel as far on older fiber as OC-48 signals can because the higher bit rate signals tend to disperse markedly faster than lower speed OC-48 signals (and obviously the problem is all the greater with 40 Gb/s OC-768). However, on newer fibers higher speed systems can be justified economically because the signals travel greater distances without the need for costly re-amplification. Because of the dispersion issue, bandwidth constrained longer distance networks, and particularly those that contain older fiber, are best addressed with WDM systems rather than upgrading the TDM systems to OC-192. Carriers that have announced OC-192 deployments include Qwest (which is the first full-scale all OC-192 network), MCI, Sprint, Bell Canada, WorldCom, GTE, LCI and IXC. Noticeably absent from the list is AT&T, which we believe has not announced significant OC-192 deployments for two reasons, the first being that Lucent is AT&T's primary equipment vendor and it does not yet have an OC-192 offering, and the second being that AT&T's fiber tends to be older and therefore more accommodating to WDM systems than higher speed TDM systems.

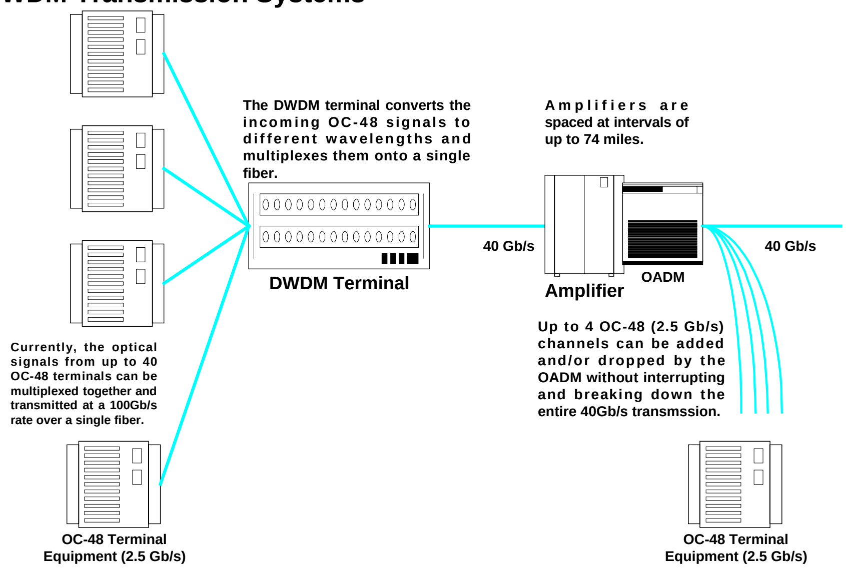
We understand from conversations with carriers that the move from lower speeds to OC-48 is not terribly expensive but the change-out to OC-192 is. In addition, if this solution is chosen, all the network elements along the fiber cable need to be changed out. Therefore, in our view, the market for OC-192 terminals likely will remain focused on "greenfield" fiber opportunities, rather than upgrades of existing SONET terminal equipment. As OC-192 transmission equipment matures, the prices likely will drop materially. Additionally, we are now hearing about some vendors working with line fiber optic lasers capable of transmitting at OC-768, or 40Gb/s, although we don't expect commercial deployment of systems operating at this speed for at least three to five more years.

The leading vendors of SONET OC-48 terminal equipment (which again is the prevailing line-speed being deployed in SONET architected networks) are Lucent and Nortel, followed by Fujitsu, Alcatel and NEC. As mentioned above, OC-192 is still in its relative infancy and Nortel appears to be furthest along in its rollout with an estimated 80%-90% market share. However, we believe that the market for OC-192 systems is starting to hit its stride.

Solution 3: Wavelength Division Multiplexing (WDM)

Simply put, WDM systems take the output of multiple fiber optic terminals transmitting at various speeds, such as OC-48 or OC-192, convert those signals to different wavelengths (or colors of light) spaced within a few nanometers (nm) of each other, and transmit all of the signals over the same physical cable. In essence, WDM systems are effectively transmitting "0s" and "1s" in multiple colors from one end and then separating them out, or demultiplexing them, at the other. Early WDM systems were limited to four or eight simultaneous signals but new technologies that permit more precise separation of the wavelengths are allowing companies such as CIENA to multiplex 16-40 signals over a single fiber strand, with the promise of 80-96 multiplexed circuits in the not-too-distant future. Appending the word "dense" to WDM systems typically refers to these new multiplexers and their closer wavelength spacing (typically at +/- 0.8 nm increments rather than at +/- 2.0 nm increments). This closer spacing makes it easier for an amplifier to fully restrengthen the various wavelengths because on non-zero dispersion shifted fiber (dispersion is the degree of scattering that takes place in the light beam as it travels along the optical fiber, causing the light of one wavelength to overlap with the light of another — more on this topic later), the fiber's "sweet spot," or its most efficient region for carrying data, is in the 1540-1560 nm range (that is, the unwanted dispersion is pretty much eliminated in this range). By more closely spacing the wavelengths, more of them can fit into this "sweet spot."

DWDM Transmission Systems



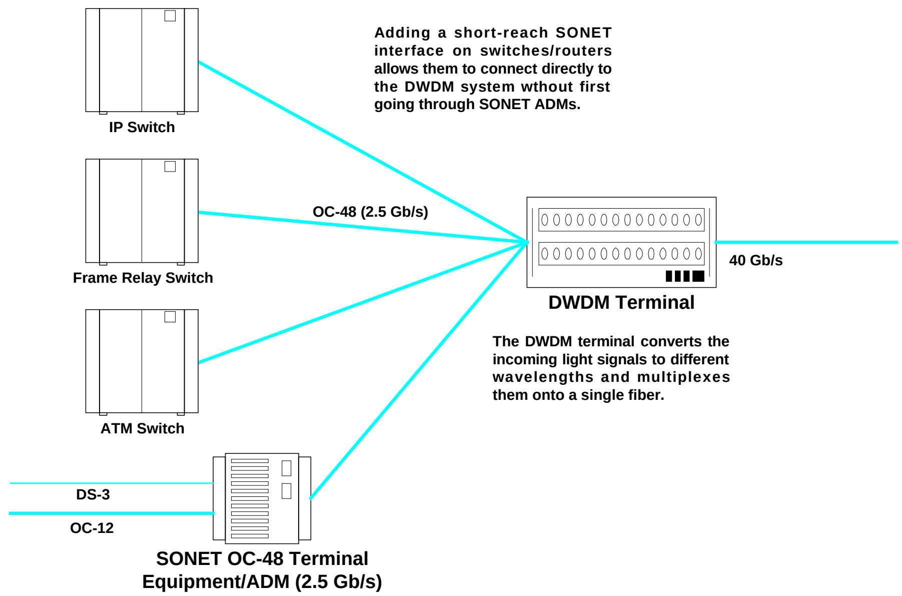
Source: Lehman Brothers

Open versus proprietary; cost versus flexibility;: Religious wars?

Open DWDM systems work with existing SONET OC-48 terminals and do not require the respacing of repeaters (an expensive proposition). But here's the catch that adds cost to many DWDM systems. Most OC-48 terminals use lasers that operate at the same wavelength (say, 1550 nm). Thus, to combine the signals from multiple transmission terminals onto one fiber through the use of DWDM equipment, these signals have to first be translated to multiple wavelengths (say, 1550, 1550.8, or 1551.6) so each signal can be transmitted independently. We believe that this wavelength translation equipment is a large component of the cost of DWDM systems, and one that can potentially be eliminated, in our view, if the WDM system is integrated more closely with the SONET transmission platforms.

This in turn leads to another catch, however. In order for a WDM system to be "open" (that is, work with SONET transmission terminals from multiple vendors), a wavelength translation technology is required. Eliminating this translation equipment in an integrated environment (that is, the WDM system and the SONET terminals from the same vendor) leads to a "closed" or proprietary system, which, in turn, locks in the carrier to one vendor. We note that the International Telecommunications Union (ITU) has established a grid encompassing 40 wavelengths in the 1540-1560 nm range, but two different vendors might choose two different subsets of the grid so their respective equipment would still not be interoperable. It is worth noting that an additional benefit of open systems is that they enable fiber circuits to handle time-division multiplexed voice traffic emanating from Class 5 switches as well as directly receive packet and circuit-switched data traffic generated by large IP routers or ATM/Frame Relay switches.

Data/Optical Internetworking



Source: Lehman Brothers, Inc.

Optical Fiber: Its Limitations, Capabilities and Potential

While optical fiber is typically viewed as a dumb strand of glass, technology innovations are constantly being made to allow it to overcome certain inherent physical limitations.

One of the most common problems in fiber transmission comes from dispersion. Dispersion occurs because as a pulse of light travels along a fiber, it spreads out in time. Think of the beam of light that comes from a flashlight: if you shine the light at your feet, you get a smaller circle of light than if you shine the light at the door across the room. The light from the flashlight spreads out or disperses as it travels through the air to the door. The same sort of effect occurs in light projected through a fiber. Moreover, the signal degradation that is caused by dispersion increases dramatically as the speed at which the signal is transmitted increases (say at 10 Gb/s OC-192 instead of 2.5 Gb/s OC-48). Since regenerators are able to refresh the optical signal, they are generally located along a fiber route whenever either the fiber loss or fiber dispersion has limited the ability of the light to continue to travel down the fiber, a costly remedy at higher speeds.

There are generally two types of fiber in use today: non-dispersion shifted fiber (NDSF) and reduced dispersion fibers. In addition, there are two subsets of reduced dispersion fiber: dispersion shifted fiber (DSF) and non-zero-dispersion shifted fiber (NZDSF). Reduced dispersion fibers were developed to minimize the negative effects of dispersion. Approximately 90% of the installed fiber in the world is non-dispersion shifted, although this stuff is no longer finding its way into most carrier's networks. Reduced dispersion fibers include Lucent's TrueWave and Corning's LEAF. Increased speed and longer distance increase dispersion. In addition to the spreading caused by dispersion, an optical signal's (or channel's) light pulse changes shape as it travels through the fiber because of fiber non-linearities. In a single channel system this results in the digital bits interfering with each other. When more than a single channel is transmitted, the signals become intermingled and likewise cause interference. It is also worth noting that these non-linearities have a strong power dependence - as the channel power increases, this signal degradation from non-linearities increases rapidly. But here's the rub - dispersion is not always a bad thing. While increasing dispersion reduces the distance a signal can travel due to dispersion penalties, it may actually increase the distance a multi channel signal can travel because the non-linearity penalties may be smaller. Maximizing the capacity of a given fiber type requires a careful trade-off between dispersion and non-linearity.

There is a direct relationship between how many bits per second are sent down a fiber and how much optical power is needed to send those bits. This is a fundamental constraint imposed on optical communication systems by the physics of photodetection. Consequently, transmission at 10 Gb/s requires four times the optical power of transmission at 2.5 Gb/s. DWDM offers an alternative to the more traditional method of time division multiplexing (TDM). Instead of sending data more rapidly (TDM), DWDM gives the data more virtual lanes to travel within the same fiber. Therefore, we can choose two different DWDM paths to obtain 20 Gb/s capacity on a fiber. We could send 8 channels of OC-48 (2.5 Gb/s) resulting in a throughput of 20 Gb/s (2.5 Gb/s x 8 channels), or, with the same power, we could send 2 channels of OC-192 (10 Gb/s x 2 channels). Transmitting at the slower (everything's relative!) OC-48 rate on each channel results in significantly lower dispersion and non-linearity penalties and is usually the preferred DWDM solution.

It is important to point out that newer non-zero dispersion shifted fiber (NZDSF) optic cables, such as LEAF (Large Effective Area Fiber) from Corning and TrueWave from Lucent have contributed greatly to the advance of photonic networking. For example, LEAF, a single-mode non-zero dispersion shifted fiber, has a larger effective area than existing fibers (that is, a wider range of spectrum to send wavelengths of light on). Essentially, this fiber allows more power to be used to propagate wavelengths through the fiber without excessive non-linear effects that degrade performance by mixing signals. The LEAF fiber uses more of the 1550 nm spectral region, thus allowing more power to be used per wavelength without worrying about signal dispersion. The net result is that traffic can travel longer distances between amplifiers, or greater numbers of wavelengths may be sent over shorter distances.

DESPITE THE GROWTH OF DATA & DWDM, SONET STILL HAS A LONG WAY TO GO BEFORE MARKET SATURATION

In our discussions with both local and long distance carriers it is clear that deployment of fiber networks, especially those utilizing a SONET ring architecture, has become a basic necessity. Despite the recognition of its importance and potential quality-of-service and cost benefits for the service providers, SONET is far from being widely deployed in long distance networks. In addition, new applications for SONET optical transmission networks are being developed by local telephone companies, cellular carriers back-hauling traffic to wire-line switches and the newest market opportunity, CATV head-end interconnection. Thus, we continue to see tremendous revenue growth opportunities for all SONET equipment vendors.

One very significant point, in our opinion, is that while many newer metropolitan fiber networks, especially those built by competitive local exchange carriers (CLECs) appear to be predominantly constructed using SONET components and architectures, interexchange carrier (IXC) networks, especially the three large incumbent ones, do not. This should continue to translate into a significant market opportunity for SONET equipment vendors as the IXCs accelerate their installation of more SONET-based systems in their networks. That is, while newer carriers such as WorldCom have largely SONETized networks, older carriers such as AT&T are still carrying significant amounts of their traffic in asynchronous format. The interconnection between SONET and asynchronous networks creates a need for specialized interconnection equipment, such as transmultiplexers, which can "break down," or demultiplex, a SONET OC-3 or OC-12 optical signal into a series of more common asynchronous DS-3 (45 Mb/s) electrical circuits, then "groom," or multiplex, the electrical signals into higher-speed optical circuits. Since most communications traffic is still being generated at either the DS-0 (64 Kb/s) or DS-1 (1.5 Mb/s) levels, and since very few end users have fiber cables all the way out to their premise, this demultiplexing and multiplexing equipment is needed for the carriers to add traffic on to, and drop it off of, their high-speed transmission facilities.

ARE PACKET-BASED NETWORKS REALLY ELIMINATING THE NEED FOR SONET EQUIPMENT? NOT JUST YET…

One extremely important point, in our opinion, that keeps getting lost in the hype surrounding the all-powerful nature of packet-based networks, is the continuing (and, believe it or not, growing) need for certain network elements that were originally designed for purely circuit switched/TDM (Time Division Multiplexed - a technique used to carry traffic in circuit-switched networks) voice networks. For example, when Sprint's ION was announced, no mention was made of the need for any type of TDM elements in its new network. The fact is, however, that next generation ATM/TDM gateways from Tellabs will play an important role in this network by interconnecting and translating between the legacy circuit switches and the new ATM switches. Moreover, SONET digital cross-connects are also being deployed in the new "data-centric" networks being built by Qwest and Level 3 (Tellabs in the case of Qwest and Alcatel in the case of Level 3) because these networks are still carrying voice traffic, which, as we all know, does not easily tolerate network failures. It is also clear that there are still many, many data-oriented circuits that would not be enhanced by adding a "constantly switching interface port" like those provided by an ATM switch in place of a passive "nailed-up" circuit like those provided by a digital cross connect.

SONET & SDH: HOW THEY INTEROPERATE

Transmission standards in Europe and North America evolved from different basic rate signals in the non-synchronous hierarchy. Time Division Multiplexing (TDM) in North America combines twenty-four 64 Kb/s channels (DS-0s) into one 1.544 Mb/s DS-1 signal. European TDM multiplexes thirty-two 64 Kb/s channels (E-0s) into one 2.048 Mb/s E-1 signal.

Digital Optical Transmission Hierarchy

DS Levels	T-Carriers	Bit-Rate		SONET	SDH	Bit-Rate
DS-0		64 Kb/s	1 Voice Channel			
DS-1	T-1	1.5 Mb/s	24 Voice Channels			
DS-3	T-3	44.7 Mb/s	672 Voice Channels	OC-1		51.8 Mb/s
				OC-3	STM-1	155.5 Mb/s
				OC-12	STM-4	622.1 Mb/s
				OC-48	STM-16	2.5 Gb/s
				OC-192	STM-64	10.0 Gb/s

DS = Digital Service
SONET = Synchronous Optical NETworking
SDH = Synchronous Digital Hierarchy
STM = Synchronous Transport Module (SDH)
OC = Optical Carrier (SONET)
Source: Lehman Brothers

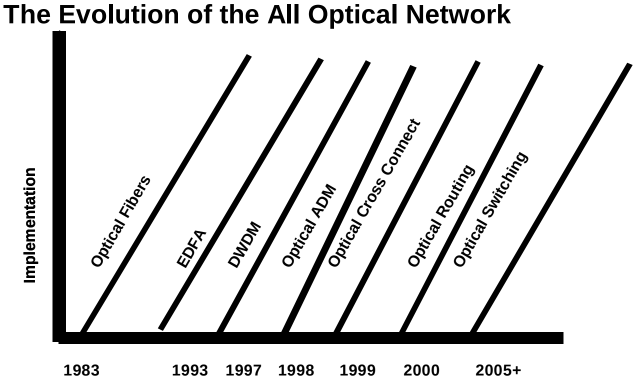
The issue between North American and ITU standards-makers involved how to efficiently accommodate both the 1.544 Mb/s and the 2.048 Mb/s non-synchronous hierarchies in a single synchronization standard. The agreement reached specified a basic transmission rate of 51 Mb/s for SONET and a basic rate of 155 Mb/s for SDH. SONET and SDH converge at SDH's 155 Mb/s base level defined as STM-1 (Synchronous Transport Module-1). The base level for SONET is OC-1 (also called STS-1), and equates to 51.84 Mb/s. Therefore, SDH's STM-1 is equivalent to SONET's OC-3. Multiplexing is accomplished by combining - or interleaving - multiple lower order signals (1.5 Mb/s, 2Mb/s etc.) into higher speed circuits (51 Mb/s, 155 Mb/s, 622 Mb/s etc.).

SONET'S PLACE IN THE FUTURE OPTICAL WORLD

A great deal of attention has been lavished on all optical network components that bypass the SONET layer. However, we do not believe that growth of the SONET market will slow materially as a result of the introduction of optical cross connects or, more importantly, DWDM systems. In fact, SONET is the only standard for single wavelength optical transmission and should continue as the dominant input to WDM networks, particularly for voice network applications. However, more than half of public network traffic is non-voice/fax (that is, non-analog) and SONET might not be the best method to handle digital data traffic. Therefore, ATM and IP traffic could be fed directly into optical networks without first being translated into SONET. However, we believe that the lack of restoration and survivability functionality in all-optical topologies should preclude them from supplanting SONET for the foreseeable future. In fact, we believe all optical networks should not be truly widely deployed until they can handle restoration, first on a point-to-point and then on a more complicated network basis, and it is worth noting that it has taken SONET ten years to get to this point of restoration reliability. Moreover, we believe that carriers with heavy investment in SONET over the past ten years will heavily sway (or delay) their decision to move to all-optical networking, which would call for ripping out their substantial installed base of SONET equipment. In addition, we believe that vendor influence also plays a significant role in technology decisions of carriers - particularly smaller/newer carriers with less of their own networking know-how - and the larger equipment vendors (Lucent, Alcatel, Tellabs, Nortel) with the long-term carrier relationships, have a very significant stake in the future of SONET.

To be sure, optical WDM systems are certainly eating into the SONET ADM market as carriers opt for DWDM over higher speed TDM as a means of increasing network capacity. Overall, we estimate that, at most, 10%-15% of the existing SONET equipment market is being cannibalized by WDM systems (for example, a carrier wants 10 Gb/s on a fiber, the carrier can buy a new OC-192 system or reuse and multiplex four OC-48s onto one fiber) but it appears that new network builds (for example, those of Qwest or the Williams Companies) and asynchronous to SONET upgrades on older networks (discussed above) are compensating for any slowdown resulting from this phenomenon. In fact, Lucent is in the process of rolling-out the latest generation of SONET equipment, which operates at OC-192 rates. Lucent's OC-192 systems are part of a complete next generation SONET product line, which is smaller, more cost effective and better integrated than existing systems. One particularly intriguing product, in our opinion, is the WaveStar Bandwidth Manager (WBM)that will eventually combine lightwave and cross-connect functionality with an ATM switching fabric- something both Alcatel and Tellabs (with the so-called BTM, which we believe should be available in late 1999) plan on doing with their cross-connects as well.

The Evolution of the All Optical Network



Source: Lehman Brothers

We believe that network evolution is clearly trending toward the point where photons should ultimately replace electrons in most network elements. The reasons for this trend are simple, optical components are inherently more reliable than electronic ones and have lower power requirements, both of which lead to lower operating costs and higher network reliability. Moreover, optical-electric-optical conversions introduce signal erosion, cost, and additional potential points-of-failure. In a nutshell, optics are making networks cheaper and simpler. Add to this the fact that the optical medium offers virtually infinite bandwidth that can support multiple wavelengths, and is therefore highly scaleable, and the end-result is that all-optical networking eventually should be the ultimate network solution. However, we do not anticipate electronic components being entirely replaced in our lifetimes due to their proven cost-effectiveness and reliability.

We believe the evolution of optical networks has and should continue to more-or-less track the following time-line: (1) In the early 1980s large-scale fiber deployments began to occur, with spans limited by the abilities/reach of the optical transmitters (lasers) and receivers used in the network; (2) Starting in the early 1990s, the Erbium Doped Fiber Amplifier (EDFA) began to be deployed in networks, greatly increasing the distance signals could travel; (3) In the mid 1990s Wavelength Division Multiplexing Systems were introduced into fiber networks, significantly expanding the capacity and flexibility of optical networks; (4) shortly after the introduction of WDM, optical add-drop multiplexing (OADM) started to find its way into the network, also adding to the flexibility of optical network architectures; (5) we believe that in another year or so, as multiple wavelength carrying fibers reach network ubiquity, optical cross connects (OCC) will start to invade the network in order to enable greater management of these fibers; (6) from these first-generation optical cross connects will stem a next generation of OCCs that will be able to translate wavelengths of light giving added flexibility to the network, and (7) eventually (and we mean well after the year 2000) optical switching should start hitting the scene, with ATM cell routing through optical decoding, and wavelength routing based on address headers.

THROUGH THE LOOKING GLASS: COMPONENTS OF AN OPTICAL NETWORK

There are a number of elements required in order to eliminate most electrical conversions from a photon's path as it traverses the public network (which, for purposes of this exercise, we will assume terminates at an optical node unit (ONU) roughly 500-1,000 feet from a customer's premise). We do not believe that optics will find their way into the residential premise for the foreseeable future due to the high cost associated with dedicating optical systems to a single end-user, as well as powering issues not worth exploring here. However, the development of low cost passive optical components and silicon based lasers and wave-guides should lead the way toward our vision of an eventual "wavelength in every home". Again we emphasize that the migration to all-optical networks is likely to be a gradual phenomenon, as is true with most technology deployments in the PSTN, although some optical elements are already in place, such as DWDM systems and optical amplifiers.

Dense Wave Division Multiplexers

As discussed above, simply put, WDM systems take the output of multiple fiber optic terminals transmitting at the same speeds, OC-48 for example, convert those signals to different wavelengths (through the use of transponders) within a few nanometers of each other, and transmit all of the signals over the same physical cable. In essence WDM systems are effectively transmitting "0s" and "1s" in multiple colors from one end and then separating them out, or demultiplexing them, at the other. Early WDM systems were limited to four or eight simultaneous signals but new technologies that permit more precise separation of the wavelengths are allowing companies such as CIENA to multiplex 16-40 signals over a single fiber strand with the promise of 80-96 multiplexed circuits in the not-too-distant future. In fact, the predicted average wavelength growth rate has leaped from 1.5 wavelengths per year from 1986 to 1996 to 16 wavelengths per year in the next three years.

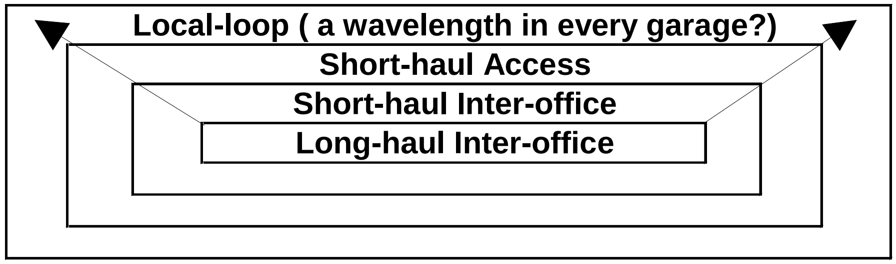
The number of wavelengths that can be transmitted by a given DWDM system is largely limited by the EDFA's ability to amplify wavelengths in a given spectral region. We note that the International Telecommunications Union (ITU) has established a grid encompassing 40 wavelengths in the 1540-1560 nm range, but it is important to note that the purpose of the ITU grid is more to standardize components, not to ensure system interoperability. Among the leading DWDM vendors, CIENA spaces wavelengths on its 16 channel system at 100 Ghz (0.8nm) increments and at 50 Ghz (0.4nm) increments on its 40 channel system. Moreover, Lucent's upcoming 80-channel DWDM system is spaced at 50 Ghz increments (0.4nm) whereas Lucent's 16-channel system is spaced at 100 Ghz increments (0.8nm). It is also worth noting that wavelengths tend to be more widely spaced when they are carrying a higher bit rate (for example, spacing OC-192 signals at 2.0 nm and spacing OC-48 at 0.8 nm) because of the non-linear properties of the light pulses. In fact, one of the primary gating factors to commercial rollout of 80-channel systems is effectively spacing the wavelengths at 50Ghz increments. The issue with allowing the wavelengths to travel this close together is that the proximity increases the problem of cross talk between channels. It is important to keep in mind that DWDM systems largely don't care if signals are OC-48 or OC-192 - the gating factor of 80x OC-192 (for example) is really the dispersion characteristics of the fiber itself rather than inherent DWDM system limitations.

Our research also indicates that network management capabilities are a critical differentiator of DWDM systems - and as the number of wavelengths transmitted over a given fiber increases, the sophistication of the network management systems increases accordingly. In fact, we believe that optical networking presents a huge OSS opportunity for vendors; each carrier has different ideas about how to manage the network, so a lot of customization will be required.

The DWDM market opportunity should keep on expanding

The DWDM market, where CIENA is currently the leading vendor, is going through a very perplexing stage in its development cycle. Specifically, despite DWDM being in the early stage of overall carrier deployment, and despite DWDM systems being highly value-added and differentiated network elements, it has already entered what appears to be a more commodity-like pricing environment. One can only speculate on the reasons for this, the most logical being that the larger equipment vendors want to prevent a fast growing company from joining their ranks. However, while the long-haul DWDM market appears to be maturing, the potential in the short-haul market appears incredibly large. This is because, we believe, the bandwidth bottleneck will migrate out to the edge of the network after a network's backbone capacity is increased. Moreover, DWDM systems will be used as enhanced services delivery platforms in the local-loop, enabling things like leasing “dark wavelengths” to corporations . However, until the metropolitan/access market starts to play catch-up (and DWDM systems for this market are just starting to become commercially available – and carriers still need to go through the evaluation and testing phase) we believe that pricing will remain incredibly competitive due to the limited nature of the long-haul customer base (primarily the older carriers with older fibers and lower bit rate SONET TDM systems, such as AT&T and Sprint). On the positive side, the future of the DWDM market reminds us of the market for digital cross-connects such as TITAN when they were first introduced. Specifically, when Tellabs introduced the TITAN in 1991, it expected a customer base of perhaps eight to ten carriers for the product (the RBOCs, GTE, Sprint, MCI and AT&T). Since then, due to the advent of the CLECs and alternative IXCs, the customer base has grown past 75, and still continues to grow. The message here is simply that as the DWDM market grows to encompass short-haul applications, the customer base will increase exponentially, the revenue concentration for vendors such as CIENA will decrease markedly, and the pricing pressure should moderate somewhat.

The DWDM Market Opportunity



Source: Lehman Brothers

The WDM Migration Path: A Wavelength in Every Garage?

We believe that the DWDM market opportunity can essentially be segmented into three categories, each of which is described below: (1) The long haul market. Deployments to date have almost entirely been focused on this segment of the market, in large part because the bandwidth shortage is most acute on long haul routes. For example, AT&T's bandwidth shortage is largely a result of the fact that back in the old days when there was no real long-distance competition, AT&T was regulated like a public utility so it had to justify any new fiber deployments to regulatory authorities. This hindrance to a build-out of excess network capacity, when combined with the unanticipated massive explosion in long-haul traffic caused by the Internet, has caused the IXC to conduct an ambitious DWDM deployment. And on longer routes the cost of deploying new fiber is substantially higher than the cost of swapping out the electronics on either end. This is because, assuming that rights-of-way are available, the cost to lay new fiber cables is quite linear with distance (as discussed earlier). (2) Short Haul Inter-Office. This market is in its initial stages of deployment and is more price sensitive to equipment costs than the long-haul market. The newer systems coming on the market this year (such as CIENA's Firefly) are specifically designed for the short haul inter-office market and should therefore offer a more economically compelling alternative to laying new fibers (which again assumes rights-of-way and permission from the municipality to dig up the streets). In our opinion, one of the first significant domestic applications of these systems will be for RBOC's interLATA circuits. The reason for this is simply that, since the RBOCs have been precluded from carrying interLATA traffic (with certain limited exceptions), their interLATA fiber routes are quite thin and are a compelling target for WDM systems, both from a time-to-market and an economic perspective. Systems designed for the short haul inter-office market are also better suited for the European market, where cities are situated in much closer proximity to each other than in the United States. (3) The metropolitan market. CLECs have built an incredible business model around building SONET rings in metropolitan markets and then "cream skimming" the lucrative business market away from the incumbent LEC. Metropolitan WDM systems will allow these CLECs (and the embattled RBOCs as well for that matter) to increase the capacity of these fiber rings (again, cities don't like allowing streets to be dug up over and over again to lay new fiber) in order to keep up with exploding demand for data services as well as provision new services. Additionally, because DWDM allows several different networks utilizing different protocols to share the same physical optical layer, CLECs will probably begin to sell "dark wavelengths" which a customer could then load up with any number of traffic types.

Erbium Doped Fiber Amplifiers (EDFAs)

Of all the advances in optical technologies, EDFAs appear to be the one key invention that has had the most significant impact on the growth of photonics in carrier networks. Furthermore, these EDFAs have made WDM very attractive in terms of capacity upgrades in point-to-point links since one repeater could handle all channels, making no need for further fiber deployment with multiple regenerators.

These optical amplifiers allow the magnification of light pulses without first converting them back into electrical signals and, unlike electrical generators, optical amplifiers are bit-rate transparent. EDFAs are the dominant method for signal amplification in long-haul lightwave transmission systems and, too a large degree, the gating factor on high wavelength count WDM systems is developing EDFAs that can effectively cover a wide spectral region (roughly 1535-1565nm). One of the challenges in developing broadband amplifiers capable of boosting 80 wavelengths of light is being able to equally strengthen all of the wavelengths across the approximately 30 nanometers of spectrum carrying the traffic. Newer EDFAs incorporate intelligent on-board amplifier control, which rapidly increase or decrease power automatically in order to maintain equal amplification levels for all the wavelengths being transmitted. As the number of channels in these is normally constant, the amplifiers operate in the constant power mode. However, in an all optical network featuring dynamic wavelength routing and protection channels, the channel load on the fibers changes significantly, depending on traffic patterns and restoration. The amplifiers have to be designed to handle dynamic loads, which basically means they should operate in a constant gain rather than a constant power mode. Flat gain over a wide bandwidth is required to preserve the optical carrier to noise (CNR) ratio throughout the entire frequency band.

Optical Add-Drop Multiplexers (OADMs)

OADMs allow optical channels (predominantly running at OC-48 rates) to be added or dropped from the fiber without interruption to other channels and therefore allow sharing of the economies of WDM among several traffic locations. The advantage of OADMs over "conventional" multiplexers is the elimination of the need to convert the optical signal to an electrical one prior to this grooming. Optical add-drop multiplexers are relatively new components in carrier networks and are always used on fibers that are wave-division multiplexed. These systems typically support the adding/dropping of up to four wavelengths of light, but newer DWDM systems that support greater than 16 channels (for example, CIENA's 40-channel system) will come with 8 channel OADMs. The current generation of OADMs is of limited use due to the fact that they support a fixed set of four wavelengths. That is, only a pre-set group of wavelengths can be groomed and in order to change any of the wavelengths a technician has to go to the OADM and manually reconfigure it. The introduction of remotely configurable/tunable OADMs, probably in 1999, should introduce significantly greater flexibility into DWDM network topologies.

Still other optical network components are in development including optical cross connects and optical switches.

Optical Cross Connects

All-optical cross connects, coupled with network interconnections at optical line rates, offer a significant cost advantage over certain current network topologies by eliminating costly opto-electronics used for optical/electric conversions. At this point in time, however, all-optical cross connect systems, such as those announced last year by Lucent Technologies, seem best suited for applications as traffic managers in the middle of a fiber optic circuit span rather than at network termination and interconnection points because, unlike SONET DCCS, they are designed to switch the physical wavelengths of light, independent of the format. At the end points of these circuits end-user services need to be derived from the circuit, which almost always requires translating the traffic back into electrical signals at rates of 50 Mb/s or less. Therefore, in our opinion, all-optical cross connects are likely to function as augmentation devices to the market for cross-connect platforms for the time being rather than supplant existing systems.

Essentially there are three types of optical cross connects: (1) Wavelength Selectable optical cross connects, allows the extraction of one wavelength from a fiber for transfer to another fiber. This is the type announced by Lucent last year. (2) Fiber cross-connects - All the wavelengths on a particular fiber are moved to another fiber. This functionality is primarily useful for restoration/protection. This type of cross-connect is already commercially available. And (3) Wavelength translator cross-connects - This allows traffic on a given wavelength on a given fiber to be transferred to a different wavelength on a different fiber. This type of cross connect is one that carriers would like to have, but the technology needed to commercially deploy it is still a few years off. Wavelength Selectable and Fiber cross connects are expected to eventually replace today's broadband 3-3 cross connects which are primarily used for service restoration within the PSTN.

Optical Switches (and Routers)

Looking out three to five years, we could very well see initial deployment of terabit switches with photonic switch matrixes as carriers struggle to cope with the ever-increasing loads their networks are carrying. This is because, beside the access segment of the network, the primary bandwidth bottleneck as transport network capacity continues to increase exponentially are the switching systems used today – including the various current generation ATM and IP switches. Currently, all switching is done in the electronic domain, and the replacement of these various electronic switches (including both the older voice-oriented Class 5 switches and the newer frame relay and ATM switches) is not likely to occur any time in the near future, both because optical switching technology is not ready for commercial deployment, and because the carriers will be loathe to replace their massive installed base of tried-and-true electronically based switches. In fact, there are a number of technical hurdles that must be overcome in a cost-effective way before photonic based switching and routing will be feasible on a commercial and widespread basis. In a nutshell, these include the ability to efficiently buffer photonic traffic and the ability to read packet headers in photonic form. Therefore, for the foreseeable future we believe that optical switches will be composed of a mix of electronic and photonic components.

TO EXTERNALLY MODULATE OR NOT TO EXTERNALLY MODULATE?

One of the (many) religious debates that appear to be occurring in the optical networking community is over whether or not there is a need to externally modulate laser used in short-haul systems. External modulators essentially act as shutters, so that instead of turning the laser on and off million or billions of times a second (off representing 0 in digital talk, and on representing 1, which can cause all kinds of operational difficulties and reduce the integrity and therefore the potential reach of the lightwave, the laser is left on at a constant level of power and the "shutter" in front of it is opened and closed instead.

The decision whether or not to use externally modulated lasers for sub-200 km systems is a function of the spacing density of the wavelengths as opposed to the distance traveled (since the distance in these systems is relatively short to begin with). As a result, 5-600 km systems with multiple channel counts typically must be externally modulated, whereas the sub 100 km 16-32 channel systems spaced at 100 Ghz (0.8nm) can work with directly modulated lasers. However, once the wavelengths are spaced closer together, externally modulated lasers will probably be the preferred solution, even in the short haul (it should definitely be noted that some WDM vendors believe that short-haul systems don't need to externally modulate the light even at higher wavelength counts. As we said, a religious issue).

ATM & IP: THEIR PLACE IN CARRIER NETWORKS

Circuit-switched networks dedicate a path from end-to end for the duration of a call—essentially creating an open pipe between two end points—while packet switched networks more efficiently utilize the network by filling a given path with traffic from multiple sources, broken up into small pieces of information, thereby maximizing network capacity. Since IP based packet networks were originally designed to carry data traffic, however, which are inherently less sensitive to delays, they don't offer the high quality of service, QoS, (read: toll-quality phone conversations) and reliability that circuit switching provides. Therefore many network planners are figuring out ways to combine IP systems with ATM and/or SONET in order to offer the QoS and network reliability that exists in the good old-fashioned PSTN.

Similar to the all-optical versus SONET debate, there has been quite a bit of controversy over the place of ATM and IP in carrier networks, and whether these technologies, either combined or separately, will obviate the need for SONET systems. Our view, in a nutshell, is that the technologies are complementary and are likely to all be deployed depending on a particular network's orientation as well as which legacy systems are already in place, as we shall explain. Imagine a four layer stack, the bottom most layer being the optical one, followed by the SONET/SDH layer, followed by the ATM one, followed by IP. The higher up this stack a system's functionality goes, the higher the cost and the higher the complexity. At the same time, the more layers that are added to the stack, arguably the more reliable (but less efficient) the transmission medium becomes.

A Four Layer Cake

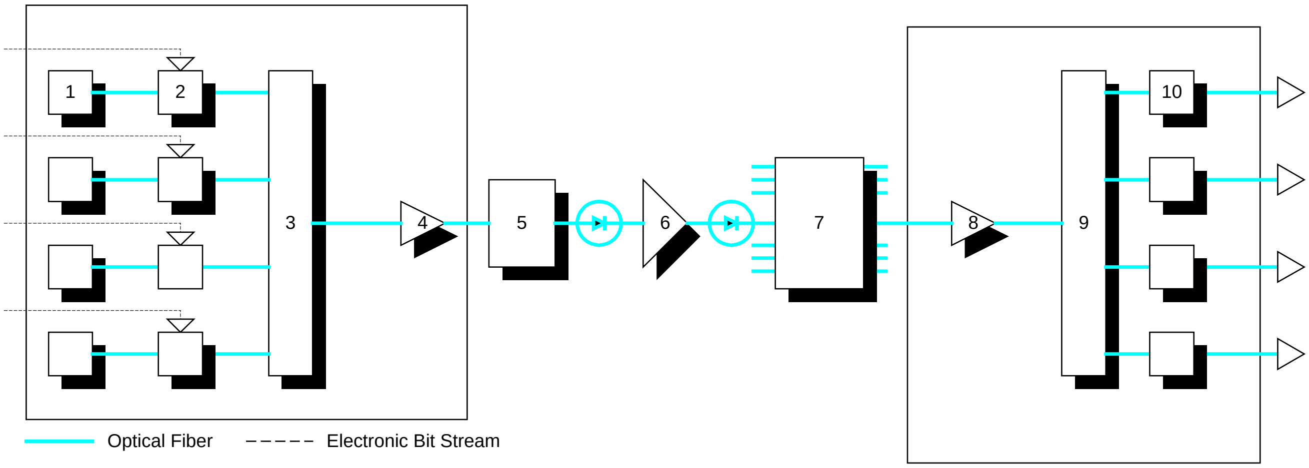
IP	Service Delivery
ATM	Network Management
SONET/SDH	Bandwidth
Optical Wavelengths	

Source: Lehman Brothers

In the ATM/SONET relationship, ATM provides the multi-application switching platform and SONET provides the digital infrastructure, physical transport and network management. With ATM over SONET, the mixing of framing types allows mixing of connection types as well - circuit and packet switched circuits on the same optical fiber. We believe there is currently minimal ATM demand from the end-user Fortune 500 community - for the most part they appear to be perfectly happy with the frame relay, IP, and leased lines networks they predominantly use. We believe, however, that ATM is currently the ideal core network solution because it is the ideal technology for allowing separate traffic types (voice, IP etc) to traverse the same networks in the same way. We also are skeptical about the concept of placing ATM straight onto the optical layer without first mapping it into SONET frames. The primary reason for this skepticism is the lack of full restoration capabilities in ATM architected networks. While ATM switches may be able to do point-to-point restoration, we do not believe they are yet capable of handling full network restoration. It should also be noted that *eventually* as IP based terabit switches gain the QoS and service restoration capabilities needed for the public network, we could very well see the elimination of ATM in the network core (by using IP over SONET instead of ATM, the ATM "cell tax" (5 bytes of every 53 byte ATM cell is header information) is eliminated, reducing overhead to under 1%). Mapping IP straight into SONET also eliminates the additional cost layer that comes from first encapsulating the IP traffic in ATM cells. Finally, it should be pointed out that there are still many digital data networks that would still be better off in a circuit switched mode and therefore would suffer in either an IP or ATM mode.

For now, the management/reliability and QoS weakness of IP and the network survivability weakness of ATM means the combination of IP and ATM over SONET is likely to predominate among public network carriers.

Optical Networking



1. Laser devices generate light pulses that are "tuned" to provide precise wavelengths, such as 1553 or 1557 nanometers, for the accurate delivery of optical-signals across the fiber-optic network.
2. Optical modulators convert an incoming electronic bit stream into an optical signal by rapidly turning the light stream on and off.
3. A WDM multiplexer combines the different wavelengths onto a single fiber.
4. Optical post amplifiers boost the power of the outgoing signal before it is sent out across the fiber. (Boosting the power increases the transmission reach, or the distance the optical signal can travel before regeneration.)
5. A dispersion compensation unit corrects dispersion - the "spreading" of light pulses as they travel down the fiber - to prevent unwanted interaction with adjacent pulses. This interaction can make it difficult for the system to distinguish the pulses at the receiving end.
6. Optical line amplifiers boost signal power to compensate for losses incurred during transmission over the fiber-optic link.
7. An optical cross-connect optically switches the signals to the correct destination.
8. Optical pre-amplifiers improve the effective noise performance of the optical photodetectors and boost the power of the incoming signal at the receiving end.
9. A WDM demultiplexer separates the multiple wavelengths carried on the incoming fiber.
10. Optical photodetectors convert the optical wavelengths into an electronic bit-stream.

Source: Northern Telecom; Lehman Brothers.

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