AN ASSESSMENT OF NEW BROADBAND WIRELESS TECHNOLOGIES AND THEIR IMPACT ON ADOPTION STRATEGIES FOR THE DOMINANT PROVIDERS

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ABSTRACT

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by Geoffrey P. Langos

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New broadband wireless products require a link between the deployment strategy and the technology. Dominance and survival in the wireless marketplace will depend on adopting new technology that creates value for customers along non-traditional performance dimensions. Providers need to look beyond their current infrastructure and core capabilities by observing their customers and continually creating new products that provide clear and quantifiable value. Successful providers will conserve resources and iterate forward with strategies that consider many broadband wireless technologies, and then introduce those that show signs of being profitable. The intent of this research is to assist the providers in holistic planning and adoption strategies for new broadband wireless products. Models and frameworks are used to demonstrate how providers can think about their strategies for assessing, organizing, funding, and deploying new technology. These models suggest that WiFi is emerging as the dominant design in a disruptive manner. This conclusion is not as important as the thought process by which this conclusion was made, and how a provider should respond to such a conclusion.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

DEDICATION

This work is dedicated to my three daughters, Taylor, Blair, and Paige. Ironically, at this time of this writing, they were all under the age of five, and none of them could read. My oldest two were amazingly patient throughout this process and seemed to understand the importance of "doing homework" when they asked what I was doing. I hope this serves as an inspiration to them, and that they see the importance of committing themselves to lifelong learning.

BIOGRAPHICAL NOTE

Mr. Langos graduated Magna Cum Laude from Case Western Reserve University, receiving both a Bachelor of Science and Master of Science in Electrical Engineering in 1994. He completed both degrees in five years as part of an integrated B.S./M.S. program, which also required a thesis. In 1991 he was selected as one of two General Motors Scholars at CWRU, and he was given two internships at GMs Packard Electric division. His first thesis, published in 1994, was titled *An Intelligent Manu Planning System*, and contained algorithms to solve multivariate optimization problems using linear programming and artificial intelligence. His most recent publication was titled, *Divide and Conquer* and was published in *SQL Server* magazine in December 2002. Since leaving General Electric Lighting in 1996, he has held positions of increasing responsibility at Verizon, where he played a critical role in the early deployment of their DSL products. He currently lives in Chesapeake, Virginia with his wife, Melissa, and their three daughters.

BACKGROUND AND INTRODUCTION

Motivation

Verizon is highly committed to educating its employees. This document is one attempt to justify the expenses incurred by Verizon in support of my degree.

After examining several potential research projects, I chose to study broadband wireless technology because it was the most complex, unclear, and diverse of my choices. Wireless products are the fastest growing part of our business, and clearly represent the largest, and riskiest, opportunity for the future of telecommunication companies. If this thesis offers *any* insight for the leaders of our industry, then I have succeeded, and Verizon has realized value for its commitment.

Goals and Reader Expectations

The dynamic nature of the communications industry, especially wireless data communications, made it difficult to contain the scope of, and make conclusions within this document. New wireless product announcements occur almost everyday. Decisions and consequences that are obvious today were undoubtedly met with speculation and/or optimism merely months ago.

For these reasons, I chose to focus on *how* to think about broadband wireless technology strategy rather than exactly *what* to think. The reader will gain a holistic understanding of ten emerging broadband wireless technologies – their underlying architecture, capabilities, market opportunities, limitations, and their performance relative to each other. These wireless technologies are also examined relative to their wireline counterparts, to other industries, and to recent product offerings, to help determine their probability of success given prior knowledge, successes and failures.

Methodology

Initially, I met with Verizon executives from five different business units. Each executive provided a daylong summary of his or her complex system design and management challenges. Broadband wireless provided enough scope and publicly available data to deliver meaningful results to Verizon in a document that is also fit for publication – a requirement of an MIT thesis.

I subscribed to several on-line wireless publications (which the reader will find in the references) and immediately became deluged with data. It quickly became apparent that finding information *relevant* to the future of broadband wireless was akin to a needle-in-the-haystack. The Internet, especially with a search engine like Google, is very useful for doing research as long as you have some frameworks for organizing the torrent of data received.

Other sources of knowledge and help came from my MIT thesis committee, attending conferences, the Verizon Information Research Network, and other MIT faculty and students. Professor Utterback's course, *Disruptive Technology: Predator or Prey*, was particularly helpful. His class required us to choose and assess an emerging technology in small teams. Five other students and I chose to look at several broadband wireless technologies. Their insight and contributions were invaluable.

Nine frameworks are used in order to assess broadband wireless technologies, competition, regulation, value propositions, and strategies. A system dynamics model summarizes all of the important interactions. I drew conclusions by gathering data and evidence, stating assumptions, and assessing the frameworks. One could repeat this process with new assumptions, data, and evidence, and reach different conclusions, which should make this work useful for assessing this dynamic space going forward.

WIRELESS BROADBAND DEFINITION AND MARKETPLACE

1.1 Speeds and Spectrum:

Since the term *broadband* is used somewhat loosely and different industries do not agree on a common broadband definition, it is important to immediately establish the data rate this paper will consider as broadband. Figure 1 shows typical data rates for existing technology. According to the FCC, bi-directional speeds above 200k bits per second (bps) are considered *broadband*. However this is well below the 1 - 3Mbps definition that the cable and telephone companies use [1]. Some industry leaders such as Craig Barrett, CEO of Intel, say that broadband is at least 5Mbps to 10Mbps [2].
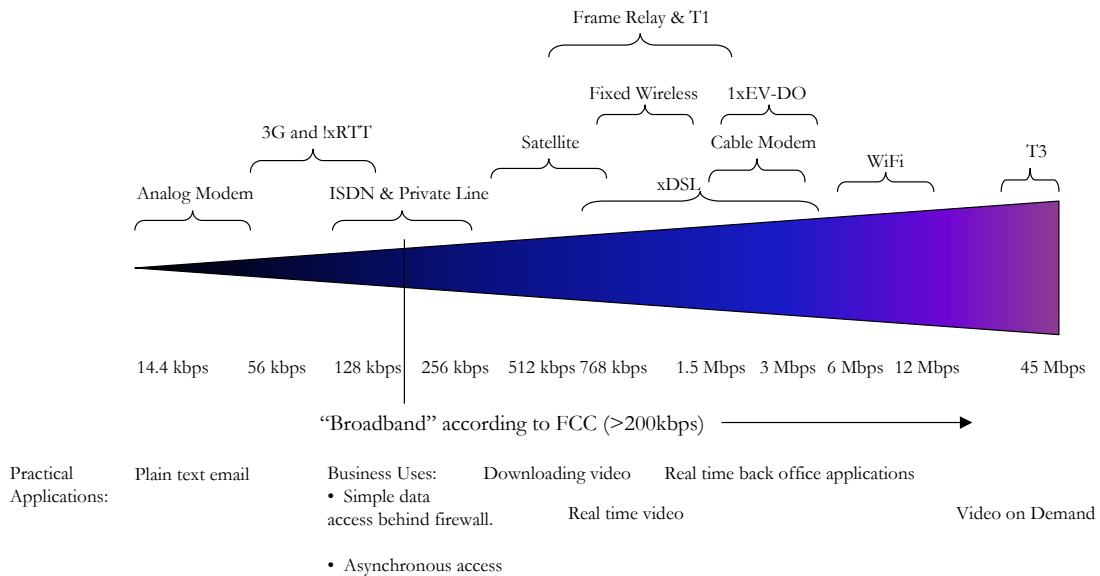
Figure 1. Speeds and Applications

These definitions are agnostic to the delivery mechanism, although Barrett advocates 100Mbps fiber-to-the-home as moving in the direction of true broadband. Others such as

James Ciriello, Director of BUILDE at Boston University's School of Management, thinks mobile wireless delivery in the 300kbps can deliver real value [3].

Intersecting the wide range of definitions with the available delivery mechanisms and assuming a Moore's-Law-type of demand for broadband performance, yields the matrix shown in Table 1. These will constitute the definition of broadband within the context of this document.

	"Broadband"		
Delivery Mechanism	2003 Definition	2004 Definition	2005 Definition
Wireline (any)	1 Mbps	2 Mbps	4 Mbps
Fixed wireless & Satellite (data)	500 kbps	1 Mbps	2 Mbps
Mobile wireless	300 kbps	600 kbps	1.2 Mbps

Table 1. Broadband Definition as a Function of Delivery
and Time

Wireless broadband has to operate within spectrum constraints and contend with issues caused by *multipath* – the composition of a primary signal plus duplicate or echoed signal caused by reflections off objects between transmitter and receiver. Figure 2 highlights the area of the electromagnetic spectrum called the *Radio Frequency Spectrum* (usually abbreviated RF)– this is the range of frequencies in which wireless broadcasting of all forms, including AM and FM radio, television, satellite, and WiFi takes place.

This diagram also shows that the wavelength decreases as the inverse of frequency and that shorter wavelength signals can carry much more energy. These are important characteristics to know because they play a vital role in the way the spectrum can best be physically used. Signals with longer wavelengths (lower frequencies) are more robust (i.e. improved performance in atmospheric noise) whereas signals with increasingly short wavelengths become directional and focused. Examining uses at the two extremes of the

RF spectrum helps to explain these properties further. Very low frequency (VLF) transmitters, operating in the 3kHz to 30KHz range, are used in submarine communications because signals of these frequencies are best able to bend and propagate across very large areas and are resilient to most noise under the surface of the water.
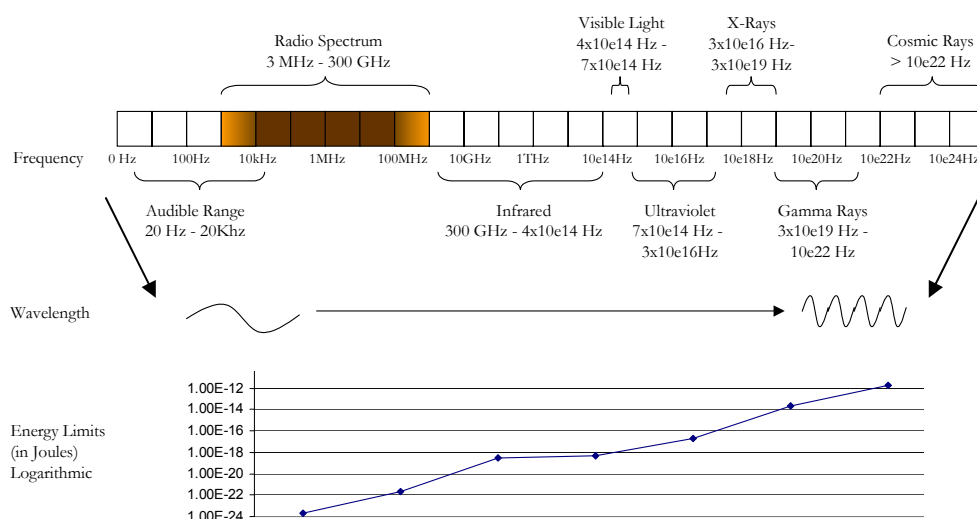
Figure 2. Electromagnetic Spectrum: Frequencies,
Wavelengths, and Energy

At the other extreme, products such as those available from Trex Enterprises can beam RF signals in the 70GHz to 80GHz range between line-of-sight targets, such as distributed office buildings that are about a mile away, as shown in Figure 3 [4]. The focused, narrow RF beam allows the delivery of very concentrated RF energy from point-to-point.

The radio spectrum is divided into frequency segments and allocated by the United States government. Other countries allocate bandwidth differently. Figure 4 shows some high-level band frequency allocations and activities in this spectrum. For a more comprehensive allocation of the radio spectrum, see the United States Frequency Allocation Designation [5].
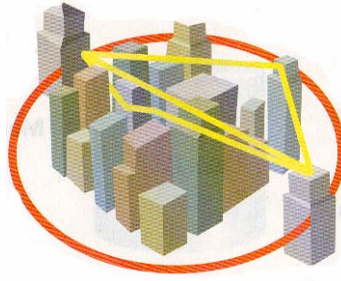
Figure 3. Ultra-High Frequency Point-to-Point RF
Application

Some portions of the radio spectrum are licensed, meaning a fee is paid by an organization for exclusive use of the bandwidth, while others are unlicensed and can be shared. Since 1994 the FCC has held over 33 spectrum auctions, which resulted in the assignment of thousands of licenses [6].

Table 2 is a listing of common spectrum/frequencies used in the US. Kobb and Wanichkorn provide detailed breakdowns of specific frequencies within the radio spectrum that are available for broadband wireless use at the time of this writing [7].

Band Designation Abbreviation	WLAN	WWAN	MMDS	U-NII	LMDS
Frequency (GHz)	2.4	2.4	2.5	5.8	28
P2P Throughput (Mbps)	1-11	11/11	44/44	100-1,000	155/155
P2MP Throughput (Mbps)	1-11	3/3	22/18	54+	45/10
Bandwidth (MHz)	83.5	83.5	186	300 (200 outdoors)	1300
Range: Line of sight P2P	400 ft	25 mi	25 mi	20 mi	3 mi
Range: NLOS P2P	N/A	N/A	7 mi	7 mi	N/A
Range: P2MP	400 ft	6 mi	5 mi	4 mi	2 mi
Affected by Rain	No	No	No	No	Yes
Over the Air Protocol	IP	IP	IP	ATM & IP	ATM
Approximate Cost Per Link	$0.3k	$1k	$8k	$3k	$200k
FCC Licensed	No	No	Yes	No	Yes

Table 2. Common Spectrum used for Broadband
Wireless in the US [8]

16

Devices operating in both the licensed or unlicensed bands must comply with FCC regulations, which impose energy and distance rules. One such limit is the Specific Absorption Rate (SAR) of radio frequency (RF) energy. The FCC requires SAR to be less than 1.6 watts per kilogram averaged over one gram of tissue while operating at the highest power level and across all frequencies [9]. Devices operating in the unlicensed bands (WLAN, WWAN) are generally limited to short distance ranges. For example, 802.11b signals – the standard used by WiFi technology – are limited to 100 milliwatts of power at a distance of 1000 meters, and cordless phones operating in the home RF space are limited to 125 milliwatts of power at 50 meters [10]. These restrictions make logical sense given that every device is competing for the same space.
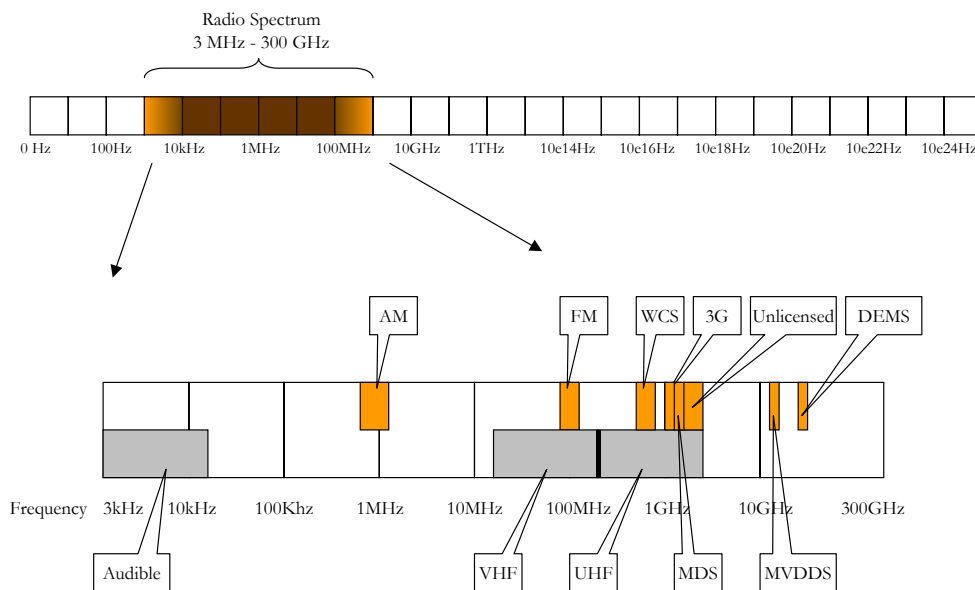
Figure 4. Sample of Common Band Designations in the
Radio Spectrum

1.2 Services: Provided Today

New services in the wireless broadband marketplace are being introduced rapidly, and the usage of wireless data features is growing at double-digit rates [11]. Figure 5 summarizes the different offerings in the market today and helps to define what constitutes a basic service from a premium one.

1.2.1 Basic versus Premium Services

Wireless data services provided today range from asynchronous, plain text messaging like Short Messaging Service (SMS), to hybrid devices that can access email, to vertically integrated applications tied to corporate databases and remote users. The basic expectations of the traveling business user are access to email and schedules. An example of a basic wireless service is secretarial automation such as notification of schedule or travel changes and appointment reminders. Business customers who have high bandwidth and quality of service demands need to partner with carriers, service providers, system integrators, and possibly even hardware manufacturers to create premium services customized to their needs.
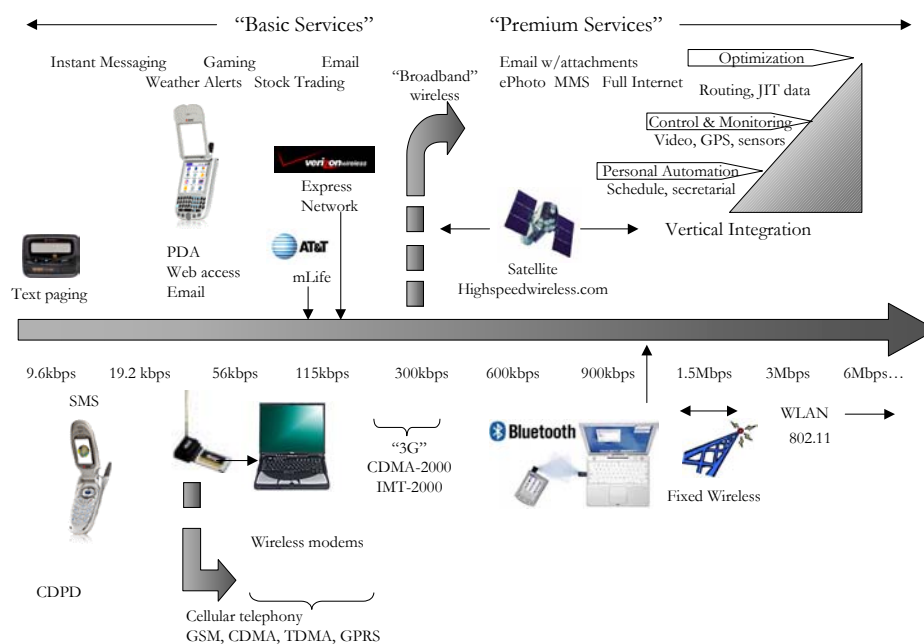
Figure 5. Basic versus Premium Wireless Services

Emerging WiFi networks are interesting to look at from a service classification perspective because their speeds, typically in excess of 5Mbps, allow users to access whatever applications are installed on their laptops, provided their corporate network infrastructure allows virtual private networking. However, when users only accesses basic services such

as email or instant messaging (IM), the WiFi network is still capable of providing premium value even though it is not being utilized as such.

Basic services in the consumer segment include services like gaming, IM, weather reports, and stock trading. Premium consumer services in the next year will likely center around location based services such as e-411 and directions.

1.2.2 Pricing Models

Current pricing models consist of a mixture of the following components, depending on the provider and delivery mechanism:

- One-time equipment charges
- One-time installation or setup fees
- Truck-roll (sending a technician on site)
- Recurring fees for the service
- Annual agreements with early termination penalties
- Roaming fees
- Per-kilobit data usage charges
- Usage charges (per minute, per hour, etc.)
- Charges for exceeding data and/or time usage limits
- Static IP charges
- Productivity and communication tool options
- Service guarantee

Table 3 provides examples of typical prices for four different wireless technologies, and Table 4 has examples of broadband wireline pricing models. Since prices and terms constantly change based upon demand and competitive offers, these tables represent only a snapshot in time.

June 2003	Wireless Delivery Mechanism (data to a device)						
	Mobile Wireless	*Satellite*	*Fixed Wireless*			*WiFi*	
Provider	**Verizon Wireless**	**Earthlink**	**AccessNet**	**Continental**	**Telion**	**Boingo**	**T-Mobile**
Class of Service	Residential or Business	Residential or Business	Residential or Business	Business	Business	Individual User or Corporate Account	Individual User or Corporate Account
Name and/or Description of Product	Express Network (unlimited)	DIRECWAY (with dialup)	AccessNet Wireless	Continental VisiNet Wireless	i-Net	Pro, Unlimited, As-you-go	T-Mobile HotSpot
Number & Size of Mailboxes	none	8 Mailboxes, 10 MB each	5 Mailboxes, 10 MB each	5 Mailboxes, 40 MB each	2 Mailboxes, no size limit placed but monitored	n/a	n/a
Hours Included	Unlimited but not "always on."	Unlimited	Unlimited	Unlimited	Unlimited	Depends on plan	Depends on plan
Web Space Included	no	10 MB / mailbox	25 MB	no ($25/mo. For 25 MB)	no	n/a	n/a
Domain Name Included	no	no	yes	no	transfer first one; $25/mo.	n/a	n/a
Installation Interval	immediate	10 Days	2 weeks	2-3 weeks	2-3 weeks	immediate	immediate
Typical Data Rates	60-80 kbps; 144 kbps bursts	400 kbps down; 128 kbps up	1 MB symmetrical	256 kbps symmetrical	384 kbps symmetrical	up to 1.5 Mbps (T1 backbone)	up to 1.5 Mbps (T1 backbone)
One-time equipment charges	PC Card is $300; service is for one device only	$550-$575	$149	$500 (rooftop equipment)	up to customer to provide LAN equipment	WiFi card is $75-$100	WiFi card is $75-$100
One-time installation or setup fees	$35 activation fee (waived w/ 2 yr contract)	$250-$325	included in one time charges	$250 (waived with 2 year contract)	$200	$0	$0
Truck-roll (sending a technician on site)	n/a	included in one time charges	included in one time charges	included in one time charges	included in one time charges	n/a	n/a
Recurring fees for the service	$80 / month	$70/month	$99 / month	$150/month	$198/month	$25/mo. for 10 connection-days, $50/mo. (unlimited)	$30/mo.(12 mo. contract), $40/mo.(no contract)
Annual agreements with early termination penalties	1 or 2 years; $175 termination fee	1 year. $400 penalty	1 year	1 or 2 years	1-3 years; penalty is remainder of contract	No. All plans are month by month	optional
Roaming fees	$0.05/kb	n/a	n/a	n/a	n/a	not available yet	not available yet
Per-kilobit data usage charges	n/a (with unlimited package)	n/a	n/a	n/a	n/a	n/a	n/a
Usage charges (per minute, per hour, etc)	voice usage ($0.25 - $0.69/min)	$1.00 / hour for dialup exceeding 20 hours / month	n/a	n/a	n/a	$7.95 / connection-day	$0.10 / minute or $50 for 300 min
Charges for exceeding data or time usage limits	$0.20-$0.40/min (n/a to unlimited plan)	n/a	n/a	n/a	n/a	n/a	n/a
Static IP Charges	not available	not available	no charge for first three	no charge for first eight (5 usable)	one included	n/a	n/a
Productivity and communication tool options	Custom applications available	$4.95 / extra mailbox monthly	Filtering services included	Anti-spam and virus protection	spam filtering; web-based mail administration	VPN and sniffer software; 1300 locations	2439 locations; partnerships with Starbucks and Bod Borders
Service guarantee	Best effort	Best effort	Best Effort	Guaranteed data rate and availabilty	> 99.5% availability	No	Yes, within 200 feet of hot spot

Table 3. Example Pricing Models for Four Broadband
Wireless Delivery Mechanisms

Businesses who use wireless technologies to *change* their processes exude signs of holistic rethinking. Imagine, for example, that you were given a wireless device when you entered an amusement park. The device would allow you to check the line at your favorite rides and give you the optimal path to minimize your wait for the rides you want. If attendance for a particular event or show is lower than expected, the park could send a coupon to the devices to stimulate attendance. Further, location based services could recognize when the customer passes by gift shops and restaurants and attempt to lure the customer in.

June 2003	Wireline Delivery Mechanism (data to a device)									
	ISDN	IDSL			COAX		SDSL & Frame		ADSL	
Provider	Verizon	Earthlink	Pinnacle	Continental	Cox	Cox	Pinnacle	Verizon	Verizon	Verizon
Class of Service	Business	Business	Business	Business	Residential	Business	Business	Business	Residential	Business
Name and/or Description of Product	Virtual Office	Extended Reach DSL	Pinnacle ISDL	Continental IDSL	High Speed Internet	Business Services	SDSL	Frame Relay	Verizon On Line DSL	Verizon On Line DSL
Number & Size of Mailboxes	6 Mailboxes, 10 MB each	8 Mailboxes, 10 MB each	1 Mailbox, 10 MB ($50/yr for each additional)	5 Mailboxes, 40 MB each	7 Mailboxes, 10 MB each	5 Mailboxes, 10 MB each (50 MB)	1 Mailbox, 10 MB ($50/yr for each additional)	no	9 Mailboxes, 30 MB (primary); 10 MB all others	6 Mailboxes, 5MB each
Hours Included	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited
Web Space Included	0MB (dynamic) 10MB (static IP)	10 MB / mailbox	no	no ($25/mo. For 25 MB)	70 MB	none	no	not included	10 MB	20 MB
Domain Name Included	transfer first one	no	no	"supported"	no	none	no	yes	no	first one (cust. still pays for reg.)
Installation Interval	10 days for line, 2 weeks for ISP	10 Days	up to 30 days (most are 7-10)	45-60 days	3 days	3 weeks	up to 30 days	up to 30 days	3-5 days	within 10 days (dynamic IP)
Typical Data Rates	128 kbps symmetrical	144 kbps symetrical	144 kbps symetrical	144 kbps symetrical	1 Mb down, 256 kb up	128k, 256k, or 384k symmetrical	384 kbps or 768 kbps	256 kbps	up to 1.5 M down, 128 k up	1.5M/128k, 1.5M/384k
One-time equipment charges	ISDN Router ($350 $695)	$515 fully refunded after first month	$400 (router)	$395 (router)	$149 or $15 / month rental	cable modem included	$400 (router)	router $400 to $1980 incl. maintenance on some	$12.95 (modem)	$99 (modem); $79-$149 (router)
One-time installation or setup fees	$100 (dynamic IP) $300 (static IP)	router included in $515	$270	$325	$0	$250 (1yr), $200 (2 yr)	$270	$1	$0	$25
Truck-roll (sending a technician on site)	n/a	included in one time charges	included in one time charges	included in one time charges	waived unless professional installation	included in one time charges	included in one time charges	$1	$0	none for self install; $199 (optional)
Recurring fees for the service	$75 / month plus ISP charges (see static IP)	$129 / month	$145 / month	$139 / month	$49.95 / mo. $10 discount w/basic cable TV	$69/mo.(128k) $139/mo.(256k) $199/mo. (384k)	$177/mo.(384k) $315/mo.(768k)	$667 / month	1st mo. free; $35/mo.	$60/mo.(/128), $90/mo.(/384)
Annual agreements with early termination penalties	1 year for ISP	1 year. $149 penalty	No -- just give 30 days notice.	2 years; $225 penalty	none	1 - 5 years (100% of remaining)	No -- just give 30 days notice.	1-3 Years	no	1 year unless cancelled withing 30 days
Roaming fees	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Per-kilobit data usage charges	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Usage charges (per minute, per hour, etc)	n/a with unlimited	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Charges for exceeding data or time usage limits	n/a	n/a	n/a	n/a	2 GB / day	n/a	n/a	n/a	n/a	n/a
Static IP Charges	$259 / month ($125 for dynamic IP)	no charge for first one	no charge for first one	no charge for first eight	not available; uses DHCP	1 included ($25 / mo. Each)	no charge for first one	up tp 32 included	not available	$30 / month for one
Productivity and communication tool options	13 static IP addresses	$4.95 / extra mailbox monthly	direct number to tech support	Firewall and VPN included	Webmail access; 7x24 support	Webmail	direct number to tech support	no	site builder tools, spam blocking, networking	20 hours of dialup; 7x24 tech support
Service guarantee	Best Effort; speed not guaranteed	99.9% Guarantee	Best effort. MTTR is 1 hour	Guaranteed data rate and availability	Best Effort	Best effort with service level agreement	Best effort. MTTR is 1 hour	Service Level Agreement; 99.9% guarantee	Speed not guaranteed; Best Effort	Speed not guaranteed; Best Effort

Table 4. Example Pricing Models for Five Broadband
Wireline Delivery Mechanisms

Another example of a business change enabled by wireless messaging is in metering. Installing a wireless meter-reading device eliminates the need to dispatch a person, saving money and providing near real time data.

1.3 Services: Emerging

One way to look at how wireless broadband services will likely evolve is to consider the dependencies on market segments and mobile device capabilities.

The US consumer segment will have expectations based upon their current Internet experience. Replicating this experience on a PDA, cell phone, or even with a 3G cellular telephony modem on a PC is difficult. Moreover, this segment is highly price sensitive and uneducated about wireless data products.

In 2002 65 percent of end users paid less than $50 for their mobile device, and half of these people paid nothing for their device [12]. Wireless data, and especially broadband wireless data, requires high-end, more expensive devices and additional usage costs. Unless consumers get more value out of these devices and services, they aren't going to spend the extra money. Neil Strother, senior analyst with Instant/MDR put it this way, "…even if people have a lot of extra cash on hand [they're] only going to buy what's useful or interesting [13]."

Educating consumers about wireless data products has not been a priority for the US carriers because they have been focused on generating revenue from voice capabilities by expanding their networks and capturing market share [14]. Since the carriers make more money by splitting cells and adding capacity than from messaging, and since only one in 20 wireless applications generates any revenue, let alone profit, they have been concentrating on voice [15]. This trend is quickly changing, mainly due to rebate offerings and aggressive advertising by mobile device manufacturers like Motorola and Nokia that has stimulated the consumer market and driven the carriers to offer more data products [16].

Businesses in the US are more likely to adopt broadband wireless in two distinct phases: First, to extend their existing capabilities and later to *change* the way they do business [17]. Equipping police cars with data retrieval devices and automatically notifying traveling

executives of schedule changes are examples of natural extensions of existing capabilities and incremental innovation. In both cases the users are more productive and benefit from the value of timely data.

1.3.1 Summary of Existing Services and Providers

The sheer amount of thrashing in this market today suggests that wireless data, and especially broadband wireless data, is behaving according to the early stage Utterback-Abernathy model (Figure 32). This model suggests that prior to the establishment of a *dominant design*, the number of products and competitors will be larger than the market can sustain in the long term, and that once the dominant design is established, there will only be a few players left [18]. Moreover, industry regulation and government intervention may have a significant impact on the dominant design in this space. The FCC ultimately controls the spectrum and therefore has the ability to promote one technology over another with any decision.

Interoperability and roaming agreements are also critical to long-term adoption rates of wireless data products. Consumers' motivation for purchasing a communication device is severely limited if the device limits their social network by only letting them send and receive messages with others who use the same provider [19]. This reason is often cited as one of the main reasons SMS has been slow to catch on in the US.

There are approximately eight categories of broadband wireless technologies, each struggling to emerge within a dominant design. There are many players in the broadband wireless data space. Each is involved in different parts of the value chain, depending on the type of technology and their specific value proposition. Figure 6 shows the value chain in the broadband wireless industry and lists some of the key players within each sector of the chain.

1.3.2 Frameworks for Assessing Long Term Services and Likely Providers

This section introduces several frameworks that are used to assess an emerging technology and market. Each framework will be described briefly here. They will be reintroduced in Chapter 4, first in general terms to provide the reader an opportunity to understand the

concepts and thought processes each framework intends to convey, followed by the application of each framework to broadband wireless technologies.

1.3.2.1 Utterback-Abernathy Models

The focus of the research by Utterback and Abernathy has largely been on the relationship between product innovations, process innovations, and the emergence of a *dominant design*. Their research shows that many firms tend to enter the market early in a product's life cycle, and then once a dominant design has been established, the number of firms the marketplace can sustain drops significantly.

Chip Sets	Devices	Providers	Transmit & Receive Infrastructure	Applications	End Users
Bluetooth					
ARM, DNP, Texas Instruments	Ericsson	Cingular, Sprint, Nextel	Ericsson, Motorola	IBM, Microsoft	PC Users, Mobile Electronic Users
Fixed Wireless					
Intersil, Wavesat, Bermai	Gateway, AeroComm, L-Comm	Nucentrix, Frontier	Beamreach, SOMA, Navinni	Portal Software	Rural customers; temporary applications
Home RF					
SiGe	Compaq, Proxim, Motorola, Siemens	User Provided	Motorola, Proxim, CommsDesign	Microsoft	Gamers, HomeOwners, Small businesses
Mobile					
ARM, Qualcomm	Palm, Kyocera, Motorola, Nokia	AT&T, Sprint, T-Mobile, Verizon	Rohn, American Tower Corporation	Microsoft, Lucent Technologies	Consumers, mobile sales force
Mesh Networks					
Intel, Texas Instruments	Nova Engineering, Texas Instruments	User Provided	Cisco	Tellium, Mobile Mesh	Wi-Fi Networks, Coporate Campuses
Satellite					
ARM, Broadcom	Hughes	LinCsat, Lucent	KVH Industries, Hughes	Qualcomm	Rural customers
Ultra Wide Band					
Intel, Fatasma Networks, Xtreme Spectrum	IBM, Intel, Motorola	Government, User Provided	Time Domain, Fantasma Networks	Celerity Systems, Lucent Technologies	Government, automobiles, Bluetooth applications, Wi-Fi users
WiFi					
ARM, Intel, Texas Instruments, Broadcom, Intersill, Agere	Cisco, Netgear,	MIT, Verizon, Individual Businesses	Vivato, Pronto, Cisco	Prism, Eedesign, Windnet, Microsoft	MIT Students, Starbuck's customers

Figure 6. Broadband Wireless Value Chain and Examples
of Key Players Within Each Sector [20]

1.3.2.2 Performance vs. Market Demand

Analyzing product performance over time, Clayton Christensen, author and Harvard Business School researcher, found many cases across a wide variety of different industries where the firms failed even though they listened to their customers, followed excellent management practices, and created wonderful products. The underlying reason for failure was that the firms kept making incremental improvements to their product's performance and eventually overshot the actual demand in the marketplace.

1.3.2.3 Sustaining vs. Disruptive Innovations

Christensen suggests that the ability of a new technology to displace incumbent firms depends upon the development of a new market within an established industry [21]. Moreover, this new market has ancillary needs that are more important than traditional product's metrics, such as smaller disk drives that hold less data (worse along traditional performance metric) but fit into newer devices (ancillary need).

1.3.2.4 Modes of Competition

Utterback and Pistorius show there are four *modes* that a new technology exudes when entering the marketplace. In some cases the new technology causes the overall demand for it and similar technologies to expand and allow both to survive. Sometimes the new technology simply takes market share away from existing technologies. Yet in other cases demand for the old technology increases when the new technology is introduced, and in some cases the new technology is overtaken by the old. These *modes of competition* can be very useful in predicting how the technology and marketplace may evolve.

1.3.2.5 Resource and Strategy Iteration Model

Christensen's research shows there is a relationship between the number of strategy changes that a successful company makes as it adapts its technology to the market's needs and the amount of resources spent developing each iteration. He concludes that beginning with the correct strategy for a disruptive technology is not as important as failing early and conserving enough resources to allow for iterations toward a viable strategy [22].

1.3.2.6 Lotka-Volterra Substitution Analysis

The effect that one technology has on another's growth rate is taken as the criterion whereby the mode of interaction is judged. Taken from the study of population dynamics, Lotka-Volterra provides a method to analyze the case of pure competition, where one technology substitutes for another, and numerically projects when a new technology will overtake market share from an existing one.

1.3.2.7 Mobility Segment Model

Christensen shows that disruptive technologies tend to perform worse than the incumbent technologies when comparing the metrics that have been traditionally valued. However, the new technology has ancillary features with performance metrics that cannot be compared to the incumbent's, and these ancillary features are attractive to a subset of the market [23]. Knowing this, it is important to attempt to segment the market in such a way that customers who might be interested in the *ancillary* features are identified.

1.3.2.8 Regulatory "Motability" Matrix

Industry regulation and government intervention may have a significant impact on the dominant design in this space, as the FCC ultimately controls the spectrum and therefore has the ability to promote one technology over another with any decision. The motability framework combines policymakers' *motivation* and *ability* to change policies and shows the impact these two dimensions have on the market.

1.3.2.9 System Dynamics

The central concept to system dynamics is in understanding how all the objects in a system interact with one another. System dynamics is a method for studying causes and effects of interactions, events, and decisions. In other fields of study it is common to decompose large problems into smaller and smaller pieces that can be modeled and more easily understood. System dynamicists look at things as a whole.

1.4 Broadband Wireless Applications

Wireless applications can be categorized by market segment – consumer, business, and government – and generally fall into one of six categories:

- Internet access (including email)

- Financial Services

- Gaming and Entertainment

- Location-based services

- mCommerce

- Advertising

The degree to which broadband speeds are required depends upon the needs of the specific application, the value of real-time data, and the amount of data being transmitted. Good architecture for wireless applications accounts for the constraints introduced by coverage area, transmission rates, and device limitations. For example, mobile applications should not depend on a constant connection and should be smart enough to automatically stay synchronized with the remote system with which they communicate. One way this can be achieved is by segregating the data into that which must be real time, from data that can be nearly real-time, from that which can be hours or days old. To overcome "variable latency" issues, applications should cache frequently used data, give priority to small chunks of data needed real-time, and employ replication concepts to accommodate other data synchronization needs [24]. A summary of some existing wireless applications is shown in Table 5.

1.4.1 Current Role of the 'Killer Application'

A *killer application* is software that is so innovative and impressive that consumers are willing to pay to use them and adopt them quickly. Killer applications can be games or applications, operating systems or multimedia platforms. Some examples are Windows, Doom, and Napster [25].

	Consumer	Business	Government
Internet Access	Email and browsing	Email and browsing	Email and browsing
Financial Services	Stock quotes; credit card balances	Providing account access from mobile devices	Custom
Gaming and Entertainment	MP3 download	N/A	N/A
Location Based Services	e-411: Directions & Maps	Meter Reading Applications	Monitoring of Ship Subsystems
mCommerce	Collaborative gaming	Business process tracking	Fleet Management
Advertising	Receiving mCoupons, mVouchers, mTickets	Providing mCoupons, mVouchers, mTickets	N/A

Table 5. Examples of Wireless Applications by Segment
and Category

Historically, communication has been far more valued than just content, and this appears to hold true now: AOL users spend most of their time using email and chat rather than the news, entertainment, and shopping services offered to them [26]. In the consumer marketplace, simple services are more likely to be adopted over content as shown by the lack of enthusiasm with wireless application protocol (WAP), which is a content service platform, and steady growth of short messaging services (SMS) [27]. Today's 'killer' wireless applications – voice in the US, and SMS in Europe and Asia – are *hardly* in need of broadband.

If the consumer wireline broadband adoption rates are any indication of the role content will play in the adoption of broadband wireless services, then pricing alone may have the most influence, followed closely by the ability to keep email addresses [28]. In Korea over 50 percent of households – 8.5 million versus a few hundred thousand three years ago – have broadband today, largely because deregulation forced prices to drop to the $25(USD) per month range. Lotka-Volterra substitution models are utilized in Chapter 4 to compare product adoption rates.

Broadband wireline technologies allowed 70-million people to put their hard disks together to make a giant jukebox on the Internet. Consumers were willing to pay the $40 to $50 monthly fee for DSL or cable modem to obtain *hundreds* of dollars worth of music. The value proposition of this "killer application" was clear and some analysts suspected the demand for wireline broadband services would decrease somewhat after Napster was ordered to shut down [29].

Another promising broadband value proposition is Real Networks' video service offering called SuperPass. As of March of 2003, Real Networks has been able to convince 900,000 customers to pay $9.95 a month for access to streaming video clips showing news and sports clips [30]. Yahoo has responded with its Platinum service.

In Europe, early deployments of mobile wireless plans were very expensive for making voice calls but relatively cheap for sending SMS messages. It is no surprise, then, that SMS became very popular in Europe, nor that the entire value network responded with products and services geared to SMS. Devices, infrastructure, software, interoperability, etc. all supported SMS simply because the value proposition to the ordinary consumer was heavily biased towards SMS.

There is nothing difficult to understand here. Unless there is a clear value proposition, customers are reluctant to spend money on premium products. Napster's value was that paying for DSL/cable modem cost less than buying music. Pricing plans and standards in Europe drove SMS adoption over voice. Killer applications in the wireless space will be a function of how mobile the person is. Consumers and businesses that depend on mobility are the most likely to find value in wireless broadband, and some business applications are more obviously suited to broadband wireless, such as metering, NAVY ships, and amusement parks. As the technology proliferates the not-so-obvious 'killer' applications will become clearer.

1.4.2 Assessment of Existing Applications and Bandwidth Requirements
The usability of applications depends primarily on bandwidth requirements, which in turn are dependent on the underlying technology. Figure 7 shows these dependencies and

serves to help explain why technology is currently the weakest link in the adoption of broadband wireless services: existing mobile wireless speeds are in the range of 60-80 kbps. At these speeds only basic services, such as plain text email and basic Internet access, work effectively. To further illustrate, Table 6 shows the time it takes to perform typical tasks assuming the connection is dedicated to accomplishing the task (one byte = eight bits).
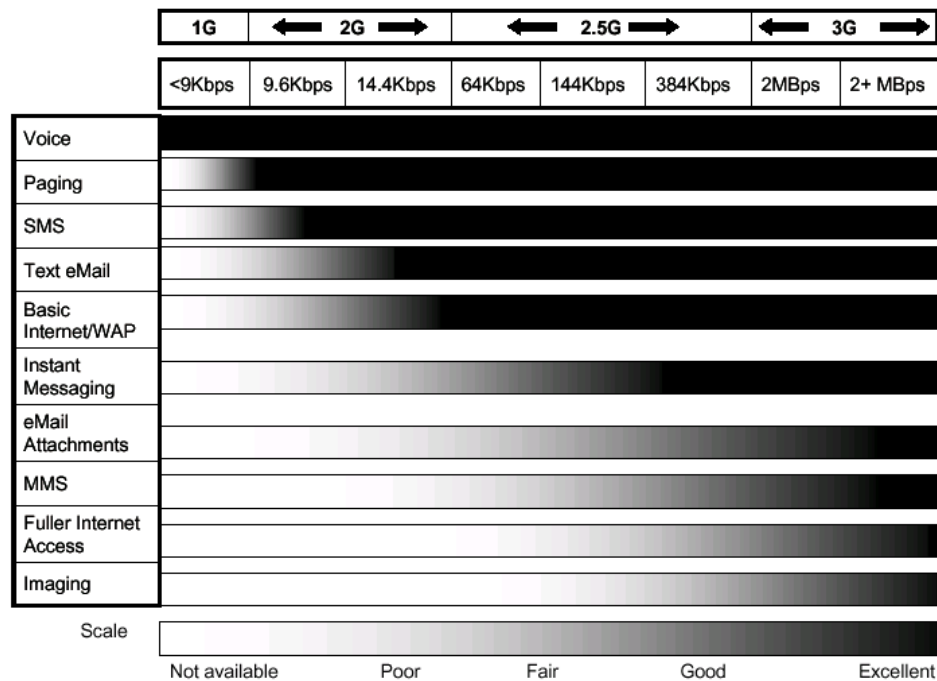
Figure 7. Application Usability by Wireless Generation
and Data Speed [31]

Data Application	Size (KB)	Approximate Download Times (seconds)					
		"2G"		"2.5G"			"3G"
		9.6 kbps	14.4 kbps	64 kbps	144 kbps	384 kbps	2 Mbps
1-page E-mail	1	< 1	< 1	< 1	< 1	< 1	< 1
5 - page Word Document	40	33	22	5	2	< 1	< 1
Basic Web Page	45	38	25	6	3	< 1	< 1
Low-resolution Digital Photo	100	83	56	13	6	2	< 1
Data File Transfer	500	417	278	63	28	10	2
20- Page PowerPoint Presentation	1,000	833	556	125	56	21	4
MP3 Audio File	4,000	3333	2222	500	222	83	16

Table 6. Approximate Time to Perform Common Tasks
by Speed/Generation [32]

Using 2G technologies for anything more than small text messages quickly becomes unbearable. In practice, 2.5G technologies can burst up to 144 kbps, which is still below the definition of *broadband.*

1.5 Customer Analysis

There are several ways to segment broadband wireless customers. Earlier in this chapter, a mobility segment model was introduced. Another way is to look at the needs of single-user-consumers, business users, and government users. The degree to which broadband speeds are required depends upon the needs of the specific application, the value of real-time data, and the amount of data being transmitted.

In this section other ways to segment the market and identify specific customer needs are explored. The performance metrics important in the broadband wireless market are introduced, and current trends and forecasts are presented.

1.5.1 Customer Needs and Segments

One method to segment the business user market is to look at *patterns of mobility.* Gartner Group, a leading research and advisory company, claims enterprises can gain tactical advantages via mobile solutions by managing mobile workers within categories and then integrating applications on the right mobile data service [33]. Gartner organizes mobile workers into five categories that exhibit common patterns of mobility as shown in Figure 8. These five classes are based on observations across a wide variety of mobile applications and vertical industries.

Each worker category exhibits a distinct set of information needs, device needs, networking costs, support issues and work patterns. Enterprises that recognize these patterns can better decide when to adopt mobile solutions for each category and how to serve each more cost-effectively.
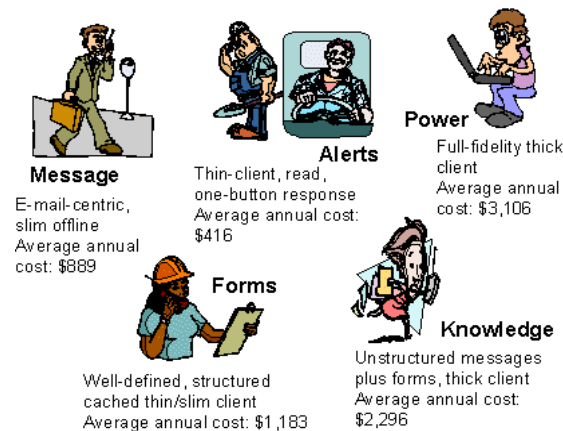
Figure 8. Gartner's Patterns of Mobility [33]

Another way to segment the market is to look at the needs of each mobility segment: fixed, nomadic, and mobile. Customers who are stationary, such as a call center agent or a home email user, are deemed fixed. Nomadic users move between locations, like airports and business locations, and don't need to be connected when they are moving between them. Mobile users, such as a field sales agent or a claims adjuster, need to be connected all the time and from anywhere. Chapter 4 explores this model further to show how each technology satisfies the connectivity needs of each segment.

1.5.2 Broadband Wireless Performance Criteria

The primary performance criteria for broadband wireless are:

- Coverage
- Price, including up front, device, recurring, and roaming costs and contracts
- Range, including roaming and interoperability
- Security
- Speed

The ancillary performance criterion is *connectivity without wires.*

1.5.3 Trends and Forecasts

A recent study by Forrester, a leading research and advisory company, concludes that 60 percent of North American consumers will want wireless access to email and location based services in the future [34]. These results, shown in Figure 9, suggest that the consumer segment may not demand applications that require broadband speeds. Consumer end-users may be more apt to pay for wireless services that provide convenience versus speed. Moreover, according to a study by Kagan World Media, a leading research and advisory company, shows in Figure 10 that by 2011, consumer wireless internet access will represent 66 percent of the wireless data subscribers but will only generate 23 percent of the total wireless data revenue. Eleven percent of all wireless data subscribers will use location-based services. However, these applications will only account for 2 percent of wireless data revenue [35]. In stark contrast, this same report predicts that in 2011 wireless data subscribers using wireless for business applications will represent 34 percent of the total wireless data subscribers and generate 60 percent of the total wireless data revenue.

Figure 9. Consumer Preferences for Future Wireless
Applications

These trends reinforce two things about the consumer wireless data market. First, consumers' expectations have already been set by their current Internet experience. Second, consumers are reluctant to pay solely for the *convenience* of wireless data services. The value proposition in the wireless data marketplace will be very difficult to create for the consumer end-user customer.

Christensen's evolutionary stage product model may help explain why the consumer wireless data market will evolve slower than the business market. This model suggests that disruptive technologies tend to evolve, according to Figure 11, where price is the last stage of evolution and competition [36]. New and disruptive products tend to satisfy niche markets, and competition on price alone does not occur until the product is almost a commodity. Since businesses tend to have more needs in niche applications, it will be easier to create value wireless data propositions that appeal to businesses.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Business Inter/Intranet Access	0.54	1.65	4.01	6.42	6.64	7.31	8.74	10.24	11.77	13.26	14.70
Consumer Internet Access	0.08	0.27	0.67	1.33	2.14	2.82	3.40	3.99	4.59	5.18	5.75
Financial Services	0.02	0.07	0.14	0.25	0.37	0.52	0.70	0.91	1.14	1.40	1.68
Gaming/Entertainment	0.003	0.02	0.05	0.10	0.17	0.25	0.34	0.46	0.58	0.72	0.88
Location-Based Services	0.002	0.01	0.02	0.04	0.07	0.12	0.18	0.25	0.34	0.45	0.58
mCommerce	0.001	0.01	0.02	0.04	0.07	0.12	0.18	0.25	0.34	0.45	0.58
Mobile Advertising	0.001	0.01	0.02	0.04	0.07	0.10	0.14	0.20	0.25	0.32	0.39

Figure 10. Forecasted Revenue Projections for Wireless Data Services

Product (Christensen)

Capacity

Size

Reliability

Price
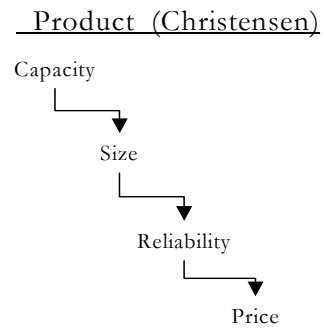
Figure 11. Christensen's Evolutionary Model of Product
and Competition of a New Technology

OVERVIEW OF BROADBAND TECHNOLOGIES

Although the thrust of this thesis is on wireless technologies, it is necessary to have a baseline set of technologies from which to compare. The first section of this chapter presents an overview of the most widespread wireline technologies, and then speculates a bit on how wireline technologies might evolve. The final two sections are dedicated to comparing the technical capabilities of each wireless technology being considered. Recall in Chapter 1 (particularly Table 3 and Table 4) the technologies were presented from a product and market place standpoint, so these facets will be mentioned but not be covered in detail in this chapter.

2.1 Current Wireline Broadband

2.1.1 ISDN

The CCITT standards body (now known as ITU-T) specified the Integrated Services Digital Network (ISDN) standards in 1984. It was originally designed as a "next generation" telephone system, integrating voice and data into one digital connection. There are two distinct ISDN standards: Basic Rate Interface (BRI) and Primary Rate Interface (PRI). BRI, depicted in Figure 12, is the type of connection you would have in a home or small business, offers two simultaneous connections (any mix of fax, voice and data). When used as a data connection, ISDN BRI can offer two independent, symmetrical, data channels of 64 kbps each, or 128 kbps when combined into one connection. The PRI standard offers 30 channels (of 64 kbps each), giving a total of 1920 kbps. As with BRI, each channel can be connected to a different destination, or they can be combined to give a larger bandwidth. These channels, known as "bearer" or "B" channels, are at the heart of the flexibility of ISDN [37].

The D (Data) channel is a 16 kbps signaling channel used to carry instructions that tell the telephone network how to handle each of the B channels. A combined BRI is often

referred to simply as "2B + D" and a PRI is "30B + D." ISDN signals can be sent up to 18,000 feet over copper loops without a repeater, and 36,000 feet with a repeater. Also, ISDN protocol standards allow the signals to be transmitted over fiber optic lines, making this a widely available technology.
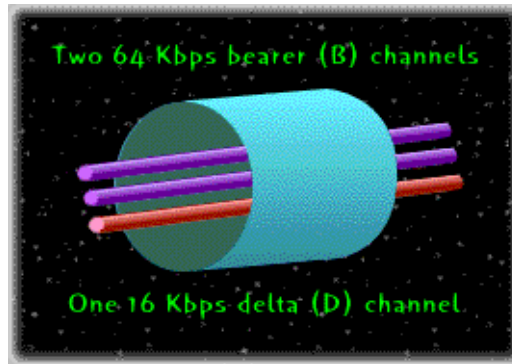
Figure 12. Basic Rate ISDN (BRI) Depiction [38]

Although each 64 kbps channel doesn't qualify as broadband by our definition, they can be bound together to provide faster speeds. ISDN has been an important step in the evolution of broadband wireline data services and is widely used throughout the U.S. as shown in Figure 13.
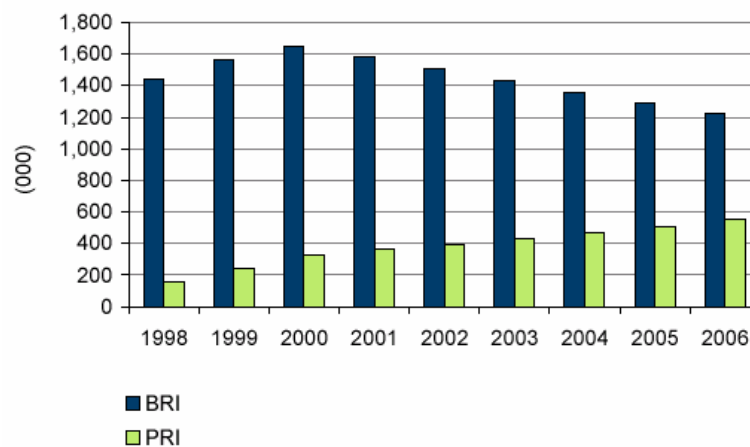
Figure 13. ISDN Lines in Service and Forecasted [39]

The primary applications of BRI are for Internet connections, point-to-point videoconferencing, and telephony applications that require multiple phone numbers. DSL

and COAX (cable modems) compete directly with BRI, which is why IDC forecasts a *negative* 5 percent CAGR through 2006 [39].

By in large, ISDN has grown into a premium service, targeted towards high-end or high-volume telephony users such as medium and large business customers who need, and are willing to pay for, PRI services. IDC forecasts a 10.5 percent CAGR for PRI through 2006 [39].

2.1.2 COAX

In the early 1990s, cable companies were making huge investments in their infrastructure in order to combat the satellite television providers who were threatening their market. When the Internet gained popularity in the late 1990s, the cable companies found themselves in an excellent position to augment their network to provide broadband service.

The International Telecommunication Union (ITU-TS) ratified Data Over Cable Service Interface Specifications (DOCSIS) version 1.0 in March of 1998. Since that time the DOCSIS standard has evolved and is now known as CableLabs Certified Cable, which insures manufacturers use the same modulation schemes and protocols. ITU-TS approved the DOCSIS 2.0 standard in December 2002.

DOCSIS transmissions look just like any other TV channel on the cable and use the equivalent of one-and-a-half channels of bandwidth. DOCSIS supports data rates of 27 Mbps downstream and 10 Mbps upstream, although the actual data rates to end users are limited by the number of concurrent users on the Cable Headend Transmitter (CHT) and the speed of the connection from the Cable Modem Termination System to the Internet, as shown in Figure 14. End users experience data rates of 1.5 to 3 Mbps downstream and 500 kbps upstream.

This architecture broadcasts downstream data packets to all users connected to the CHT, leaving it up to each cable modem to decipher which packets belong and which to reject. Some argue this poses security risks.
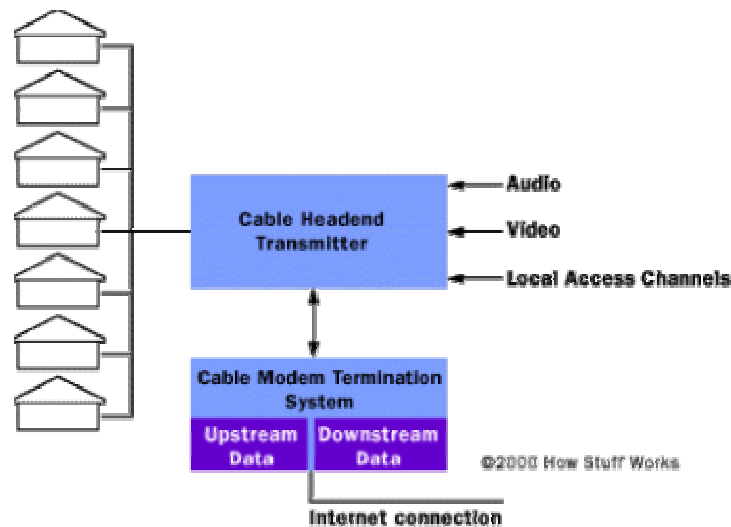
Figure 14. How Data Over Cable Works [40]

Cisco and Microsoft are collaborating on Hybrid Fiber-Coax (HFC) networks called Multimedia Cable Network Systems that are also DOCSIS compliant. HFC allows cable companies to blend very-high-speed fiber optic cables with existing coax cables to create higher-speed and more cost-effective networks than could be accomplished by either technology alone.

2.1.3 xDSL

Digital subscriber line (DSL) is a generic term for a type of broadband access technology that sends data over legacy phone networks. It blasts data over regular copper telephone lines at megabit speeds using frequencies far above what the human ear can detect. DSL is an always-on technology, meaning that computers are always connected to the Internet; no additional steps to log on are required. The technology carries voice and data over the same line, as shown in Figure 15, meaning that customers can talk on the phone and access the Internet at the same time. There are a number of technology issues such as distance limitations and competing standards impeding DSL technology from becoming the technology of choice for Internet access, especially with enterprise customers, but subscriber numbers are still increasing: in the second half of 2002 there were 6.5 million new ADSL subscribers in the US [41].

39

DSL is capable of delivering and supporting bandwidth-intensive applications, such as streaming video, online gaming, and conferencing. Some of the technology's other advantages include the following:

- Operates over existing phone lines and generally does not require new wiring
- Much faster than a dial-up Internet connection
- Customers can receive phone calls and be online at the same time
- Relatively easy to install [42]
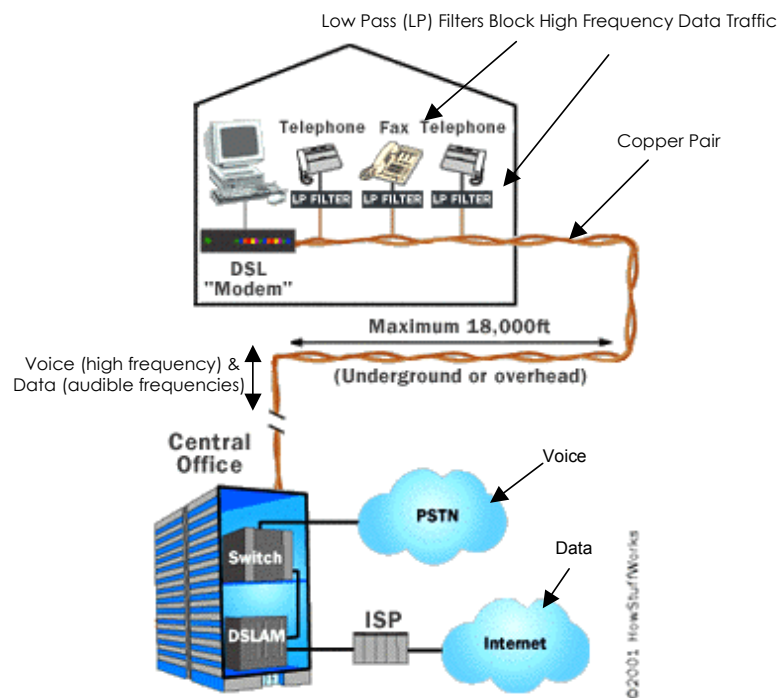
Figure 15. Adopted from How xDSL Works [43]

The reason many refer to the technology as *x*DSL is because there are multiple versions of DSL, the most prevalent being ADSL, IDSL, SDSL.

Asymmetrical Digital Subscriber Line (ADSL) – Specifically designed for activities such as Internet browsing, ADSL is engineered to receive data at high rates at the expense of sending at slower rates (asymmetrical rates). Speeds of 1.5 Mbps downstream and 256 kbps upstream are typical. ADSL signals can only travel 18,000 wire-feet before the signal deteriorates too much to stay in sync with the host provider.

ISDN Digital Subscriber Line (IDSL) – Designed by Ascend Communications, ISDL is a method for providing DSL technology over ISDN lines. This allows the signals to be transmitted twice as far as ADSL signals, however the speed, 144 kbps symmetrical, is not much faster than ISDN. Further, IDSL circuits typically only carry data traffic, not voice. The benefits are further-reach, an always-on connection, no call setup delays, and flat rate versus measured billing.

Symmetrical Digital Subscriber Line (SDSL) – Symmetrical speeds upstream and downstream are necessary for applications such as gaming and enterprise systems that would otherwise need a dedicated data circuit. SDSL service offerings mimic traditional fractional T1 speeds: 384 kbps, 768 kbps, and 1.5 kbps. SDSL is also subject to the same distance limitations as ADSL.

2.1.4 Frame Relay and Dedicated Circuits

The terms *frame relay* and *dedicated circuit* encompass a wide variety of products, standards, and protocols. Medium-to-large businesses and government agencies are the primary customers of these technologies due to their need for high bandwidth, excellent security, and very resilient data networks.

Frame relay circuits work by sharing bandwidth within the frame relay network amongst all customers. Customers receive a private line connection to the nearest node on the frame relay network. From there, traffic is routed in packets throughout the network until it reaches its destination. Customers pay their provider based on a Committed Information Rate (CIR), which is the average amount of data traffic they expect to use. They are able to send more data than their CIR up to a Committed Burst Size (Bc). If the customer continually exceeds the CIR and Bc, the provider and customer will renegotiate the terms of the contract.

Frame relay protocol is efficient, relatively easy to administer, and is supported by a wide variety of providers and vendors. The pricing plans for frame relay are straightforward and are usually much cheaper than a dedicated circuit of equal bandwidth. Moreover customers can "grow into" their CIR over time if the application bandwidth requirements are unclear at first.

Dedicated circuits are also referred to as point-to-point connections. These lines can be very expensive and can take several weeks to provision due to the coordination that has to happen at each switching station between the two connection points. The most common dedicated circuits use PRI signaling protocols:

- DS0 - 64 kilobits per second
- ISDN - Two DS0 lines plus signaling (16 kilobits per second), or 128 kbps
- T1 - 1.544 megabits per second (24 DS0 lines)
- T3 - 43.232 megabits per second (28 T1s)
- OC3 - 155 megabits per second (84 T1s)
- OC12 - 622 megabits per second (4 OC3s)
- OC48 - 2.5 gigabits per seconds (4 OC12s)
- OC192 - 9.6 gigabits per second (4 OC48s)

2.2 Future Wireline Broadband

2.2.1 Fiber to the Premise

Fiber-to-the-Premise [FTTP] extends fiber connections from the central office to the "curb" (fiber to the curb or FTTC) and into customer's houses or places of business. Dedicated fiber connections provide extremely high bandwidth and make possible movies-on-demand and online multimedia presentations would arrive without noticeable delay. Fiber-optic technology delivers Internet, voice and video at speeds from 2Mbps to 100Mbps and beyond. On a fiber optic network, data is transmitted as light impulses along thin strands of silica glass. Unlike copper cabling, optical fiber is not subject to electromagnetic interference because it uses light, not electricity. Moreover, fiber optics can transmit data over much longer distances; 6.2 to 49.6 miles over single-mode fiber-optic cabling vs. a few thousand feet for copper cabling [44].

In May of 2003, BellSouth, SBC, and Verizon announced that they adopted a common set of technical standards for FTTP equipment based on established industry standards and specifications. Subsequently, Verizon unveiled a 10-year, multi-billion dollar initiative to overhaul their network by deploying FTTP. This move is apparently in response to the triple-play the cable companies currently enjoy: bundles of voice, data, and video services, and is economically feasible given that the cost of deploying FTTP has dropped as much as 75 percent since the late 1990s [45].

2.2.2 Trends and Forecasts

As stated in Chapter 1, the value proposition for broadband must be clear for a customer or an enterprise to subscribe and stay subscribed. Given that 80 percent of US Internet users still connect via narrowband services (such as dialup), the value clearly isn't there for a significant portion of the *potential* market [46]. However as shown in Figure 16 and Figure 17, the number of subscribers to broadband wireline technologies are expected to more than double over the next two years.
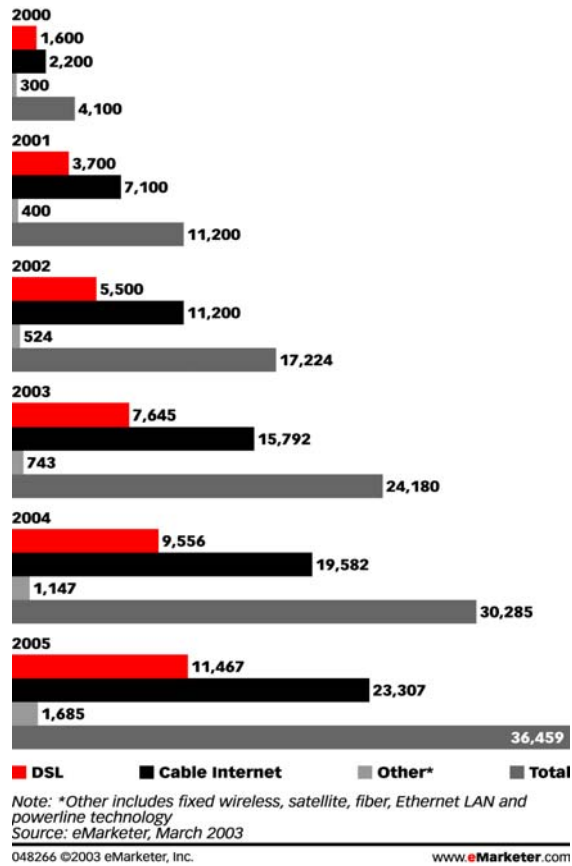
Figure 16. Broadband Households in the US, by Access
Technology, 2000-2005 (thousands) [47]
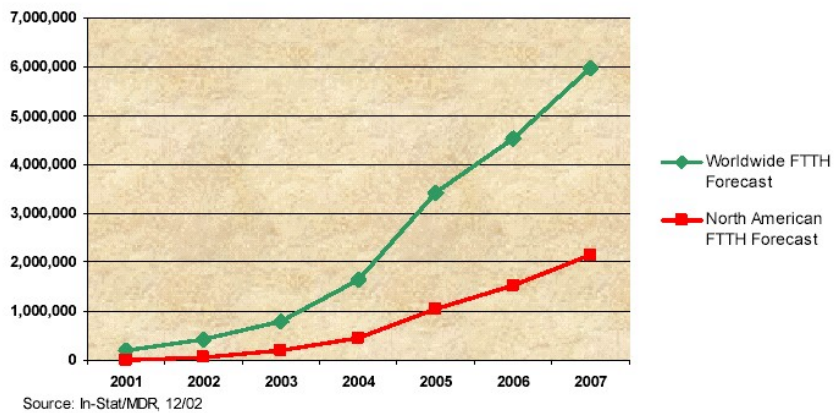
Figure 17. Fiber-to-the-Home Forecasts for US and
Worldwide Through 2007 [48]

2.3 Current Wireless Broadband

The Abernathy-Utterback model, which will be examined closely in Chapter 4, suggests that prior to the establishment of a dominant design the number of products and competitors will be larger than the market can sustain in the long term and that once the dominant design is established there will only be a few players left. This model applies to the current state of the broadband wireless space, so a subset of what we believe to be the most promising technologies had to be chosen.

2.3.1 Bluetooth

Bluetooth is an open architecture wireless communication protocol capable of communicating at 1Mpbs in the 2.4 GHz (unlicensed) spectrum at a range of about 30 feet. Bluetooth operates on radio signals and provides electronic devices a method to communicate over short distances without the line-of-sight required by infrared technology. It is intended for use in close-proximity electronics such as PC's, printers, headsets, cell phones, appliances, digital cameras, and any other electronic device requiring cable connections to communicate.

The idea for Bluetooth came from Ericsson in 1994. Ericsson was developing telecommunications infrastructure equipment and saw the need for an inexpensive way that electronics could communicate. The name "Bluetooth" comes from a story about a Viking named Bluetooth who successfully joined two Scandinavian Kingdoms peacefully. Ericsson looked for partners to help with the development of the technology and in 1998 the Bluetooth special interest group was formed.

2.3.2 Home RF

Home RF was a consortium of manufactures that developed a standard called Shared Wireless Access Protocol (SWAP). SWAP is similar to Bluetooth and 802.11B in that it uses RF signals, however, SWAP utilizes six voice channels based on the Digital Enhanced Cordless Telecommunications standard. SWAP can transfer data at 1 Mbps.

Home RF was invented to compete with the 802.11b standard by being a cheaper alternative for the home user. This would mainly be targeted for personal computers

accessing and transmitting data in a particular location.   While it was initially more inexpensive then the 802.11b, it also was not as capable. The 802.11b is now available at a lower cost, which eliminated the need for Home RF and resulted in the abandonment of Home RF technology.

The Home RF consortium launched in 1998 to establish wireless protocols for the home networking applications shown in Figure 18, but recently disbanded because the 802.11b platform has lowered it's cost enough to make the existing Home RF technology obsolete. The developers wanted to focus on a common platform for 802.11b and Bluetooth rather than pursue a third platform for Home RF.
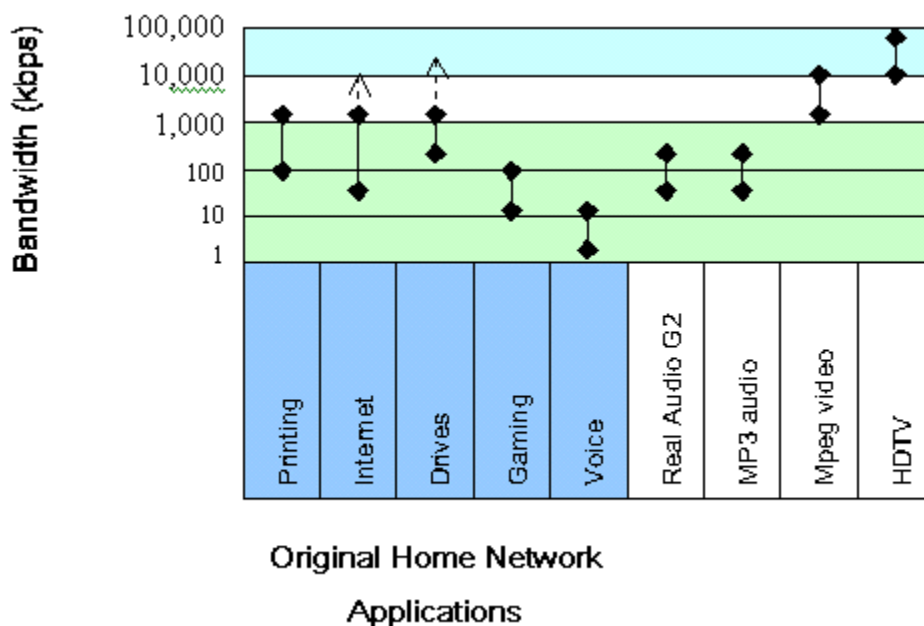
Figure 18. Intended HomeRF Applications [49]

2.3.3 Mobile Wireless

Mobile wireless data began as an add-on to the existing voice platform much like dial-up modems used existing phone lines to transmit data over voice-grade infrastructure. The first generation wireless data technology was cellular digital packet data (CDPD). Developed in 1995, CDPD uses unused cellular channels (in the 800- to 900-MHz range) to transmit data in packets. This technology offers data transfer rates at 9.6 Kbps on average, bursting up to a maximum of 19.2 Kbps. Manufacturers and mobile companies

recognized the need to separate mobile data so that the voice network didn't suffer at the expense of lower-revenue data traffic.

Many different technologies and standards evolved to meet the rising demand for mobile wireless data as shown in Figure 19. The differing technologies primarily stemmed from the strengths of the particular transmission mechanisms and the spectrum available.
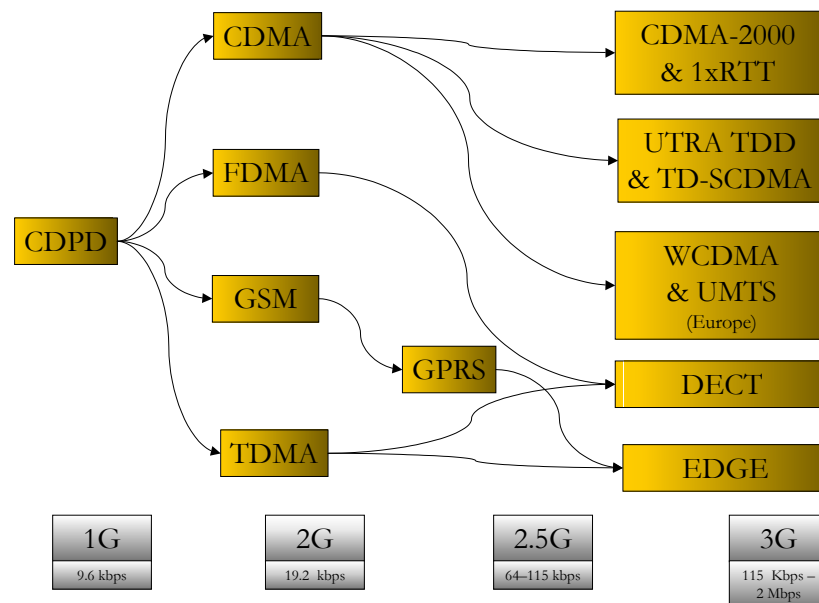
Figure 19. Evolution of Mobile Wireless Technologies [50]

CDMA – Code Division Multiple Access was introduced commercially in 1995 and works by converting an analog signal to a digital, packetized signal (for voice traffic), assigning a unique code to the packet of data, then transmitting the signal over a designated block of frequencies as shown in Figure 20. Manufacturers of CDMA technology claim that this method allows many more devices to share the same spectrum because the limitation is not on spectrum, but on the ability of the system to code and decode in near real time. Frequency hopping can also lessen the effects of multipath and other types of interference because the signal can be retransmitted at a different frequency.

47
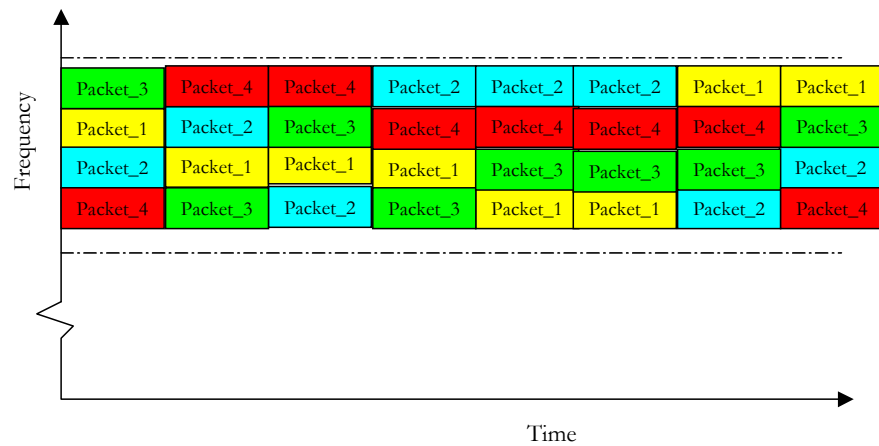
Figure 20. CDMA Technology Depiction

FDMA – In Frequency Division Multiple Access each frequency channel is assigned to one call. During the call period, no other calls can share the same frequency. This method, depicted in Figure 21, immediately imposes a constraint on the system – the number of simultaneous users is proportional to the amount of spectrum available. Manufacturers of FDMA technology claim that this method provides the highest quality service.

GSM – Global System for Mobile communications is an international standard that was released by ETSI (European Standard and Technology Institute) back in 1989. The first commercial GSM services were launched in 1991. The GSM family of wireless communication platforms includes GSM, GPRS, EDGE and 3GSM. GSM is based on time division multiple access transmission methods (TDMA).
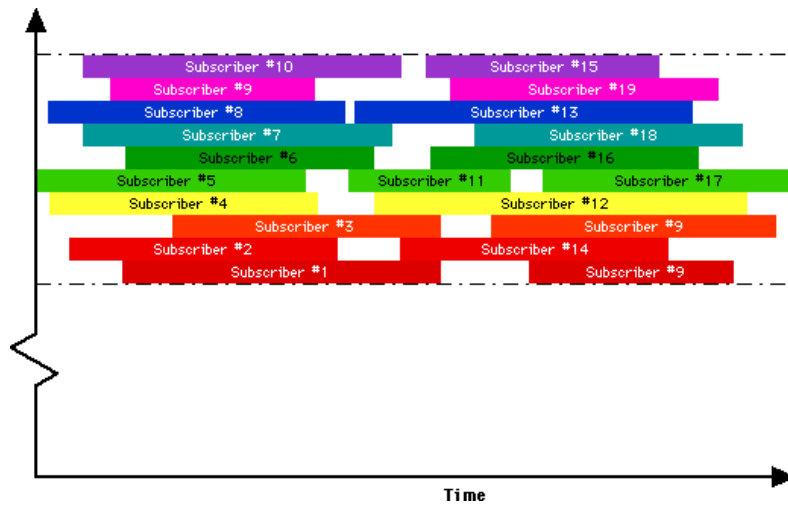
Figure 21. FDMA Technology Depiction [51]

TDMA – In Time Division Multiple Access (TDMA), each time slot is assigned to one call. During the call period, no other calls can share the same time slot. Similar to FDMA, this imposes an immediate constraint on the number of concurrent users within a particular range of spectrum.
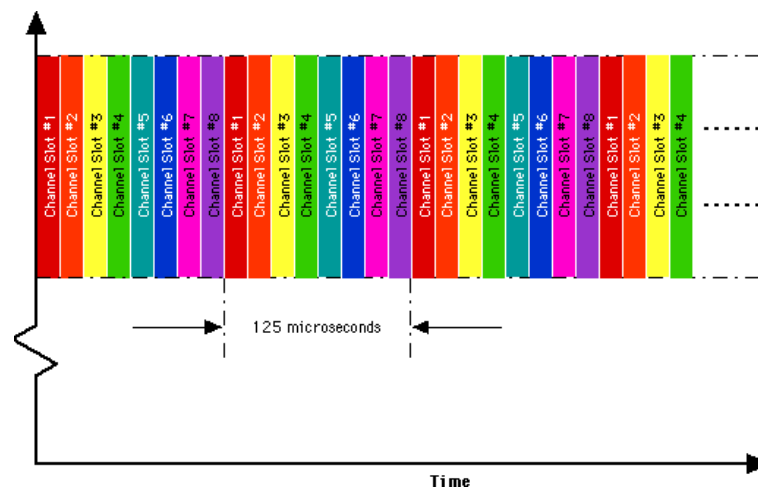
Figure 22. TDMA Technology Depiction [51]

2.3.4 Satellite

Satellite data uses a specialized wireless receiver/transmitter that is launched by a rocket and placed in orbit around the earth. There are hundreds of satellites currently in

operation. They are used for such diverse purposes as weather forecasting, television broadcast, amateur radio communications, Internet communications, and the Global Positioning System, (GPS). There are three types of communications satellite systems. They are categorized according to the type of orbit they follow. A geostationary satellite orbits the earth directly over the equator, approximately 22,000 miles up. A low-earth-orbit (LEO) satellite system employs a large fleet of "birds," each in a circular orbit at a constant altitude of a few hundred miles. Some satellites revolve around the earth in elliptical orbits.

In the late 1970's, satellite data transmission was pioneered with the development of the first electronically steerable antenna flown in space. The system ensures secure communication transmissions among U.S. military and country leaders. By the early 1980's, wireless data collection was introduced in warehouse environments. And by 2000, satellite broadband was becoming more affordable and more readily available to Internet users worldwide.

2.3.5 WiFi

WiFi is an RF signal based on the IEEE 802.11 standard and is capable of transmitting signals up to 300 feet. It uses Orthogonal Frequency Division Multiplexing (OFDM) that supports high data rates with very low latency, over a distributed all-IP wireless network that can penetrate walls and associated structures. WiFi shares the unregulated, 2.4 GHz radio spectrum along with other common wireless devices including cordless phones and baby monitors. WiFi networks are called hot spots. For the most part, thousands of "do-it-yourselfers" worldwide have rigged antennas to create their own hotspots. Some of them have even joined together to form networks so that the public can access the Internet for free. Currently, there are about 5000 free hot spots worldwide and more than 18 million people worldwide have used WiFi and the numbers continue to grow daily [52].

WiFi is primarily meant for use in a local area wireless network and for Internet access. As an alternative to current wireline broadband, WiFi offers the opportunity of cheap, mobile Internet access. It is also an amplifier of other technologies: It can turn almost every machine, from laptops to cash registers, into network devices. And it also fuels the

demand for always-on broadband connections. Applications range from the obvious (laptops with the WiFi friendly Windows XP) to the not so obvious (consumer electronics providers linking a host of appliances in the home to send MP3 songs and videos from their computers to TVs and stereos via WiFi). With the next generation of WiFi lifting connection speeds to 54 megabits per second, WiFi phones could become viable options to the consumer, allowing them to move from WiFi to cellular networks seamlessly. This is only the proverbial tip of the iceberg. Smart networks in the home or factory could even monitor climate control or supply chains through data fed by WiFi [53].

WiFi's origins can be traced back to 1985 when the Federal Communications Commission opened up areas of the radio spectrum for experimentation. Multiple companies (NCR, Symbol Technologies, and Apple Computer) started building wireless networks. Due to development of systems that did not work with each other, the momentum slowed in the late 1980s. Vic Hayes, a scientist from NCR led the movement towards a standard in the 1990s, and finally succeeded in 1997 through the release of 802.11b, which is now known as WiFi or Wireless Fidelity. In 1999, Apple kick-started the market by adding WiFi to its iBook portables for the then stunningly low price of $99. This started a race and in cities worldwide, technical savvy consumers started setting up wireless networks. Rob Flickenger in San Francisco and Anthony Townsend in New York pioneered some of these early Linux based hot spots. They even used empty Pringles cans as antennas, thus providing a cheap alternative to expensive equipment. They also united neighbors to start forming growing community networks. Hence, WiFi actually developed in the streets of the world. During this grassroots development, some businesses had started using these networks for their own needs, most famously by CareGroup Inc. hospitals in Massachusetts where 2000 doctors and nurses connected to the corporate system. Entrepreneurs started coming into this picture in an effort to link this ragtag collection of hot spots and network communities into a secure nationwide network. In 2001, Sky Dayton, founder of Earthlink Inc. founded Boingo Wireless Inc. to certify networks everywhere as Boingo providers and charge subscribers $50 a month. In the past two years, the number of entrants has grown exponentially, thus causing the number of commercial hotspots to mushroom to 16,000 [54].

2.4 Promising Broadband Wireless Technologies

2.4.1 "3G" Mobile

The term "3G" is used to describe the next generation of mobile communications that promises to deliver improved voice and data services. There are many interpretations of what "3G" means, however the International Telecommunication Union (ITU) has the only official definition accepted universally. The ITU is comprised of stakeholders from around the world who set the requirements and standards for 3G known as IMT-2000.

IMT-2000 networks must meet minimum data bandwidth requirements of 144 mbps for mobile devices and 2 Mbps for fixed indoor wireless. Figure 23 shows the technologies that comprise the 3G mobile wireless family.
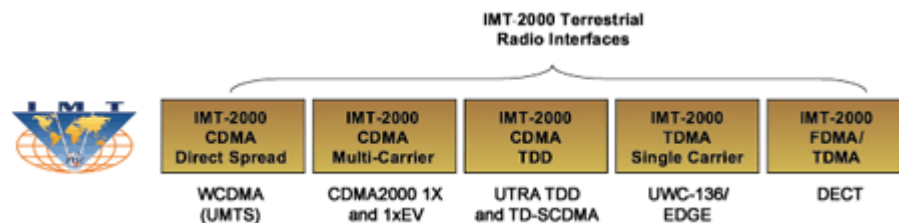
Figure 23. 3G Mobile Family [55]

2.4.2 Fixed Wireless

Fixed wireless is an alternative transport mechanism to traditional broadband wireline services in areas where these are not available, such as rural locations and places where competing wireline providers own the infrastructure. Figure 24 shows the form of one particular fixed wireless solution provided by BeamReach. Regardless of the manufacturer, there are six major components of a fixed wireless system:

- Base station (transmitter)
- Configuration tools
- Element management system
- Remote premise units (receivers)
- Transport mechanisms (wireline)

- Wireless signals
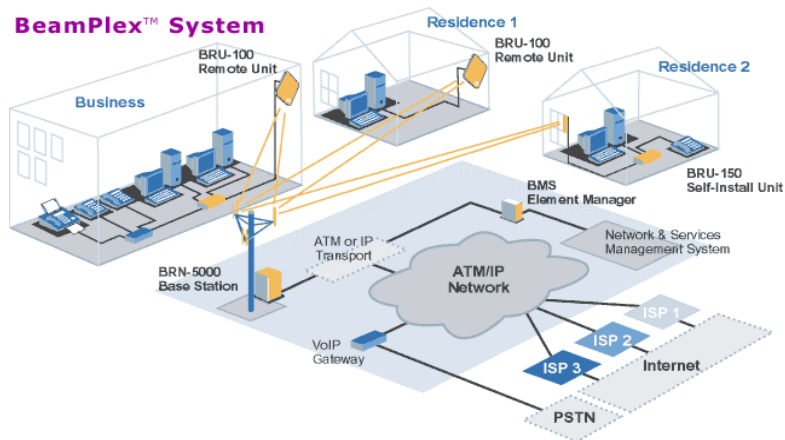
Figure 24. Form of the Fixed Wireless Solution offered
by BeamReach

The typical data rate for fixed wireless technology is in the range of 1.5 Mbps downstream and 1.2 Mbps upstream. Actual throughput experienced by the end user will vary with environmental factors, signal level, and air link quality. Some fixed wireless signals are require line-of-sight while others are non-line of sight. Typically fixed wireless signals can propagate several hundred feet to several miles, depending on the spectrum and technology.

Fixed wireless systems are configurable to work in the licensed or unlicensed spectrum. Each manufacturer has proprietary methods for transmitting signals that are largely based upon existing methods or standards.

A comparison between BeamReach's efficiency and other forms of wireless data transmission is shown in Figure 25. This diagram shows that fixed wireless has the highest capacity for data transmission than competing forms of mobile wireless technologies.
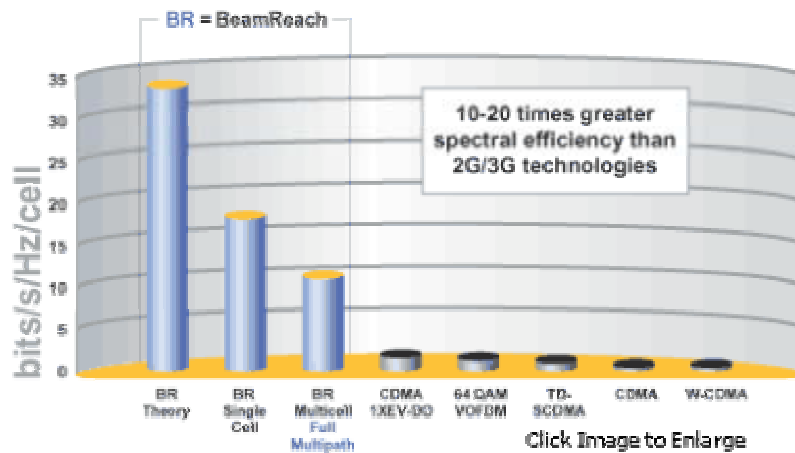
Figure 25. Comparison of spectral efficiency between
BeamReach's fixed wireless product and mobile wireless
technologies

Although various forms of fixed wireless technologies have been in existence for a long
time, it is an immature technology for use in large commercial applications and has proven
only to be cost effective in areas of less than 100 lines/square-mile [56]. The manufacturers
are supplying firmware upgrades to customers on a regular basis, and CPE models are still
evolving: some require a truck roll to install an antenna while others ship CPE with
antenna's built in.

If the longer-term cost and technology issues are overcome, regional bell operating
companies (RBOCs) could deploy fixed wireless solutions to gain access to customers in
neighborhoods or business parks where cable companies own the wireline infrastructure
or where fiber equipment is already in place. Further, RBOCs could consider investing in
fixed wireless instead of adding expensive DSL equipment in new COs. Finally, fixed
wireless could be deployed to compliment mobile and WiFi networks if interoperability
technology and agreements were available.

2.4.3 Mesh Networks

Mesh Networks describes a topology that employs either of two schemes: full mesh and
partial mesh. In the full mesh topology shown in Figure 26, each node is connected
directly to each of the other nodes in the network. In the partial mesh topology, some

nodes are connected to all the others, and some are connected only to those other nodes with which they exchange the most data.
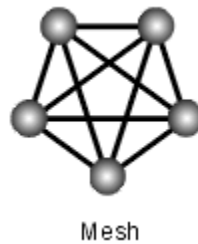
Figure 26. Full Mesh Network Concept

Mesh Networks provide significant advantages because they can adapt to changes in network topology, such as nodes being added and removed, node outages, or changes in location of devices. Another advantage is the need for low power transmissions because the node only has to communicate with the nearest node. Mesh networks are able to benefit from channel reuse, resulting in improved spatial capacity. This increases the aggregate network capacity, or bandwidth, enabling high-bandwidth applications such as video transmission throughout the home, or for teleconferencing in offices. Equally important in high-density and urban environments, mesh networks are more resilient to the interference caused by multiple households using wireless networks in close proximity. Mesh networks also provide greater redundancy and traffic balancing options, improving the overall quality of service.

Mesh networks can help overcome some of the last mile problems inherent to broadband. Meshes are bottom-up networks that capitalize on the rise of WiFi and other open wireless technologies. They shimmer into existence on their own, forming ad hoc networks out of whatever wireless devices are in range – phones, PC's, laptops, tablet computers, PDA's, etc. Each device in the network donates a small amount of resources to intercept and forward wireless messages. Packets jump from one device to the next, finding the best path for the conditions at any given moment, and ultimately land either on the device intended to receive the message or on to a wired device which taps into the Internet.

The mesh topology provides the largest benefit to the range of wireless signals. A network consisting of 50 meshed PC's, PDA's, and phones can extend a typical WiFi network's 300-foot range into one that extends 5 miles.

2.4.4 WiFi (802.11g)

The 802.11g IEEE standard was approved in June, 2003. It uses the same 2.4 Ghz spectrum as the previous 802.11 standards, is backward compatible with 802.11b, has the same range as 802.11 (200-300 feet), and still utilizes OFDM technology. The major difference is that 802.11g can deliver theoretical speeds up to 54 Mbps. Actual throughput of 24 Mbps has been achieved on some preliminary products utilizing 802.11g. Just like in 802.11b, distance, multipath, and communication overhead are still the primary factors that contribute to bandwidth degradation in 802.11g.

This standard is primarily aimed at enterprise markets and existing wireless applications that demand higher bandwidth than the 802.11b standard can deliver, such as large-scale IP-based video surveillance systems and data center back up systems.

2.4.5 WiMax (802.16)

In 1999, the IEEE recognized the need to develop a wireless standard that would meet the demands of a metropolitan area network (MAN). The 802.16 standard was broken into three pieces:

- IEEE 802.16.1 - Air interface for 10 to 66 GHz.
- IEEE 802.16.2 - Coexistence of broadband wireless access systems.
- IEEE 802.16.3 - Air interface for licensed frequencies, 2 to 11 GHz

802.16.1 was originally published in 2002 and focused on the efficient use of the 10 Ghz to 66 Ghz spectrum for a large number of people and was intended to support individual channel data rates of from 2M to 155M bit/sec over a 30 mile area [57].

Transmission from subscribers to a base station uses the Demand Assignment Multiple Access-Time Division Multiple Access (DAMA-TDMA) technique. DAMA is a capacity assignment technique that adapts as needed to respond to demand changes among

multiple stations. TDMA is the technique of dividing time on a channel into a sequence of frames, each consisting of a number of slots, and allocating one or more slots per frame to form a logical channel. In the downstream direction (base station to subscriber stations), there is only one transmitter. Unlike the upstream direction where multiple subscriber stations compete for access, a TDMA technique is used, in which the data stream is divided into a number of time slots. Figure 27 shows an 802.16 MAN [58]. As of the time of this publication, 806.16 is not a finalized standard.
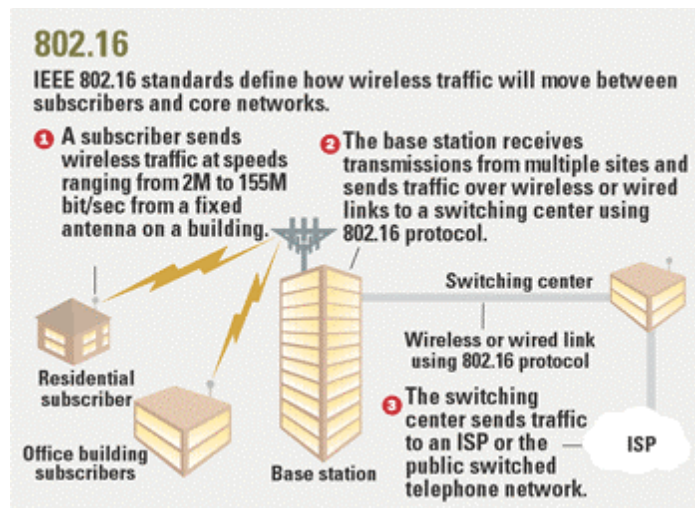
Figure 27. Depiction of an 806.16 MAN [58]

2.4.6 Ultra Wide Band (UWB)

UWB was first developed in the 1960s for the U.S. military. Within the U.S., much of the early work in the UWB field (prior to 1994), particularly in the area of impulse communications, had been classified for about three decades. Its standard was made public in the mid 1990s and is now thought to be one of the potential next waves in wireless communications.

UWB device transmits very low power radio signals with very short pulses, often in the pico-second (1/1000th of a nanosecond) range using very wide signal bandwidths. UWB uses the same spectrum that is currently being used by conventional radio communication devices, including emergency services. Ultra wide band (UWB) devices can be used for a

variety of communications applications involving the transmission of very high data rates over short distances without suffering the effects of multi-path interference. UWB communication devices could be used to wirelessly distribute services such as phone, cable, and computer networking throughout a building or home. Police, fire, and rescue personnel to provide covert, secure communications devices, could also utilize these devices.

Since the classification restrictions were removed, the development of UWB technology has greatly accelerated. A number of recent UWB developments in the fields of communications, radar and localization have been demonstrated. A few examples of UWB developments are a full duplex UWB handheld transceiver, ground wave communication systems, vehicular electronic tagging and alerts, and intercoms.

UWB has shown promise for many commercial applications, including wireless communications within buildings and in locating objects behind walls or other barriers. To use UWB for wireless communications, the receiver simply detects whether received impulses have been time advanced or time retarded to know if the data bit being transmitted is a "1" or "0," assuming pulse position modulation technique is used. To use UWB for range-finding applications, the receiver determines the time delay for the signal to get from the transmitter to the receiver and works out the range by multiplying the measured time delay by the speed of light, which is a known constant. To use UWB for radar applications, the receiver extracts information from the reflected signal to derive certain useful characteristics about the target. In all these applications, if the amplitude of the transmitted impulses is kept sufficiently low, it may be possible to keep its frequency spectrum below the ambient radio frequency noise floor and thus operate in stealth mode. As it is necessary for a receiver to have prior knowledge of the timing and code sequences of the UWB transmitter to effect detection and decoding, it is very difficult for another person to eavesdrop or intercept UWB transmissions, making them highly secure.

2.5 Summary of Technologies

The large number of technologies and standards in the broadband wireless space coupled with the rapid pace of change makes this a very dynamic and broad field to study. Table 7 attempts to summarize the key dimensions of each technology.

| Technology | Operation | Customer Needs | Target Market | Traditional Performance Metrics | | | |
				Price	Range	Security	Speed
Wireline	fiberoptics cable telephone line fiber optics	Access at a specific location Internet access High Transmission speeds High Security	Business locations Residential Commercial Academia & Gov't	Very large range	wire connection	Secure	up to 55 Mbps
Bluetooth	RF Technology in the 2.4GHz unlicensed frequency range	Wireless Internet while traveling Compatibility of software for transfer Security Multiple connections	Cellular phones Cable-less computers Appliances Electronic data transfer	less than $10	10 meters	Secure	1 Mbps
Fixed Wireless	Configurable to work in licensed or unlicensed spectrum	Broadband alternative for the "last mile"	Home Owners Small Business	High installation	Several miles	Secure	1 Mbps to 2 Mbps
Home RF	RF Technology using voice and data channels	Low cost Signal range	Home Owners Small Business	Low	38 meters	Secure	1 Mbps
Mobile Wireless	PCS 1850 - 1900MHz	Wireless connection anywhere Moderate data transfer Secure computing Compatibility of software transfer	Business travelers Leisure travelers Mobile electronics Field technicians	Low	Short	Improving	60-90 kbps
Mesh Networks	Meshed wi-fi users	Greater range than line-of-sight while maintaining mobility	Densely populated areas Schools	Low	Theoretically limitless	* Major concern *	11 Mbps
Satellite	Satellite 'birds' in earth orbit using RF technology	Ubiquitous availability anywhere in the world Secure wireless communications	Remote areas Military Vehicle uses Marine uses	High initial costs Low expansion costs	Limitless	Very good encryption	40 Mbps
Ultra Wide Band	Very low power radio signals with short pulses	High data rate transfer over short distances	Ground penetrating radar, imaging systems, automotive safety & collision avoidance systems, communications systems (phone, cable, computer networking), positioning applications and locator beacons.	High	Depends on power. At low power 15-100 meters. Can be longer ranges with high power.	High	Currently 100 Mbps; 500 Mbps by 2004
WiFi (802.11a,b)	RF Technology in the 2.4GHz unlicensed frequency range	Wireless Internet in a specific area Moderately secure computing Compatibility of software for transfer Use office applications	Business travelers Business locations Schools Home Owners	Moderate	100 meters	Improving via WiFi Protected Access (WPA)	802.11b:up to 11 Mbps; 802.11a: up to 54 Mbps
WiFi (802.11g)	2.4 GHz	Wireless data at very high speeds over short range	Existing wireless enterprise applications that demand more bandwidth	Moderate	100 meters	Improving via WiFi Protected Access (WPA)	up to 54 Mbps
WiMax (802.16)	10-66 GHz	Wireless data at very high speeds over longer ranges	Wireless Metropolitan Area Networks	High	up to 30 miles	Secure (2 levels of authentication)	2 Mbps to 155 Mbps

Table 7. Summary of the Broadband Wireless
Technologies [59]

A detailed comparison of each technology's architectures would require a thesis in and of itself. Since DSL and COAX are arguably the most visible and fiercely competing products today, it is prudent to at least point out the high level architectural differences between the two. Wanichkorn [60] illustrates the two architectures nicely, as shown in Figure

28.   The most significant difference is in the "last mile" – DSL provides a dedicated connection between the central office and the end user, where COAX uses a shared cable to distribute to multiple end users. Despite this architectural disadvantage, COAX still has 65 percent of the market share compared to 35 percent for DSL [61].
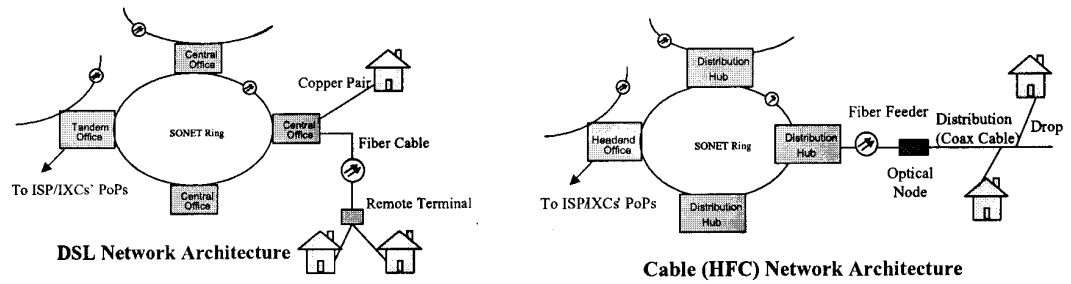
Figure 28. Generic Depiction of DSL Versus COAX
Network Architectures [60]

ANALYSIS OF RECENT SUCCESS AND FAILURES IN WIRELESS DATA
PRODUCTS

3.1 Success Stories: Analysis of Customers, Technologies, and Value Propositions

This section briefly describes four wireless data products and initiatives that looked promising at the time of this writing. The intent is to point out the value each product offers, and then draw conclusions in the final section of this chapter.

3.1.1 Boingo

Boingo provides Internet access via WiFi to over 1300 hotspots around the US. It has two distinct and well-defined market segments, attractive pricing options, and a strategy that creates value for multiple stakeholders.

The two market segments Boingo targets are the business traveler and the establishments where business travelers are likely to frequent: airports, restaurants, and hotels. The business traveler can choose between pay-per-use, 10 connection-days, or unlimited pricing plans. This allows him to try the product with no commitment, and ease-in to higher usage plans over time.

Boingo also offers a franchise-type arrangement – for $695 an establishment becomes a Boingo provider. The do-it-yourself kit comes complete with everything the establishment needs to resell Boingo's WiFi including authentication and billing software, and decals that can be displayed within the establishment alerting patrons of WiFi availability. In return, the establishment receives a bounty of $1 for every connection made [62].

3.1.2 Blackberry

Research in Motion (RIM) developed the Blackberry two-way messaging device and corresponding service that allows users to synchronize them with data stored on their main computer. Blackberry devices quickly gained popularity with traveling executives, who use

the devices to send and receive email messages remotely, and to synchronize their schedules. Many Blackberry customers reported using their devices so frequently that observers dubbed them "Crackberries," citing the devices' addictive qualities [63].

In 1999, RIM partnered with resellers such as Hewlett Packard and Dell to take advantage of manufacturing and distribution channels. RIM also partnered with wireless operators to insure the next generation data networks support BlackBerry standards. Their market share of handheld devices has grown modestly – 5 percent per year, and revenue growth in 2002 was 33 percent over 2001 numbers [64].

3.1.3 Gilat Satellite

Gilat Satellite Networks, Ltd. is based in Israel, and is the leading provider of Very Small Aperture Terminal (VSAT) satellite network technology in 70 countries across six continents. It has shipped 400,000 VSATs worldwide, primarily to rural locations and enterprise customers for telephony and broadband data applications [65].

Gilat delivers value through partnerships and joint ventures. In 2000, it partnered with Microsoft Corporation and Echostar Communications to form Starband, a consumer, two-way, high speed Internet service provider capable of reaching most of the US population [66]. Most recently, Gilat and SES Global co-founded SATLTNX, a two-way broadband service provider in Europe that is also 17.9 percent owned by Alcatel [67]. SATLYNX is focused on wholesale and enterprise customers, consistent with Gilat's strategy in the US – to be the network infrastructure provider, and let the partner companies create the products for the end users.

3.1.4 SMS in Europe

Short Message Service (SMS) became part of the European digital phone standard called GSM as the mechanism to send and receive 160 byte text messages. The European Union required that every wireless provider support the GSM specification on their network, and that mobile phones had to support message origination from either a user or from the network [68].

The high cost of making voice calls in Europe drove demand for SMS in first generation mobile networks. To send an SMS message in Europe in 2001 would cost the sender between seven and 15 cents. A voice call would have cost up to 30 cents plus airtime charges, all incurred by the calling party (dubbed "calling party pays"), not shared between the two parties like it is in the US [69]. Clearly, European subscribers chose SMS over voice to save money, and industries providing SMS-enabling products were born. In Western Europe, 11.9 billion SMS messages were sent in 2000, 57 billion in 2001, and 240 billion in 2002 [70,71].

3.2 Failures: Problems with Customers, Technologies, and Value Propositions

This section briefly describes a few wireless data products and initiatives that either totally failed or are having problems at the time of this writing. The intent is to look objectively at each case and draw conclusions in the final section of this chapter.

3.2.1 Metricom

Metricom was established in 1985 to develop MicroCellular Data Networks. Their original strategy was to build a wireless network using the unlicensed spectrum and sell airtime to municipal utilities for meter-reading applications. This strategy changed in the 1990s when the Internet became popular and Metricom realized they could sell wireless Internet access. They launched their first Internet access product, called Ricochet, in three cities. Ricochet provided 28.8 kbps Internet access and was targeted at residential consumers.

In 1995, Metricom announced an aggressive new strategy dubbed "road warrior," which was a plan to build a proprietary, high-speed, wireless network in densely populated metropolitan areas in the US. Worldcom, a reseller of Metricom's business services, realized that the unlicensed spectrum would quickly become too crowded, and they made a bid for dozens of MMDS spectrum licenses, but lost. In 1997 several of the wireless companies who had won the MMDS auctions were strapped for cash and sold the licenses to Worldcom for $1 billion. In 1999, Worldcom and Vulcan Ventures each invested $300 million to purchase 49.5 percent and 38 percent shares of Metricom, respectively.

Metricom appeared well positioned to deliver their wireless network from technology and funding standpoints. They partnered with resellers like GoAmerica and targeted small to medium-sized business, and residential customers living in multiple dwelling units (MDUs). Their mission was to provide enterprise users with high-speed laptop service equivalent to the quality of wired service. However their product offering didn't support their mission statement in several ways. First, it was a "best effort" service without service level guarantees. This is all right for MDU customers, but not for enterprise customers. Second, the speeds were 28.8 kbps to 128.8 kbps, which was comparable to dialup and ISDN, but not to other broadband products being rolled out in 1999 such as DSL. Third, wired service in the 28.8 kbps to 56 kbps range could be accomplished via dialup, which was ubiquitously available wherever the customer traveled. Metricom did not have roaming agreements or partnerships with any other providers and wanted to maintain their proprietary standards.

Laden with debt, Metricom had to build their network quickly so they could start getting customers and collecting revenue. They needed at least 44 subscribers per square mile to break even [72]. Their goal was to be in 48 cities by the end of 2001.

Metricom severely underestimated the amount of time and money that would be needed to build their own network of this size. Consequently, customers were given unrealistic installation dates, and investors were misled by Metricom executives in order to inflate the company's stock price, which soared from $11.06 to $109.95 per share in January of 2002. The executives were later sued.

In addition to overextension of debt, deployment difficulties, and unethical management practices, the company was plagued by regulatory issues, competition from mobile wireless and WiFi providers, and worst of all, the lack of a quantifiable value proposition that warranted spending $80 per month. Marketing efforts were not focused on a particular subscriber base. In the end, Metricom was only able to attract 51,000 customers in 13 metropolitan areas. Further, it is unclear if the MMDS licenses that Worldcom so coveted were actually necessary for deployment or not. Table 8 shows the chronology of the events that led to the demise of Metricom.

In summary, some of the probable failure reasons were:

- Underestimated deployment difficulties and costs
- Spent too much cash too fast instead of focusing on acquiring customers
- Didn't want to partner with other providers: stuck on proprietary architecture
- Customers realized they didn't need their laptops/PDA's as much as they thought
- Poor management and marketing
- Coverage was inadequate
- Substitute products readily available at lower cost
- 700 MHz spectrum auction delayed and the need for MMDS licenses not clear
- Products didn't support the company's mission statement

3.2.2 SMS in the U.S

SMS adoption in the US has lagged behind Europe and Asia, primarily due to the lack of interoperability (i.e. little cooperation or technical standards) between mobile operators. Secondarily, making voice calls on mobile phones is relatively inexpensive in the US and fits the culture better than "texting." US subscribers have been limited to sending SMS messages within their providers network only. This means, for example, that a Verizon subscriber could not send an SMS messages to a Sprint phone. With all these inhibiting circumstances, US providers have done little to educate consumers about SMS and it is amazing that SMS is used in the US at all.

1985	Metricom Founded to develop MicroCellular Data Network technology
	Original goal was to serve municipal utilities by providing wireless meter-reading using unlicensed spectrum
1995	Metricom launches road warrior service
	Begins "buying geography" to roll out its proprietary network
1999	Metricom deploys wireless product called Richochet, operating at 28.8 kbps in 3 cities
1996	Worldcom bids for MMDS spectrum licenses but loses
1997	Worldcom purchases MMDS licenses from cash-strapped wireless companies like CAI Wireless and Wireless One for $1 Billion
1998	Worldcom pursuades FCC to alter rules and allow two-way MMDS transmissinos
1999	Vulcan Venures and Worldcom each invest $300 million to by 38% & 49.5% stakes in Merticom (respectively).
2000	January: Three Metricom executives release series of misleading statements causing stock price to jump from $11.06/share to $109.95/share
	February: Metricom's stock trades for $87/share
	US and European regulators raise concerns about Worldcom / Sprint merger because their combined MMDS licenses would cover 60% of US.
	Worldcom offers Metricom's 128 kbps service to business users under the name Worldcom Wireless Internet
	Worldcom failes to execute merger agreement with Sprint due to US and European regulatory objections.
2001	February: national expansion stops at 17 cities. Metricom tells investors it will run out of cash.
	March 16: Metricom announces first round of layoffs, cutting 22% of its workforce
	June 18: Metricom lays off an additional 23% of its workforce
	July 2: Metricom files for Chapter 11 bankruptcy protection
	August 3: NASDAQ Delists Metricom
	August 7: Metricom has 51,000 subscribers in 17 cities and $1 Billion in debt
	August 8, 6 PM: Metricom powers down all equipment
	August 16: Assets are placed on auction block
	August 16: Sierra Networks writes off $10 million owed from Metricom and fires three dozen employees
	November: Aerie Networks buys Metricom's assets for $8.3 million
	November: Metricom shareholders sue underwriters, officers, and Vulcan Ventures claiming they made false statements in prospectus

Table 8. Brief Metricom History and Sequence of Events
Prior to Metricom's Failure [73,72, 74,75]

Despite these issues, SMS is beginning to catch on in the US. In June 2001, 33 million SMS messages were sent in the US. This number jumped to 1 billion in December 2002, and represented a 49 percent increase for that year [76]. This growth was driven by three factors: the growing popularity of Instant Messaging (IM), SMS interoperability by the major US carriers in mid-2002, and by subscribers upgrading their mobile devices to ones that support SMS. Still, only 12 percent of US subscribers use SMS compared to 80 percent in Europe, and the service is still considered to be in the early-adopter phase in the US, with the fastest growth rate among teens [77,78]. Had the issues of interoperability, device capabilities, and customer education been addressed earlier, SMS may have caught on sooner in the US. Providers would be encouraging innovative SMS applications rather than reacting to the IM demand and concentrating on Multimedia Messaging Service

(MMS) – the next generation of messaging that will include graphics and sounds – effectively leapfrogging SMS [79].

3.2.3 Video on Demand

In the mid 1990s, Bell Atlantic, BellSouth, Tele-Communications, Inc. (TCI), Time Warner, US West, and Westminster Cable each performed technical and market trials of Video On Demand (VOD) services in select markets. VOD provides the customer with the ability to choose from amongst a wide variety of television programs, usually by following on-screen instructions via their remote control, and watch them at their convenience. VOD also provides VCR-type functionality such as pause, rewind, and fast-forward. The VOD providers maintain programming content on their equipment, remotely located from the end user.

Market trials demonstrated that customers liked the product but were reluctant to pay a monthly fee just to have the ability to pay for additional content. Some customers said they would be willing to pay a recurring fee for either cable or VOD, but not both. Independent surveys showed that customer expectations in Bell Atlantic's trial were met or exceeded 96 percent of the time, while Time Warner's Full Service Network experienced glitches that attracted negative press to its Orlando-based VOD trial [80]. Customers were 12 times more likely to purchase VOD content over pay-per-view, and were in parity with the volume of video rentals during the same period, except for new releases, where VOD customer were five times more likely to order it than to rent the video. The average cost per movie was $3.29 to $4.49, right in line with the cost of a video rental, with the added benefits of convenience and no risk of incurring late fees. The only consistent complaint was demand for more content [81,82,83].

These statistics painted a positive outlook for VOD. The value proposition was clear and quantifiable – so what happened?

A standard TV picture contains 30 megabytes of data per second. Left uncompressed, this requires a 240 Mbps (eight bits per byte) connection to carry a digitized version of the signal [84]. Hardware and software technologies available at that time were able to compress

the signals so they could be carried over DSL or cable lines, however this equipment cost $13,000 per stream [85]. One stream is required for each VOD subscriber. Bell Atlantic would have had to spend $494 million to reach their goal of 38,000 VOD subscribers in 1995. If they made the investment and depreciated the equipment over 20 years, assuming no maintenance or recurring costs, the average VOD subscriber would need to purchase 12 movies per month, 3.7 times higher than the average movie rental per person of 3.2 per month (see Table 9). The revenue doesn't cover their costs without making some radical assumptions about the behavior of VOD subscribers.

Break Even Analysis (Per Subscriber)	
Cost per stream	$13,000
Depreciation time (years)	20
Yearly depreciation cost	$650
Average Movie cost	$ 4.49
Movies per year required to break even	145
Movies per month required to break even	12
Known average movie rentals per month	3.2
Additional usage required to break even	377%

Table 9. Break Even Analysis, per Subscriber, for Video
on Demand in the mid 1990s

The cost per stream has come down considerably with time. As Figure 29 shows, in 1990 it cost $20,000 per stream to deliver VOD compared to $475 per stream in 2003. These costs are expected to continue to drop to below $300 per stream in 2004, making VOD a more realistic profit proposition for the providers.
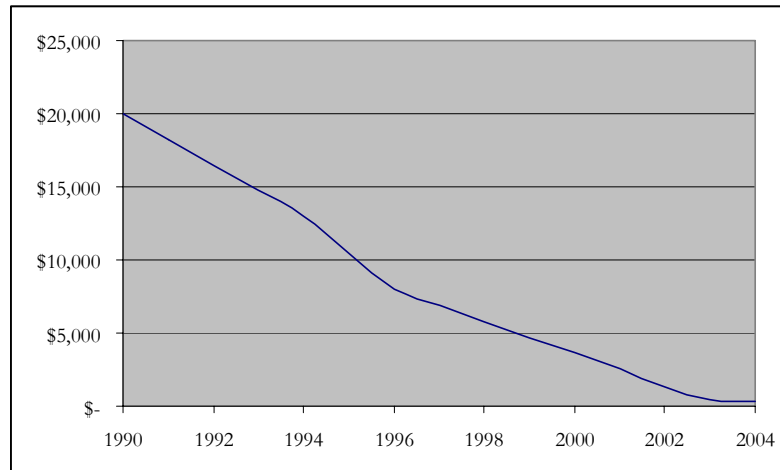
Figure 29. Historical Cost per Stream to Provide Video
on Demand (Note: Some Years are Extrapolated) [86,87,88]

There were also network infrastructure issues within each company. For the RBOCs, DSL was not deployed widespread and required line conditioning. They recognized fiber as a better technology choice for VOD than DSL, however regulations prohibited this strategy. RBOCs were required to unbundle networks and sell at wholesale prices, which meant they would incur the enormous up front expense of building fiber networks that could not be passed along to their competitors. The cable companies had sufficient bandwidth to send VOD signals however their network was not designed for two-way communications, which was necessary for customer interaction. They also reported system integration problems and small demand during their trials [89,90]. Satellite providers could only sit back and watch VOD because they sent common signals to entire regions of people, rendering their delivery mechanism incapable of VOD altogether.

3.2.4 Xtratyme's Wireless Broadband

Xtratyme launched its fixed wireless initiative in September 1999. Its strategy was to provide broadband wireless data access to rural parts of southwestern Minnesota. This part of the state is home to early adopters in high-tech farming, technology businesses such as 3M, and Mankato State University. In February of 2003, Broadband Wireless

Exchange Magazine recognized Xtratyme as the second largest Wireless Internet Service Provider (WISP). Their network consisted of 69 transmitting "towers" capable of providing high-speed Internet access to 9 percent of Minnesota's population, covering 7,000 square miles as shown in Figure 30 [91].
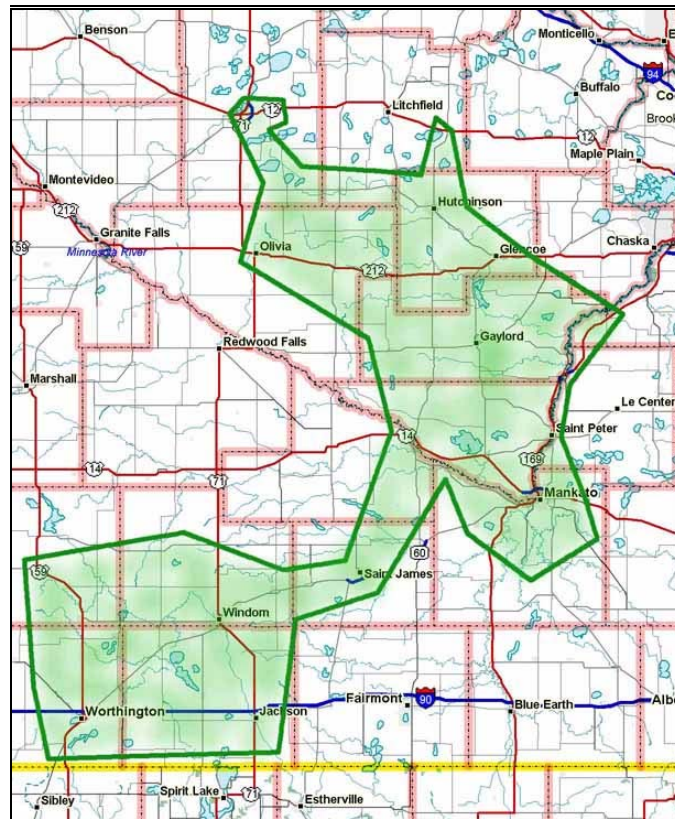
Figure 30. Xtratyme's Coverage Area in Minnesota

Xtratyme's business model is built around co-op partnerships – Xtratyme provides the wireless network infrastructure and leaves the "service provider" functions such as product development, marketing, and billing to its partners. Xtratyme does no direct marketing because their customer is the reseller. The resellers build products offerings for their customers, such as farm co-ops, based upon Xtratyme's three access options: fixed (home or office), portable (connect at certain geographic points), and mobile (moving vehicles).

Since their inception, 600 customers have signed on with Xtratyme and its partners, generating $30,000 per month in revenue ($50 / month, each). There are 97,509 homes

and 6,737 businesses in the Xtratyme footprint, meaning they have only managed to gain 0.6 percent penetration – averaging 100 new customers per year [92].

In 2001, Southwest Wireless, one of Xtratyme's largest resellers, began complaining about poor quality of service being provided by Xtratyme's network. Southwest claimed Xtratyme's makeshift towers – ranging from grain elevators to water towers, to buildings and agricultural structures – were at the heart of a system built, "with bubble gum and duct tape," and could only achieve 70 percent up time [93]. According to Southwest, Xtratyme's problems were caused by spreading itself too thin, causing them to over promise and under perform [94].

Kyle Ackerman, Xtratyme's founder, CEO, and wireless advocate, described the Southwest situation as a 50-50 partnership that required both companies to uphold the terms of the contract. Some of the remote areas in Southwest's territory required 15 hops between wireless access points, and without the capital dollars required from Southwest as part of the terms of the contract, Xtratyme could not completely build the network [95].

Ackerman learned that embracing wireless Internet access and making money at it are two different things. He discouraged Xtratyme from taking on long-term bank debt and instead, advocated that capital should come from the partner companies and from the Xtratyme management team. This left the company undercapitalized. When Southwest defaulted on payments, Xtratyme was forced to file for Chapter 7 bankruptcy in January of 2002 [96]. As of the time of this writing, Xtratyme had emerged from Chapter 11 bankruptcy (back to Chapter 7) and was seeking a buyer for its $1 million in assets and $500,000 in liabilities, claiming that the right buyer will be able to sustain the service and make a profit.

3.3 Common Themes

Collaboration has symbiotic, positive growth effects on *both* technologies and *both* organizations, as demonstrated by the success of SMS in Europe – due in large part to the standards being set early and adhered to by all providers, by Research in Motion's BlackBerry strategy – partnering with resellers and carriers, and by Gilat Satellite – creating

partnerships and joint ventures allowing it to focus on its business strategy. On the contrary, monopolistic approaches such as those taken by Metricom, often fail. Metricom's customers could only connect when they were within the geographic areas being covered due to the proprietary networking standards and lack of interoperability with other providers.

The value proposition must be quantifiable and easy to understand. SMS flourished in Europe because voice calls were so expensive in comparison. In the US, mobile customers were satisfied with the value of making voice calls enough not to justify learning and using SMS. Metricom's failure proved that people weren't getting enough value from the ability to connect at dialup speeds via their laptop or PDA to justify paying $80/month.

Profit models are to the providers as the value propositions are to customers. As VOD showed in the mid-1990s, the providers have to be able to build a solid business model showing how revenues will cover their costs enough to justify making the investment. Xtratyme's business model demonstrated the risk of investing in the broadband wireless space. Even with the risk spread 50-50 between partner companies, their profit model barely works.

Simple applications designed for PCs can be the breeding ground for new wireless applications. Instant messaging and email are perfect examples. The popularity of IM is expected to be the driving force behind SMS growth in the US [97]. BlackBerry simply extended the reach of email to wireless devices and created a $300 million company. Over 690,000 customers have been willing to buy a BlackBerry or Palm.Net device for $350 to $500 plus pay $40 per month to run lightweight versions of PC/Internet-based applications [98].

3.3.1 Lessons Learned

The cases of Metricom, Xtratyme, and VOD clearly show that providers must recognize and admit their limitations and only promise what they can deliver. In all three cases, company officials promised massive product rollouts only to learn that the technology would cost much more than expected, and/or take far longer to deploy. Metricom

promised to deliver their network to 48 metropolitan areas in less than two years, but by the end of their self-imposed two-year deadline they only deployed to 13 of them, and racked up $1billion in debt. Xtratyme grew rapidly, building the second largest wireless network with only 21 employees. In June of 1995, Bell Atlantic claimed VOD would be installed in 2000 households by the end of the summer, and 1500 per month thereafter, up to 38,000 homes, only to abandon VOD altogether in 1997 [99].

An organization's mission must be *able* to be accomplished and the product must support the mission statement better than any other competing products. Metricom's mission changed three times in 15 years, with each iteration getting more aggressive.   Had they examined their product's capabilities – nominal speeds of 28.8 kbps – with the market segment they intended to capture – highly mobile professionals – they would have realized that dialup internet access was superior in price and coverage.

Marketing and customer education are paramount when a new technology is available. SMS in the US has not been promoted until recently. Despite the interoperability issues, the carriers could have generated revenue by promoting SMS between their customers or from innovative applications within their own networks. Xtratyme attempted to build their business model by completely depending on their partner companies to do the marketing, which resulted in very low subscriber penetration. Proving, "If you don't market, you won't make it. [100]"

"If you build it they will come," is absolutely false: Metricom and Xtratyme are proof. Technology by itself does not solve business problems or provide value to consumers. Good managers who stay intently focused on their customer's requirements can *potentially* solve problems with technology if the value is clear and quantifiable.

Financial success is the result of proper management and ethical behavior. Metricom lacked both. Its overaggressive "road warrior" strategy required significantly more capital than its business plan could sustain, possibly leading three misguided executives to release incomplete financial information to shareholders, misguiding them, and inflating its stock price. Xtratyme's CEO attempted to keep the company afloat by relying on capital from

its partners and management team. Alternatively, he could have taken on *some* long-term debt from financial institutions – a perfectly legitimate financial strategy – and possibly avoided being undercapitalized and bankruptcy protection.

3.3.2 Frameworks for Comparing and Evaluating

Chapter 1 briefly introduced nine frameworks that are useful for assessing business and technology strategies. In Chapter 4, these frameworks will be applied to broadband wireless technologies in more detail.

Here, the reader is advised to keep the following scenarios in mind to enhance the understanding of Chapter 4.

Utterback and Abernathy discuss the relationship between product innovations, process innovations, and the emergence of a *dominant design*. SMS *could* be described as the dominant design for two-way message communication between wireless devices. 802.11 may turn out to be just a step in wireless product innovation, however it is showing signs of being the dominant design.

Metricom's performance vs. the market's demand is a good example of failure along traditional *and* ancillary measurements, which could provide some insight into why it failed. Ricochet was not much faster than competing products and cost three times as much. A disruptive technology can survive despite being worse along traditional performance metrics as long as its ancillary performance – connectivity without wires – is something valued by customers. Their service was only available in selected areas, rendering its ancillary performance worse than a substitute such as dialup.

Products targeted for similar customer segments compete in different ways. Collaboration in the telecommunications marketplace tends to produce symbiotic effects that expand the overall demand for products. This was evident with SMS in Europe, and with VOD in the demand for infrastructure. Pure competition, in which one provider attempts to "go it alone," as did Metricom with its proprietary architecture, tends to be way too expensive and time prohibitive.

Christensen documented the failure modes associated with the link between resource allocation and strategy iteration, showing those most likely to succeed conserved resources and changed strategies over time. Metricom followed half of Christensen's advice – they changed strategies three times, attempting to change from a metering application provider to a metropolitan area network provider. However, they did not conserve enough resources after their final strategy iteration to sustain them for the long term. Xtratyme didn't change their co-op strategy, even when it became questionable, nor did they go after additional financial resources that could have been conserved during periods of low cash flow. VOD appears to be going through very long cycles of strategy iterations, starting some 30 years ago with Smith's book, Wired Nation, Cable TV, lasting through each wave of new and promising technology that providers attempt to deploy [101].

3.3.3 Conclusions

Poor strategies in the telecommunications industry cause firms to lose a lot of money and often fail completely. Complex dependencies within the value chain, unpredictable regulatory influences, and unproven technical capabilities make broadband wireless strategies very difficult to create and assess. In Figure 31, Charley Fine, Professor of management at Sloan Business School, depicts the industry as a mesh of interlocking gears, each having an impact on the overall strategy – what appears to be a "good" strategy today may become better or worse, very quickly, depending on the direction of change.
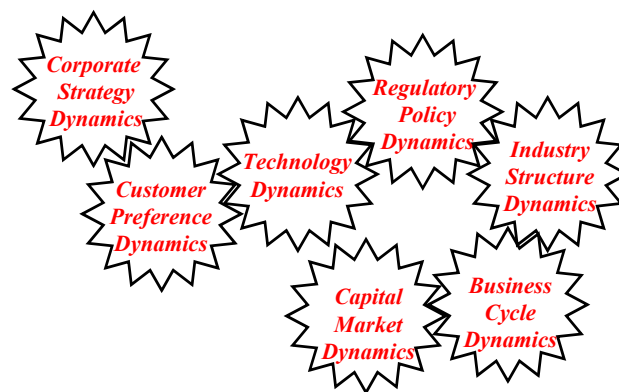
Figure 31. The Dynamic and Complex Relationships
Within the Telecommunications Industry [102]

APPLICATION OF TOOLS FOR ASSESSING BUSINESS OPPORTUNITIES

4.1 Frameworks Applied to Broadband Wireless

In chapter 1 several thought models and frameworks were briefly introduced. Here, they will be discussed in more detail in order to convey their overarching concepts. Then they will be applied specifically to the broadband wireless space.

4.1.1 Utterback-Abernathy Models

Figure 32 shows the Utterback-Abernathy model and serves to explain the dynamics of innovation over time [103]. As the model shows, early entrants are heavily engaged in making product changes. Processes are ad-hoc, flexible, and frequently subject to change in order to support rapid changes to products. Over time, the innovations most accepted by the marketplace become part of the *dominant design*, a term used to describe a stable product architecture most likely ready for mass market that contains the *essential features* required for success. At that point in time, process innovations become more important as cost and time pressures mount.

Throughout the evolution, corresponding changes are happening to the organization, the market, and the competition as summarized in Table 10.
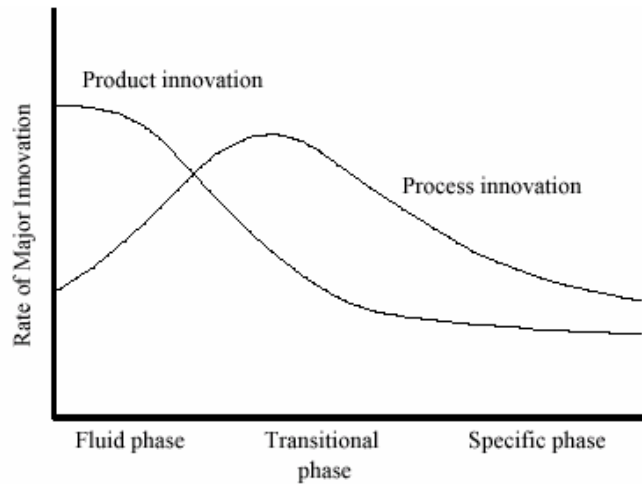
Figure 32. Utterback-Abernathy Model Explaining the
Relationship Between Product and Process Innovations
Over Time

Product	From high variety, to dominant design, to incremental innovation on standardized products.
Process	Manufacturing progresses from heavy reliance on skilled labor and general-purpose equipment to specialized equipment tended by low-skilled labor.
Organization	From entrepreneurial organic firm to hierarchical mechanistic firm with defined tasks and procedures and few rewards for radical innovation.
Market	From fragmented and unstable with diverse products and rapid feedback to commodity- like with largely undifferentiated products.
Competition	From many small firms with unique products to an oligopoly of firms with similar products.

Table 10. Evolution of Five Dimensions During the
Product Life Cycle [104]

According to Utterback, frequently the products developed by companies that entered the market early are the most successful [105]. Broadband wireless differs from most other

innovative products that this generalization applies to in that the delivery mechanism is highly regulated and is subject to distance limitations. Utterback's models were built by studying products like typewriters, ice, and glass, that can be shipped anywhere. However, broadband wireless appears to have many of the same characteristics as these other products in their infancy and this framework can provide good insights as long as the differences are kept in mind.

The incumbent technologies include conventional wired services, mobile phones, and both phone line modems and wireline broadband. While there remain significant dynamics relative to these technologies, the relative dynamic location of these two being in a Transitional / Specific phase (Figure 33), and in an effort to simplify the modeling effort, there are combined into a single heading. As this model shows, the wireless broadband space is undergoing enormous product changes versus wireline broadband, in which the dominant design is established and the incumbents are focused on processes to generate more revenue and provide better service.
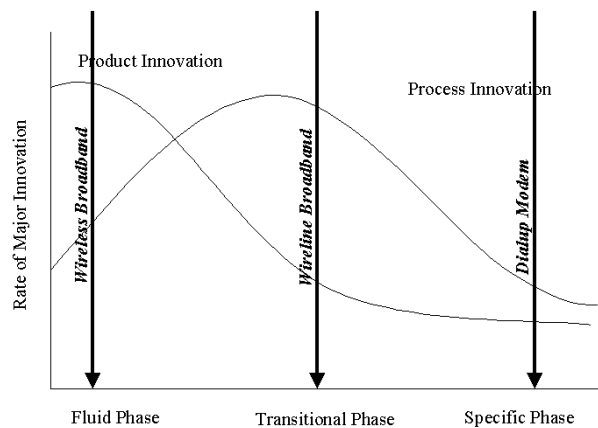
Figure 33. Dynamic Location of the Various
Technologies Being Considered

Three major components contribute to the emergence of a dominant design: technology, marketplace, and value proposition. The model in Figure 34 shows these components and

the factors that need to be addressed by companies at all levels of the broadband wireless supply chain.

Value Proposition
• Applications
• Convenience
• New ways to work
• New ways to do business
• Productivity
• Return/ROI
• Ubiquitous

Dominant
Design

Technology
• Bandwidth
• Devices
• Existing innovations
• Frequency/Spectrum
• Interoperability
• QoS
• Range
• Roaming ability
• Standards/Protocols
• Security

Marketplace
• Availability
• Cost
• Coverage
• Education/Advertising
• Pricing models
• Roaming agreements
• Substitutes

Figure 34. Three Major Components of the Emerging
Dominant Design

Some of the high level questions that Figure 34 evokes are:

- What are the essential features that will contribute to the dominant design?

- Will these essential features be the same for both the consumer and the business market segments?

- To what extent will device technology impact adoption?

- What can be learned from recent history of similar technology? Are there parallels to the early years of the TV industry – spectrum issues, screen size, B&W versus color, industry consortiums led by RCA?

- How important is interoperability between carriers and technologies?

- Will regulation help or hinder the emergence of a dominant design?

- What are customers willing to pay? Which pricing models work?

Architectural innovation occurs when combinations, creative synthesis of existing components, results in a standard or dominant design which changes the terms of competition in an industry [106]. For example, the DC3 combined 33 existing innovations and was the first airplane to succeed in the three most important dimensions for creating a viable passenger market: size/passenger capacity, range, and speed. Broadband wireless could accelerate from *architectural innovations* because there so many components are involved.

Some of the major architectural components that could play into the emergence of a dominant design are:

- Antenna technology
- Application architecture
- Battery technology
- Compression technology
- Device technology
- Display technology
- Software technology
- Storage capabilities
- Transmission technology
- Wireline broadband technology

4.1.2 Performance vs. Market Demand

Christensen suggests that the ability of a new technology to displace incumbent firms depends upon the development of a new market within an established industry [107]. He believes the new market segment is more price sensitive than the mainstream market and is willing to sacrifice the level of traditional level of performance as measured by the mainstream market, but requires performance along a different metric than the established mainstream market. Once new entrants gain a foothold, they move up-market into the mainstream with a lower cost product that meets the traditional performance demanded by

the mainstream market as shown in Figure 35. The incumbent firms tend to outpace the demand band of the mainstream market, chasing the more lucrative lead user market, perhaps even listening too closely to their current customers.
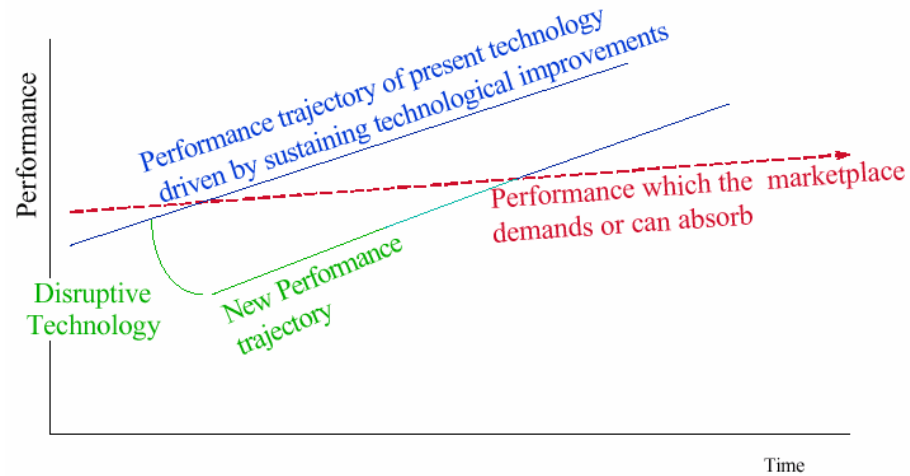
Figure 35. Christensen's Performance Compared to
Market Demand Over Time [108]

Another, more traditional version of Figure 35 is the technology S-curve which plots performance over time on a non-logarithmic scale, as shown in Figure 36.
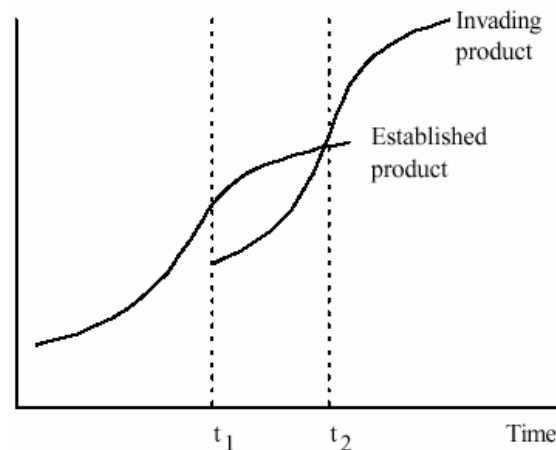
Figure 36. S-Curve: Plot of Performance Over Time [109]

81

Christensen and Utterback extend this model to show that the established product reacts to the threat of a disruptive product by making substantial improvements to the performance of the product along the lines *traditionally valued* by the market [110]. This reaction, depicted in Figure 39 is often quite impressive, as in the natural ice and gas lighting industries where orders-of-magnitude improvements were made and helped the industry survive a little longer. However, as the model shows, ultimately a disruptive product overtakes the incumbent, usually because the new technology has better performance along a *non-traditional* performance dimension: convenience in the ice industry and safety in the lighting industry.

Applying this framework to one of the traditional performance dimensions – speed – for each technology results in the graph shown in Figure 37.

Performance: Speed
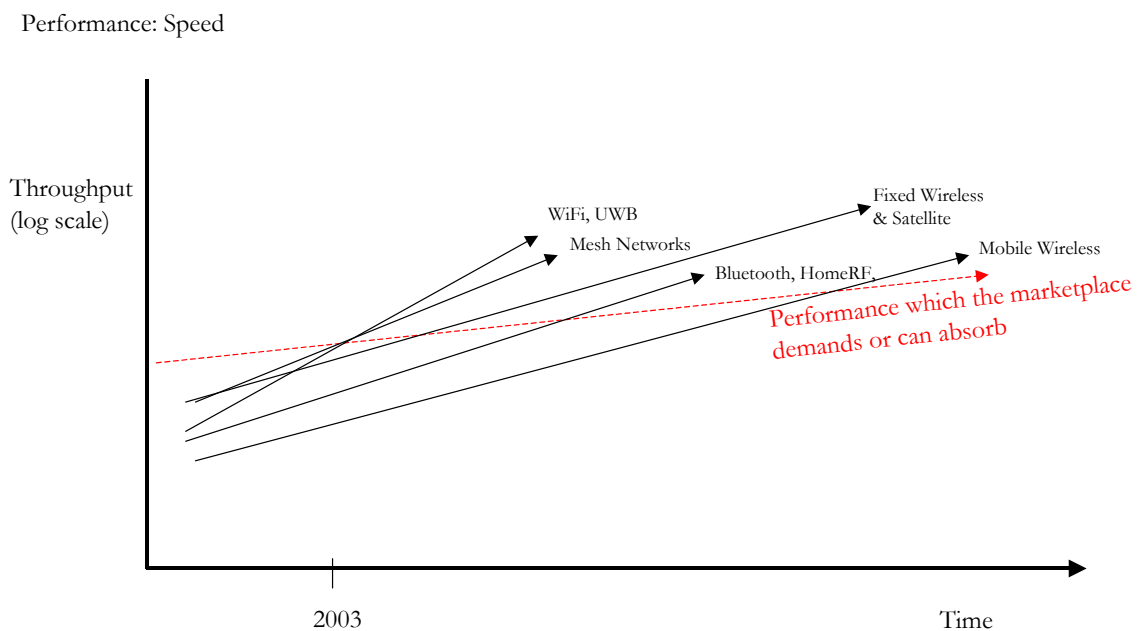
Figure 37. Christensen's Framework: Speed of the
Connection Versus Time for Each Broadband Wireless
Technology

Comparing wireline broadband (established) to wireless broadband (emerging) yields valuable insights that require rethinking how Christensen's model applies. The probability that wired broadband speeds are progressing too fast for their consumer base can be seen in the broadband market as current mainstream broadband providers – the cable and

telecom industries – continue to push toward faster and faster connection speeds, and at the same time continually escalating costs. In his MIT thesis, Hap Acee argues that disruptive innovations can actually move down-market, rather than solely up-market, as Christensen suggests [111]. Cable companies appear reluctant to introduce tiered service, slower connection speeds at a lower cost (moving down-market), for fear of cannibalizing their current business, which is growing at 50 percent per year. Phone companies fear attracting more DSL broadband customers may hurt their bottom line if a significant portion of their customers disconnects a second phone line in the house that previously handled data (Internet connection). Recent data indicates that as many as half of the people who sign up for broadband disconnect a second home phone line [112].

Right now the technology appears to be moving faster than the mainstream broadband market, as shown in Figure 38, leaving the current providers open to a potential attack from below as Christensen suggested, unless incumbents can drive the need for faster speeds through ancillary programs, as Intel and Microsoft have done with processor speeds and software which requires greater speed. Other examples are Napster and Kazaa. Napster was developed as a means for online sharing of music MP3 files. Similarly, Kazaa was developed as a pier-to-pier sharing mechanism for these same music files. The transfer of a single MP3 file would often surpass 2MB, basically shutting out dial-up Internet customers. Each has come under legal attacks that have slowed the sharing of these files online. One can surmise that the failure of Napster led to a decrease in the wireline broadband customer base. Perhaps without the value proposition of paying $50 per month to download $500 (or more) worth of music if they were to purchase the compact discs, these consumers could no longer justify the increased price of broadband over dial-up. Without this value proposition these same customers were unwilling to pay the added cost.
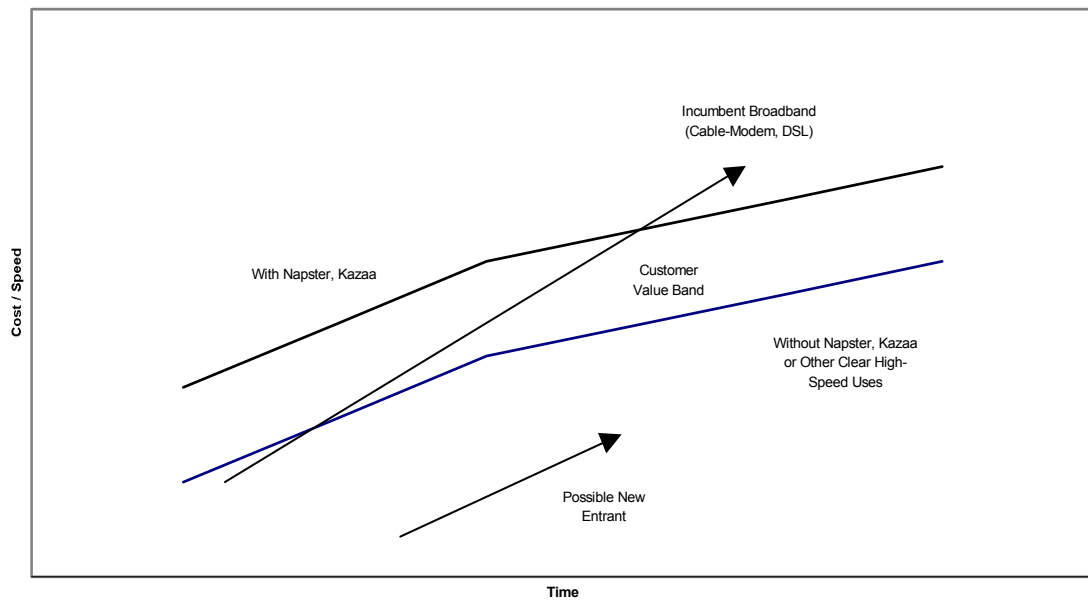
Figure 38. Revised Performance Versus Market Demand

This value differential between what mainstream customers are willing to pay and current offerings leads one to believe that it may be possible for a low cost, new technology to gain a foothold in the broadband market, or perhaps a sub market as proposed by Acee. The main lesson learned from industries such as steel mini-mills and hydraulic excavators is that disruptive technologies tend to thrive where their perceived weaknesses are actually strengths or are subordinate to better performance along other dimensions. Mobile wireless data services under perform in every performance dimension except for range and coverage. If mobile wireless becomes disruptive, sub markets that are not favorable for current dial-up or broadband wireline incumbents, such as rural and third world applications could provide a breeding ground for the disruption to take a foothold and thrive.

4.1.3 Sustaining vs. Disruptive – Determining the Classification

According to Christensen most new technologies are *sustaining* in nature, meaning that they improve the performance of established products, along the dimensions of performance that mainstream customers have historically valued. *Disruptive* technologies change the

value proposition in the marketplace by performing *worse* than the incumbent technologies along the dimensions valued, but they have other features that a few fringe (and generally new) customers value [113].
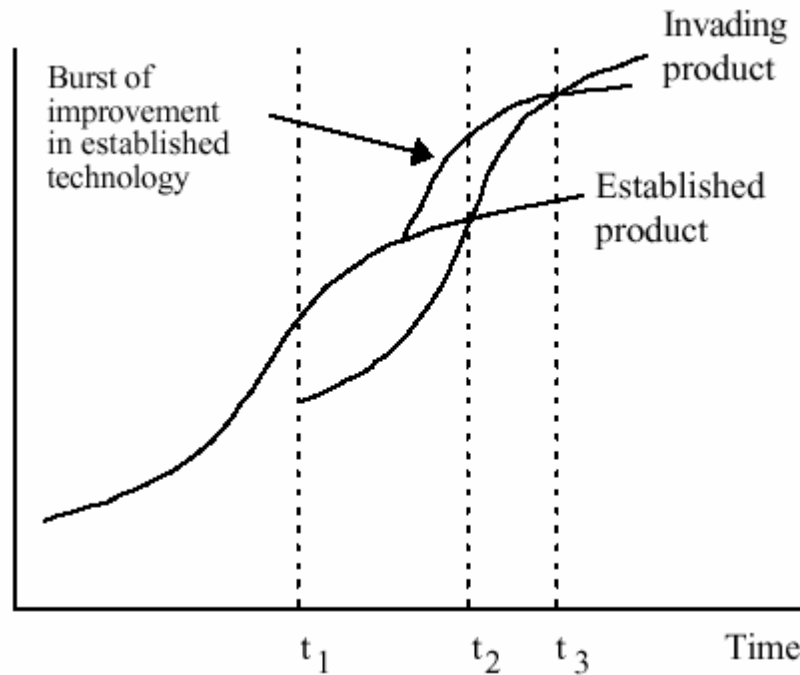
Figure 39. Modified Performance S-Curve Showing How
the Incumbent Firm Reacts to a Disruptive Technology
[114].

Sustaining technology improvements, even if they are radical, rarely provide a significant competitive advantage to one firm over another because other firms will quickly copy or make even further improvements of their own. Failing to see and respond to a disruptive technology almost always causes incumbent firms to fail [113].

Disruptive innovations tend to be technologically straightforward, simpler and more convenient than mainstream products, different in the rank ordering of the value of attributes, and priced with lower gross margin dollars per unit. Customers will not lead you to them. "Good" management practices will actually steer companies away from

85

disruptive technologies because they are less profitable, sales and marketing plans won't make sense, and senior management will often attach little importance to what appears to be a niche technology [115]. These factors are precisely what Christensen says sets up the *Innovator's Dilemma*.

Other criteria that can be used to classify an emerging technology as sustaining or disruptive are summarized in Table 11.

Sustaining Technology	↔	Disruptive Technology
Incremental improvements	Technology qualities	Simpler, more reliable, more convenient
Predictable - can be modeled and forecast	Market	Unknown & orders of magnitude larger than "expected"
Quantified, accurate estimates	Information	Pure speculation - none exists
Business as usual	Sr. management perception	Distraction from business as usual
Addresses important customer needs	Customer needs	Niche needs at best
Positive impact	Profit	Negative Impact
"Wait until market is large enough to be interesting"	Management Tendencies	Entrepreneurial
High dependence on existing resources, supply chains, & products	Dependencies	None or very few dependencies
"Fits" within existing	Value network	Totally different and usually not obvious or apparent
Completely identified	Application and uses	Not apparent or foreseen

Table 11. Summary of Criteria Used to Classify a
Technology as Sustaining

Now this framework will be applied to the broadband wireless technologies under consideration in this thesis to determine where each might be classified. Figure 40 shows each broadband wireless technology and the degree to which it fits the criteria for being a sustaining technology. By this analysis, fixed wireless, mobile wireless, and satellite technologies appear to be the most likely to be classified as sustaining.

	Sustaining Technology	Bluetooth	Fixed Wireless	HomeRF	Mobile Wireless	Mesh Networks	Satellite	Ultra Wide Band	WiFi
Technology qualities	Incremental improvements		✓		✓		✓		✓
Market	Predictable - can be modeled and forecast			✓	✓		✓		
Information	Quantified, accurate estimates		✓		✓		✓		
Sr. management perception	Business as usual		✓		✓		✓	✓	✓
Customer needs	Addresses important customer needs		✓		✓	✓	✓	✓	
Profit	Positive impact				✓				
Management Tendencies	"Wait until market is large enough to be interesting"						✓	✓	
Dependencies	High dependence on existing resources, supply chains, & products		✓		✓			✓	✓
Value network	"Fits" within existing	✓		✓	✓				
Application and uses	Completely identified		✓	✓			✓		

Figure 40. Degree to Which each Technology Seems to
Support Sustaining Characteristics

Figure 41 shows the broadband wireless technologies most likely to be disruptive in nature, which appears to be Bluetooth, Mesh, and WiFi.

	Disruptive Technology	Bluetooth	Fixed Wireless	HomeRF	Mobile Wireless	Mesh Networks	Satellite	Ultra Wide Band	WiFi
Technology qualities	Simpler, more reliable, more convenient	✓		✓		✓		✓	
Market	Unknown & orders of magnitude larger than "expected"	✓				✓			✓
Information	Pure speculation - none exists			✓					✓
Sr. management perception	Distraction from business as usual	✓		✓		✓			
Customer needs	Niche needs at best	✓		✓					✓
Profit	Negative Impact		✓						✓
Management Tendencies	Entrepreneurial	✓		✓		✓			✓
Dependencies	None or very few dependencies	✓		✓			✓		
Value network	Totally different and usually not obvious or apparent					✓		✓	✓
Application and uses	Not apparent or foreseen	✓			✓	✓		✓	✓

Figure 41. Degree to Which each Technology Seems to
Support Disruptive Characteristics

Being a sustaining technology does not mean that it is not important or should be ignored. Most new technologies *are* sustaining in nature and provide value to customers and profits to firms. What is important for firms to understand is that given a particular classification, it is critical that they respond appropriately in the way they organize, strategize, and manage the technology. This will be addressed in the conclusion. Moreover, firms should pay careful attention to disruptive technologies becoming predators in the future and making sustaining technologies obsolete.

4.1.4 Modes of Competition

This framework is helpful for looking at the competitive nature of existing and new technologies and technology pairs to determine if any of them demonstrate patterns of a disruptive innovation that the market will likely adopt and whether they appear to be replacing a specific technology.

Utterback and Pistorius further show that there are multiple modes of competition, not just simply one technology taking market share away from the other [116]. In fact, there are four modes of competition, as shown in Figure 42: Predator (existing technology) / Prey (new technology), Predator (new technology) / Prey (existing technology), Symbiosis, where both the new and existing technologies thrive and expand the market, and Pure Competition, where one technology takes market share from the other and the total market size does not change. It is important to note that the modes of competition can shift over time.

Examples of an emerging technology causing positive growth of a mature technology are quite common. As a recent example, when dial-up internet access emerged, households subscribing to dial-up services were nearly four times more likely to purchase a secondary plain old telephone service (POTS) line [117]. When companies promoting a mature technology feel threatened, they often respond with dramatic improvements in performance and cost, causing the mature technology to actually gain additional market share, such as in the harvested ice, mechanical typewriter, and gas lighting industries [116].

		Effect of A on B's Growth	
		Positive	Negative
Effect of B on A's Growth Rate	Positive	Symbiosis	Predator (A) - Prey (B)
	Negative	Predator (B) - Prey (A)	Pure Competition

Figure 42. Utterback's Modes of Competition and the
Effect each Technology has on Each Other and the
Market [118]

Utterback's predator-prey framework is helpful for looking at the competitive nature of existing and new technologies. Applying these models to wireless broadband technologies in useful in determining if any of them appear to be following patterns of a disruptive innovation that the market will likely adopt and whether they appear to be replacing a specific technology. Figure 43 shows some possible scenarios, starting at the industry level, where one could argue that the wireline industry could become prey to the wireless industry.

89

	Predator	Prey
Communications Industry	Wireless	Wireline
Technology Categories	Short range wireless	Cables, cords, etc.
	Stationary, long range wireless	Dialup
	Stationary, long range wireless	DSL, Fiber, COAX, etc.
	Nomadic, medium range wireless	Station wiring, hard-wired connection
	Mobile, ubiquitous wireless	Dialup
	Mobile, ubiquitous wireless	DSL, Fiber, COAX, etc.
	Mobile, ubiquitous wireless	WiFi
Specific Technologies	Bluetooth, HomeRF, UWB	RS-232, Mouse and Keyboard cables
	Satellite Data	Dialup
	Satellite Data	DSL, Fiber, COAX, etc.
	Fixed Wireless	Satellite Data
	Fixed Wireless	DSL, Fiber, COAX, etc.
	WiFi	Cat-5 cable
	WiFi	Fixed Wireless
	3G Mobile	Dialup
	3G Mobile	DSL, Fiber, COAX, etc.
	3G Mobile	Fixed Wireless
	3G Mobile	WiFi
	Mesh Networks	WiFi
	Mesh Networks	3G Mobile

Figure 43. Utterback's Predator-Prey framework applied
to wireless and wireline technologies

Examples of an emerging technology causing positive growth of a mature technology are quite common. When the companies promoting the mature technology feel threatened they often respond with dramatic improvements in performance and cost, causing the mature technology to actually gain additional market share such as in the harvested ice, mechanical typewriter, and gas lighting industries [116].

While Christensen tends to support the idea that disruptive innovation is always a cheaper product with lower traditional performance, but with improved ancillary performance on a metric not yet considered important in the mainstream, Acee suggests that this is not necessarily true. In this case, wired broadband is a disruptive technology to dial-up Internet service. In fact, a new entrant, cable service providers, are currently the leading

firms in this field, holding approximately 70 percent of the market after the major telephone companies did not fully embrace the 1988 discovery of Joe Lechleider, a research scientist at Bell Labs, of how to rush signals along ordinary copper wire at high speed using digital technology [119]. The phone companies were making large profits controlling local phone lines, so they were not terribly interested. However, cable companies, perhaps worried about the infringement of satellite television, were making huge investments in fiber optics and found that the two-way systems were ideal for connecting to the Internet. Wired broadband has greater cost, but with greater traditional and ancillary performance.

The larger picture may be that the entire industry is churning. Dial-up services are being replaced with wired broadband service, which may in time be replaced with wireless broadband services. A dominant design has not yet have been established. Regulations may hinder or support one technology versus another temporarily, but the winds of politics change quickly and today's mega-corporation trying to help write future regulation may be out of business in the next wave of disruptive innovation.

Applying this framework to emerging broadband wireless technologies, one finds that many of these modes exist today or may exist in the future depending on how the technology evolves as shown. Figure 44 attempts to analyze the modes of competition between the different technology categories. It shows, for example, that wireless and wireline compliment each other at the point where the receiver connects into the backbone network; the installation of a new wireless base station (transmitter and receiver) requires a new high-speed landline connection. Profit models can be built by incumbent firms to determine if this mutual advantage makes sense, taking into account the cost of the base station, recurring landline charges, number of expected subscribers, and sunk cost of existing wireline infrastructure, such as DSL or COAX lines, that will be substituted. Pure competition, according to this model, primarily occurs when the ancillary performance criterion – communication without wires – is valued less then QoS or price, or when policies scrutinize the use of wireless networks. Further, pure competition between different wireless products occurs only when the applications must communicate wirelessly and a decision has to be made to choose one.

A	B	Symbiosis B→A= + A→B= +	Predator (A) Prey (B) B→A= + A→B= -	Predator (B) – Prey (A) B→A= - A→B= +	Pure Competition B→A= - A→B= -
Wireless Technology	Wireline Technology	WiFi router plus DSL line	Satellite replacing dialup in rural areas	Highly sensitive business system; very large data volumes	Cell phone substituting for POTS line
Short Range Wireless	Cables, cords, etc.	N/A	Bluetooth, HomeRF, Ultra Wide Band	N/A	N/A
Stationary, Long Range Wireless	Dialup	Fixed wireless or Satellite with dialup backup option	Satellite replacing dialup in rural areas	Poor wireless QoS and no other alternative	Equal wireless QoS and no other alternative
	DSL, Fiber, COAX	Base stations require large wireline backbone connection	Poor wireline QoS and comparable pricing	Poor wireless QoS and wireline services available	Equal QoS, little price difference, and all available
Nomadic, Medium Range Wireless	Station Wiring	N/A	WiFi router installed in new construction	N/A	Wireless is not an option due to corporate policy or interference issues
Mobile, Ubiquitous Wireless	Dialup	Packages that offer free dialup as backup	3G wireless PC cards	Poor 3G QoS or 3G too expensive	N/A
	DSL, Fiber, COAX	Base stations require large wireline backbone connection	Truly mobile users who rarely dock to a landline	Poor 3G QoS or 3G too expensive	N/A
	WiFi	Forthcoming chipsets like Intel's Centrino	N/A	Nomadic users that have enough access to hot spots	Vertically integrated wireless applications and platforms

Figure 44. Examples of Competition Modes that Exist
Today

4.1.5 Resource and Strategy Iteration Model

In his book, Christensen specifically discusses four cases that illustrate four different combinations of iteration and resource consumption as shown in Figure 45. The four quadrants apply to potentially disruptive technologies. The four cases in Christensen's book include one that succeeded, two that failed, and a placeholder for emerging technologies whose disruptive classification is unknown.

Christensen concludes that beginning with the correct strategy for a disruptive technology is not as important as failing early and conserving enough resources to allow for iterations toward a viable strategy [120]. This is very difficult for an established firm to do since failure flies in the face of traditional performance metrics.

Iterations towards viable
strategy / # of early failures   several

High Probability that a   Disruptive Technology
Disruptive Technology   Abandoned Prematurely.
Will Thrive.   Ex: HP Kittyhawk Disk   Resources
Ex: Honda dirt bikes   Drives

conserve   exhaust

Discovery Mode.   Disruptive Status Unknown
Disruptive Status   And Venture Fails (Burnout).
is Emerging   Ex: Apple Newton

one
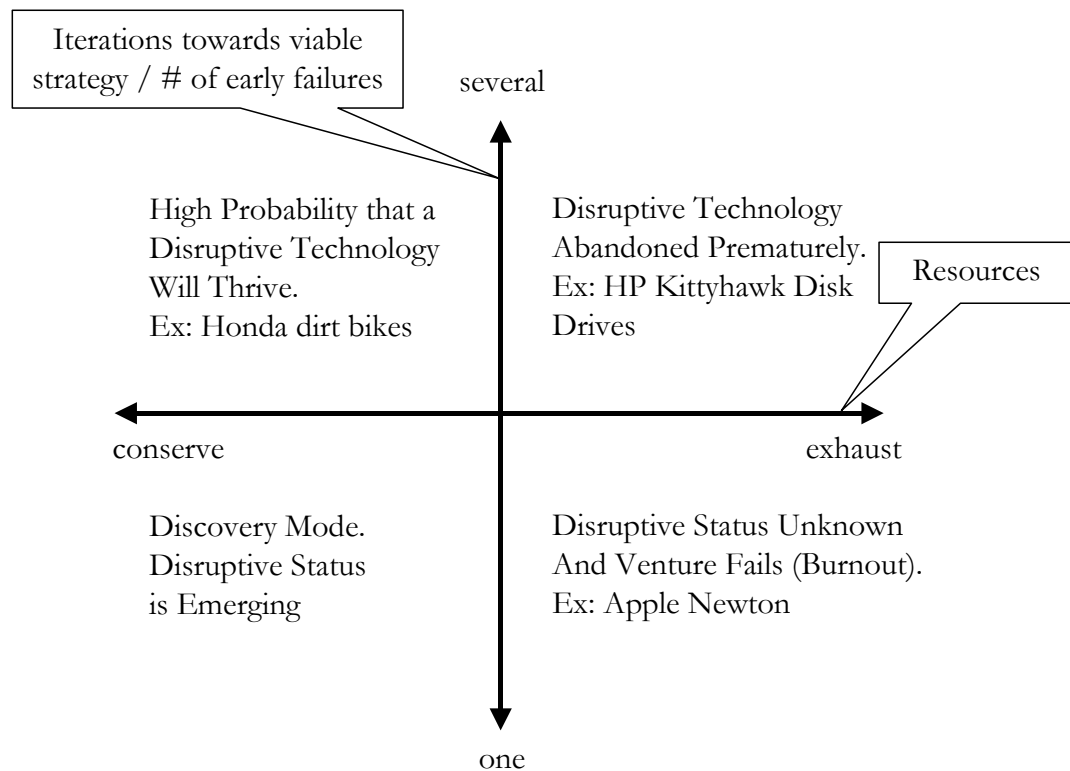
Figure 45. Christensen's Framework Showing the
Relationship Between Technology Strategy and Resource
Allocation

He also suggests that separate subsidiary organizations be established to promote disruptive technologies so they can be measured and evaluated differently.

Christensen's research shows there is a relationship between the number of strategy changes that a successful company makes as it adapts its technology to the market's needs and the amount of resources spent developing each iteration.

Applying this model to broadband wireless technologies in Figure 46 suggests that mobile wireless and WiFi technologies are going through iterative generations and are backed by companies that have enough resources to ensure successive iterations in the future. Fixed wireless and satellite are in early product development stages, however large amounts of money have already been spent on them, and it is not clear that the companies supporting these products are willing to commit more resources to them. Wireless mesh networks are in very early stages of development and have yet to prove their value. HomeRF showed many of the signs of being a classic disruptive technology, however, consortium efforts to standardize the technology recently failed citing the emergence of a standardized version of Bluetooth as the main reason.
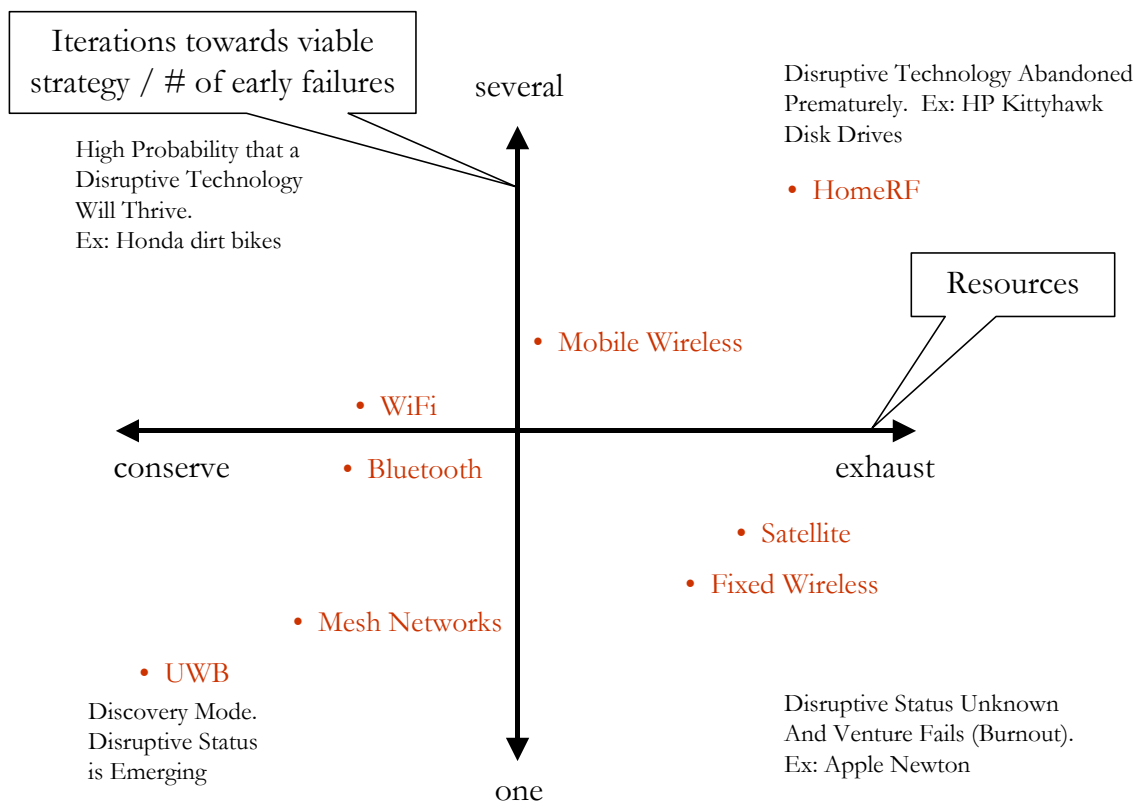
Figure 46. Christensen's Resource Allocation Framework
Applied to Broadband Wireless

94

4.1.6 Lotka-Volterra Substitution Analysis

The basis of this model is a system of coupled differential equations shown in Equation 1 that can be numerically approximated using the time-difference solution shown in Equation 2.

$$
\begin{cases}
\dfrac{dH}{dt} = rH - aHP \\[2em]
\dfrac{dP}{dt} = bHP - mP
\end{cases}
$$

Equation 1. Lotka-Volterra Differential Equations

The equations have two variables (P, H) and several parameters:

H = density of prey

P = density of predators

r = intrinsic rate of prey population increase

a = predation rate coefficient

b = reproduction rate of predators per 1 prey replaced

m = predator mortality rate

$$
T_i(t+1) = \frac{e^{a_i} T_i(t)}{1 - \displaystyle\sum_{j=1}^{J} \frac{s_{ij} c_{ij}(e^{a_i} - 1)}{a_i} T_j(t)}
$$

Equation 2. Lotka-Volterra Time-Difference Numerical Approximation [121]

Given some historic data about the growth rate of the predator and the prey and making some assumptions about the context of the market, the model can be useful in predicting if and when one technology will overtake another.

Referring back to Figure 44, further assessing the *pure competition* mode-of-competition requires an analysis of the substitution rates of one technology over the other. Lotka-Volterra is one such method to aid in the analysis of substitute products when some historical data is available. An interesting case to consider when assessing the substitution impact broadband wireless *may* have, is to look first at the substitution effect broadband wireline is having on dialup products. Figure 47 is the familiar Utterback-Abernathy transitional model with placeholders for each generation of technology and a bracket indicating the area of interest for the Lotka-Volterra models.
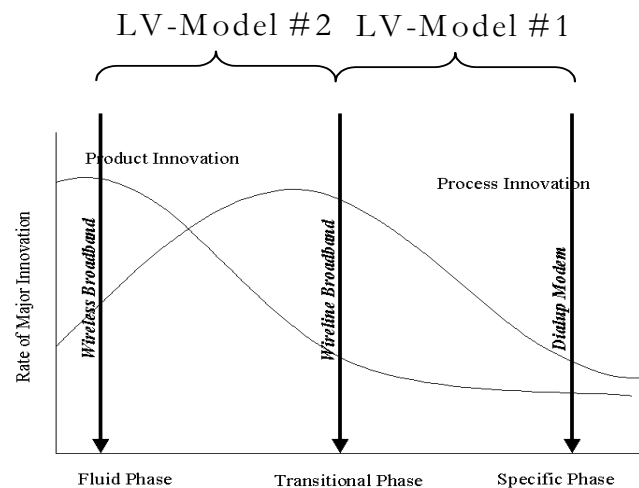
Figure 47. Utterback-Abernathy Model Showing the
Areas of Interest for the Lotka-Volterra Model in
Figure 48

Obtaining data from a recently published *Newsbyte* article [122] produces the graph shown in Figure 48, the Lotka-Volterra model of US broadband wireline substituting for dialup products. As this model shows, in 2007 broadband wireline connections are expected to surpass the number of dialup connections in the US residential market. Interestingly, a Yankee Group report cited in the same *Newsbyte* article confirms this model.
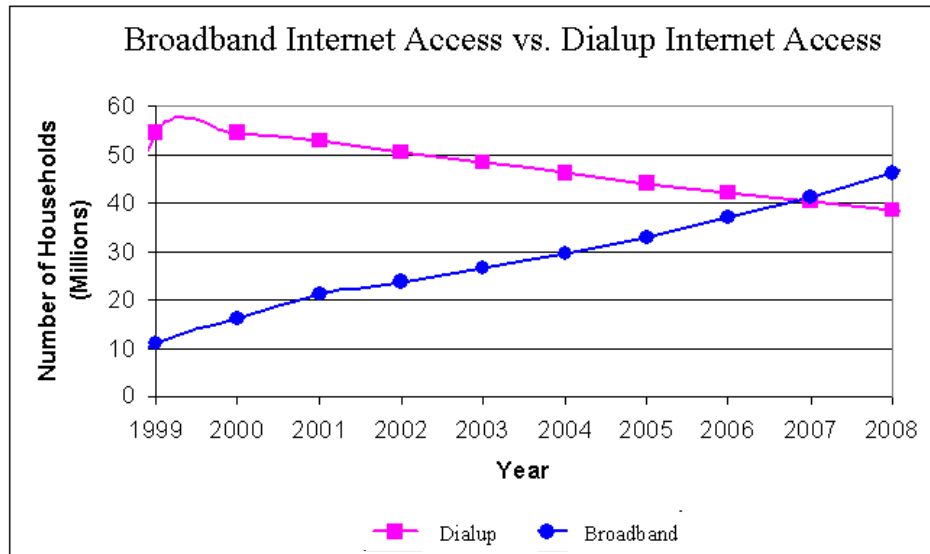
Figure 48. Lotka-Volterra Analysis of Wireline
Broadband Products Substituting for Wireline Dialup
Products [122]

Moving to the left on Figure 47, we now use the Lotka-Volterra model to predict the substitution effect broadband wireless may have on broadband wireline. Finding data for broadband wireless prior to 2001 has not been possible, so this model, shown in Figure 49, was created using data found for years 2001 – 2003. The broadband wireless technologies considered were satellite and fixed wireless, the two technologies currently being offered for residential Internet access.
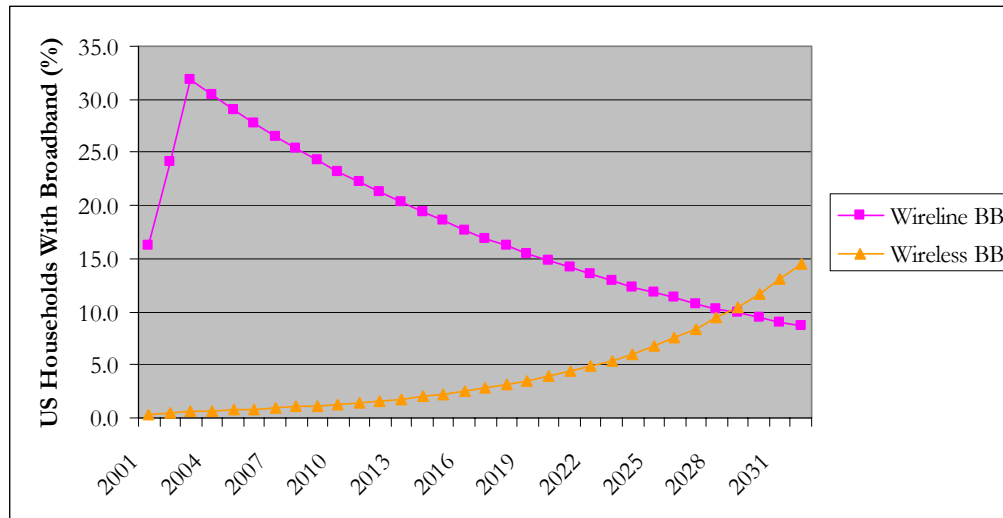
Figure 49. Lotka-Volterra Model Comparing Broadband
Wireless and a Substitute for Broadband Wireline
123,124,125,126

As the model shows, in the year 2031 wireless broadband for residential use equals the percentage of wireline. Moreover the two combined only have two-thirds of the total market share at that point. This model stands in stark contrast to a recent prediction by Verizon CEO Ivan Seidenberg who predicts that wireline broadband will penetrate 60 percent of Internet households within five years [127], suggesting that the model may be more complex and that the Lotka-Volterra framework alone is not enough to accurately predict this market.

4.1.7 Mobility Segment Model

Some performance metrics traditionally valued in data networks include data rate (speed), availability, and security. Broadband wireless data networks can be compared to traditional data networks along these lines, however, it also adds the ancillary feature of *connectivity without wires* for which there is no *traditional* metric that can be used as the basis of comparison. The new performance metrics associated with *connectivity without wires* include range and coverage.

98

Following Christensen's framework, one must seek out customers who could benefit from connectivity without wires enough to justify decreased performance in speed, availability, and security. To do this, the market is divided into three mobility segments – stationary, nomadic, and mobile – and the potential benefits of connectivity without wires is analyzed.

Stationary: These customers have no need to receive data when they are not at their computer. Example customers in this segment include a call center agent, an office worker, and a home PC user.

Nomadic: These customers move between "home base" and a number of typical or predictable locations, such as airports, restaurants, subsidiary business units, etc., and do not need to stay connected when moving between them. Example customers in this segment are a manager of a distributed team, claims adjuster, and students.

Mobile: These customers have unpredictable travel destinations and need to stay connected all the time. Example customers in this segment are field sales representatives, ambulance / emergency medical technicians, and field service technicians.

Mapping the need for ancillary performance in each of the three mobility segments: fixed, nomadic, and mobile produces the matrix shown in Figure 50. This matrix can help determine which broadband wireless technologies are most likely to be adopted by each segment and will be useful in making recommendations and conclusions later in this paper.

Technology	Fixed / Stationary	Nomadic	Mobile
Description of market segment	*Users stay put and has no need for mobility*	*Moves between "home base" and a number of "typical" locations like airports, subsidiary business locations, etc and doesn't need to stay connected between locations*	*People with very unpredictable travel schedules that need to stay connected all of the time.*
Examples	*Call center agent, office worker, home PC user*	*Manager of a distributed team, claims adjuster*	*Field sales or service representative*
Wireline (DSL or cable)	Meets	Sometimes	Infrequently
Fixed Wireless & Satellite	Meets or Exceeds	Sometimes	Infrequently
Bluetooth, HomeRF & UWB	Meets or Exceeds	Sometimes	Sometimes
WiFi	Exceeds	Meets	Sometimes
3G Mobile	Exceeds	Meets	Usually Meets
Mesh Networks	Exceeds	Exceeds	Usually Meets

Figure 50. Need for Ancillary Performance –
Communication Without Wires – Provided by
Broadband Wireless Type by Mobility Segment

4.1.8 Regulatory "Motability" Matrix

Christensen et al. believe that regulators operate without fundamental understandings of the effect regulations have in all situations [128]. The factors of motivation (market incentives) and ability (capability to obtain resources, craft them into a business model, and offer them to customers) are observed in environments where innovation flourishes. From this, they developed a 'motability' framework shown in Figure 51. They believe innovation can be heavily shaped by legislative and regulatory context.

They developed a motability matrix as a 2x2 matrix with ability on the x-axis and motivation on the y-axis. A 3-step process is used to:

1. Identify or define target market or technology.

2. Analyze players / understand current & likely business models.

3. Classify participants.

Figure 51. Motability Matrix for Classifying Regulation
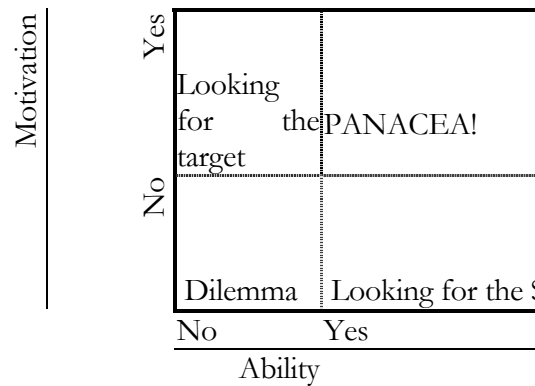
Policy tools that influence motivation:

- Rate regulation

- Regulatory asymmetry

- Network element pricing

- Tax treatment

Policy tools that influence ability:

- Resource-related regulation

- Unbundling

- Standards

The authors use the matrix to argue that although well intentioned, the Telecommunications Act of 1996 made the mistake of attempting to create both ability

and motivation – predicted by the authors to be an ineffective approach. Instead, they argue that by increasing motivation, often times ability will be stimulated.

Wireless broadband has so far proven to be more popular outside of the United States, particularly in South America and Europe [129]. Providers in the United States have gone through significant FCC and Congressional regulatory churn, similar to what we might expect from the Abernathy-Utterback model [130]. A group of Cornell economists even suggested that government regulations are stunting the growth of broadband [131]. Just in the past 18 months, there have been a variety of bills proposed meant to assist the broadband industry in different ways:

1. Broadband Regulatory Parity Act of 2002 – Designed to level the playing field between current DSL and cable-modem broadband suppliers. Many have argued that this amounts to a gift to the current telecom giants.

2. Tauzin-Dingell Internet Freedom and Broadband Bill – Designed to free the phone companies of equipment-sharing obligations as set forth in the 1996 Telecommunications Act.

3. National Broadband Strategy Act of 2002 – Designed to provide affordable broadband connections of 10 Mbps – 100 Mbps.

4. Jumpstart Broadband Act   – A bill requiring the FCC to allocate 255 MHz of contiguous spectrum for unlicensed use by wireless broadband devices.

In *The Policymaker's Dilemma*, Christensen et al also look at the residential broadband debate by using the matrix to map out the current playing field of the cable companies (CC), phone companies (PC), wireless/satellite (WS), and new entrants (NE). The completed matrix is shown in Figure 52 [132].

Figure 52. Motability Matrix for Broadband Industries

This study makes special note of some factors that affect the entire industry:

- The motivation of all players is diminished by the uncertainty surrounding the U.S. customer's willingness to pay upwards of $50/month for a high-speed connection.
- Cost and difficulty of deploying services, limiting motivation and ability.
- Limitations of today's technologies, lowering ability.

They do propose a number of generic policies that are sensible for the government to pursue that will successfully promote innovation:

- Increase ability by taking actions making it easier for companies to get right-of-way access and release more spectrum. This could create the *ability* for new lower-cost wireless broadband companies to emerge.
- Create artificial motivation where it is needed most, in rural areas where it is difficult to build economic business models.
- Increase motivation by allowing people access to content that can be shaped into a killer application requiring broadband technology.

Areas with low population density – less than 100 lines/square mile – are more cost effective to serve via broadband wireless technologies than wireline technologies such as DSL, and in cases where the line density is less than 5 lines/square mile wireless is the only

103

viable choice [133]. In an effort to develop universal service, regulators have incorporated a cross-subsidized pricing structure where long-distance rates subsidize local rates, business rates subsidize residential rates, and urban rates subsidize rural rates for basic telephone service. This tends to distort the natural market for innovation by reshaping market incentives. Regulators can free up scarce resources and take down barriers, or conversely, they can constrain scarce resources, and create barriers.

The authors of *The Policymaker's Dilemma* believe that 802.11 technologies fail the litmus test for being truly disruptive technologies because they are so dependent on or interact with the incumbents' value networks. However, they see wireless as a high potential market where disruption could originate, if government is able to "turn on" the innovation spigot.

4.2 System Dynamics Models

A system can be anything from a steam engine, to a bank account, to the broadband wireless marketplace. The objects and people in a system interact through "feedback" loops, where a change in one variable affects other variables over time, which in turn affects the original variable, and so on.

An example of this is money in a bank account. Money in the bank earns interest, which increases the size of the account. Now that the account is larger, it earns even more interest, which adds more money to the account. This goes on and on. Another example of a simple feedback loop that we have all experienced is adjusting the water tap to reach a desired temperature. You turn the faucet, feel the temperature, and compare it to the desired temperature. You continue to adjust the water, with smaller and smaller adjustments, until you reach the desired temperature [134].

What system dynamics models attempt to do is understand the basic structure of a system, and thus understand the behavior it can produce. Many of these systems and problems that are analyzed can be built as models and simulated on a computer. System dynamics tools take advantage of the fact that a computer model can be of much greater complexity

and carry out more simultaneous calculations than can the mental model of the human mind [134].

It is fitting that the system dynamics model is the final framework considered in this research, as it ties everything together. Using the data and results of other models as input to the system dynamics model, all of the important interactions within the broadband wireless space will be analyzed.

It should be clear to the reader at this point that there are many variables and constraints in the broadband wireless space. The technologies, standards, devices, and providers that ultimately survive must prove themselves to be valuable. This section uses system dynamics conceptually to explain the dependencies of this complex set of relationships.

The first step in building this system dynamics model involves defining some basic causal loops for the disruptive technology and its growth in the marketplace. The incumbent technologies are introduced into the model later. Figure 53 shows a simple reinforcing loop, taking into account the number of customers and the relationship to the number of providers and the associated convenience. This loop shows that as the number of providers increases, the availability of the service, and hence the convenience to the customer, increases. This results in the number of customers increasing, which in turn increases the size of the market.
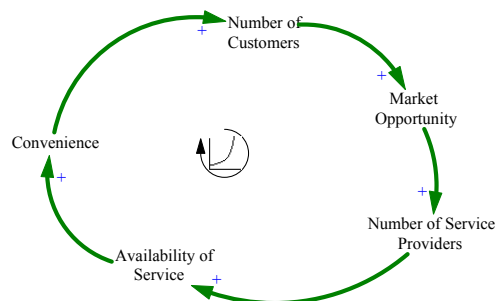
Figure 53. Reinforcing Loop showing growth of the Market

The next loop shown in Figure 54 essentially shows that enhancements to the product increase the ease of use. This is also a reinforcing loop.
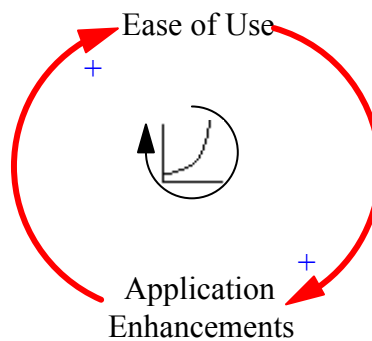
Figure 54. Increasing Ease of Use – Reinforcing Loop

Similarly, there can be other loops that show the growth in the number of customers for these technologies. Figure 55 is another example which shows that as the number of customers increase, there is more word of mouth advertising, which increases product awareness, which in turn increases the number of customers.
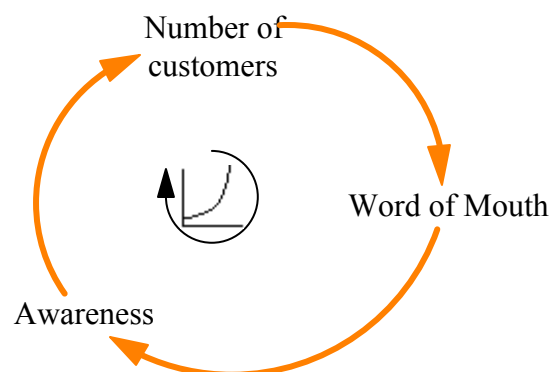
Figure 55. Reinforcing Loop Showing the Growth of Customers

Now these loops would lead us to believe that there would be an exponential growth in the number of providers for these incumbent technologies. However, there are business dynamics that ensure that this does not occur. Figure 56 shows one such balancing loop which represents that as competition increases, some providers find a way to differentiate themselves, thus leading to a reduction in the number of providers.
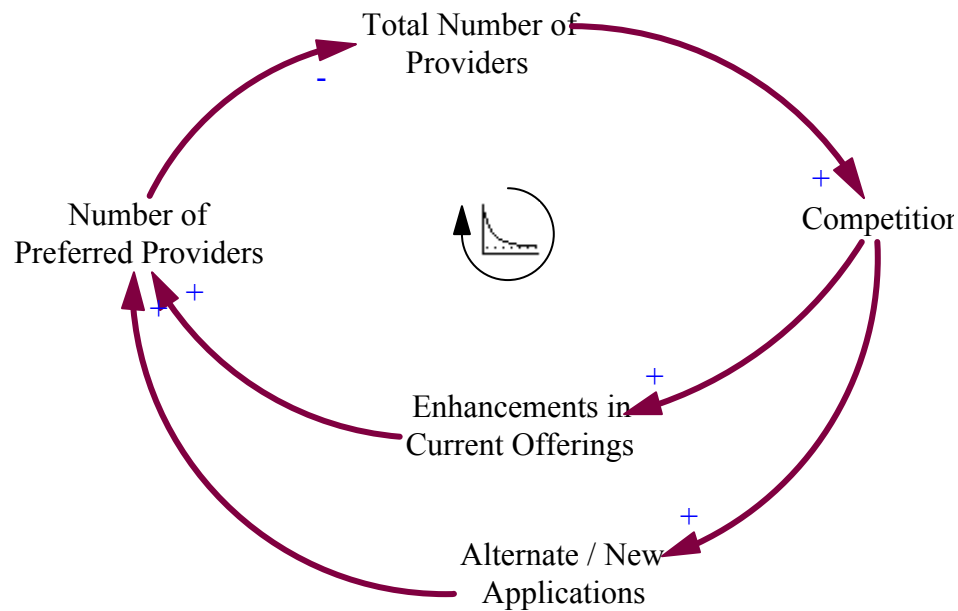
Figure 56. Balancing Loop Showing the Effect of
Competition on the Number of Providers

Combining these loops provides a better representation of the business dynamics influencing the marketplace with this insurgent technology. This is shown in Figure 57.
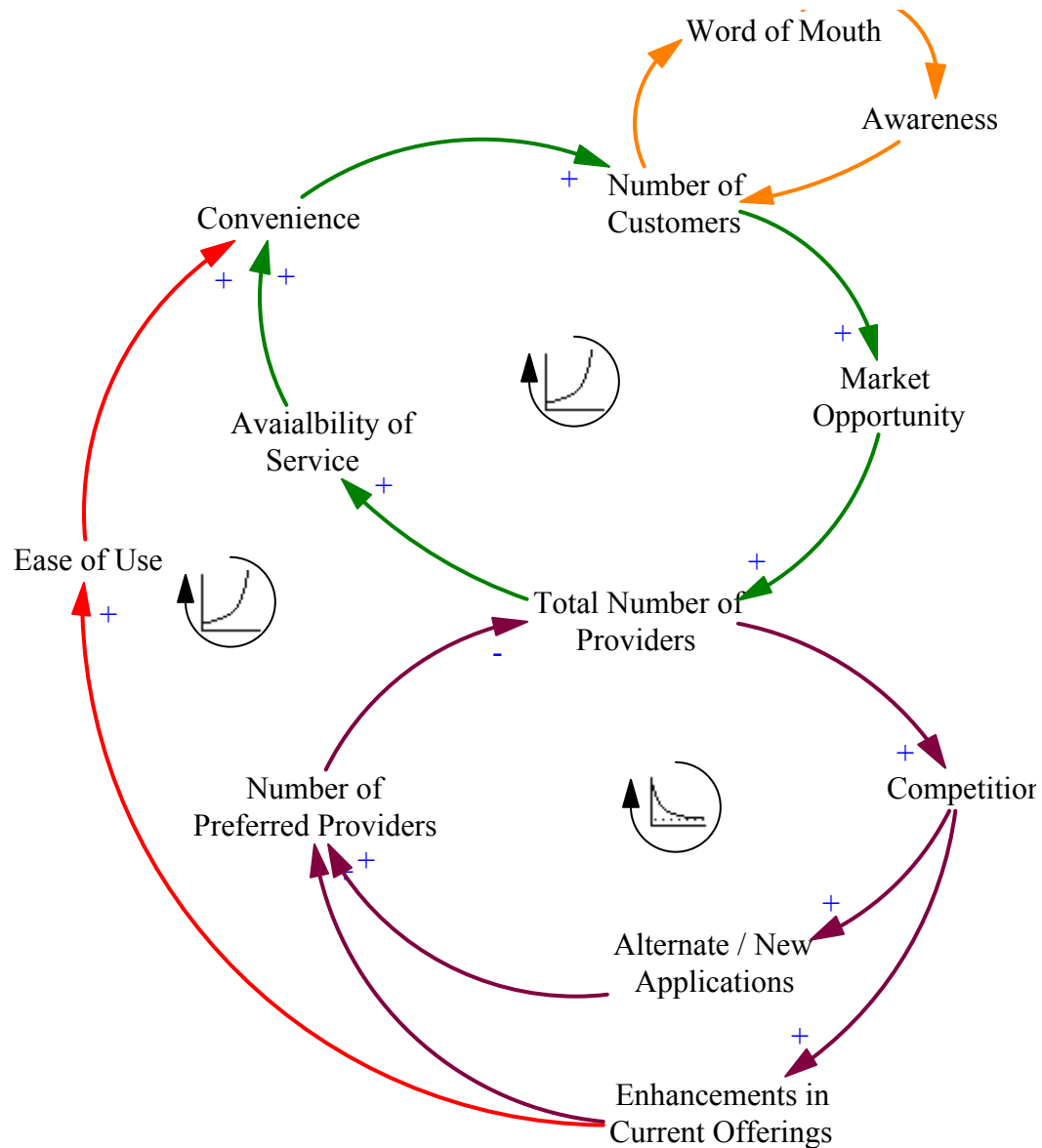
Figure 57. Feedback Loops Representing the Business
Dynamics of the Marketplace with the Insurgent
Technology of Wireless Broadband

The model so far assumes an infinite pool of customers with no other product alternative, which is not the case in the marketplace. There exist some very powerful and well-established incumbent technologies. Wireline broadband was an insurgent technology to dialup modems a couple of years ago. It ate into the dialup modem market share, and

increased its own percentage of the market. Now both these incumbent technologies are under attack by the next generation of wireless broadband, which offers superior product features. Figure 58 shows the increase in the number of dissatisfied customers with the incumbent technologies and the reinforcing loop behind the growth of wireless broadband.
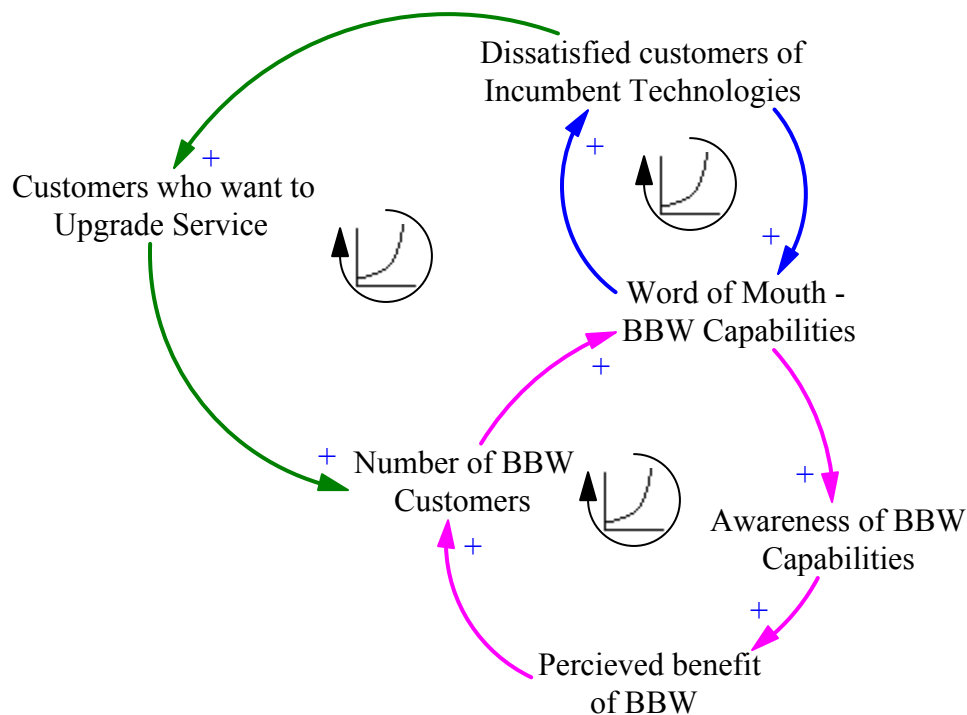
Figure 58. Reinforcing Loops Showing the Migration of
Customers from the Incumbent Technologies to the
Disruptive Technology (Broadband Wireless)

But the incumbent technologies fight back. Incentives and better features help balance the erosion of their customer base and reduce the number of dissatisfied customers who would consider leaving to the insurgent technology. Customers who want to upgrade their capabilities just because the enhanced features are available (and not because of a pressing need) are also categorized as dissatisfied customers for convenience. These balancing loops are shown in Figure 59.
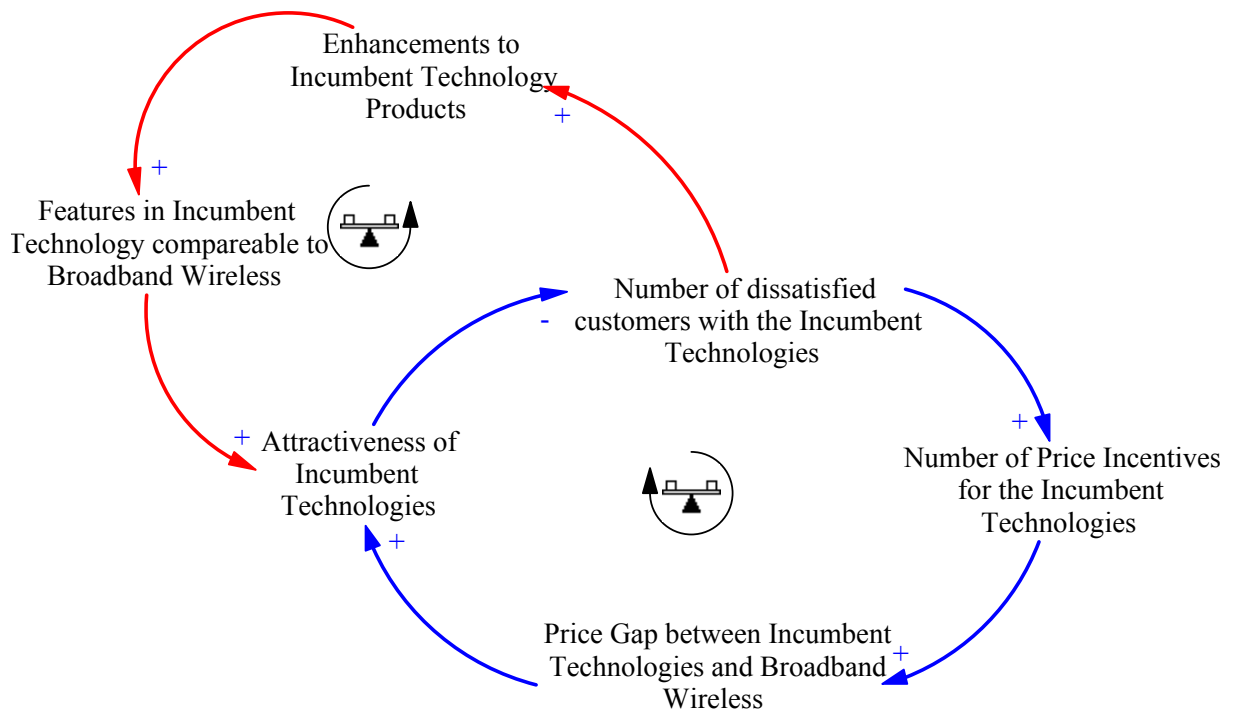
Figure 59. Balancing Loops that Stabilize the Number of
Dissatisfied Customers with the Incumbent
Technologies

Now combining all the loops, we get a better representation of the business dynamics of the marketplace as represented by feedback loops. This is shown in Figure 60.
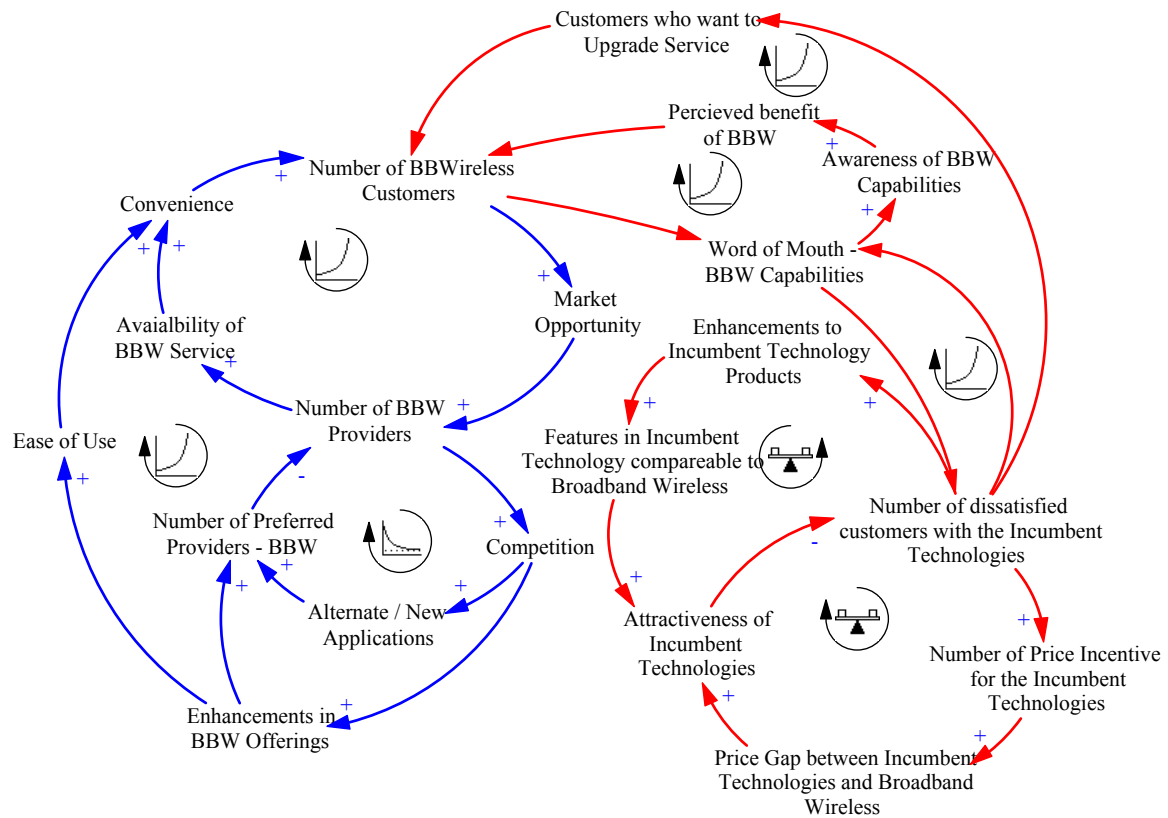
Figure 60. The Battleground. Causal loop
Representation of the Business Dynamics of the
Broadband Wireless / Broadband Wireline / Dialup
Modem Marketplace

Looking at possible predictions from these models yields pretty interesting results. Due to the dynamics described above, the model would predict a steady increase in the number of users for the broadband wireless systems. This growth becomes exponential for a while due to the convenience and word of mouth feedback loops. However, the balancing loops due to competition and the improvements in the incumbent technologies slow down the growth and eventually it stabilizes. This is captured in Figure 61.
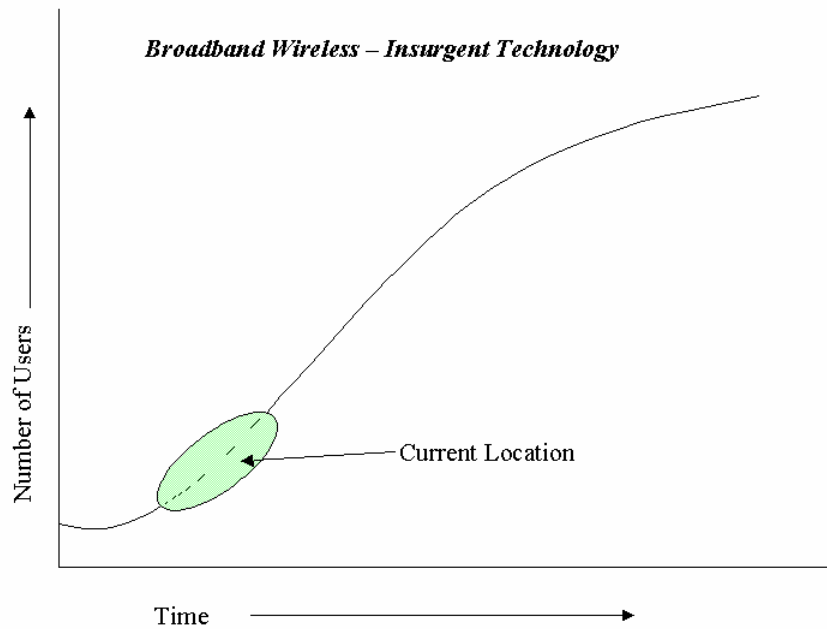
Figure 61. Growth in the Number of Broadband
Wireless Users Over Time

Looking at the comparable situation with the incumbent technologies, the number of subscribers continues the growth trend that they have been enjoying currently. This represents the growth in the overall market for these services, but due to the insurgent technologies, the growth slows down and stabilizes. The growth in the broadband wireless sector eventually starts eroding the market share of the wireline and dialup industries. This decline is then slowed down and eventually stopped by the "fight back" by these incumbent technologies. The market share finally stabilizes for these technologies as is shown in Figure 62.
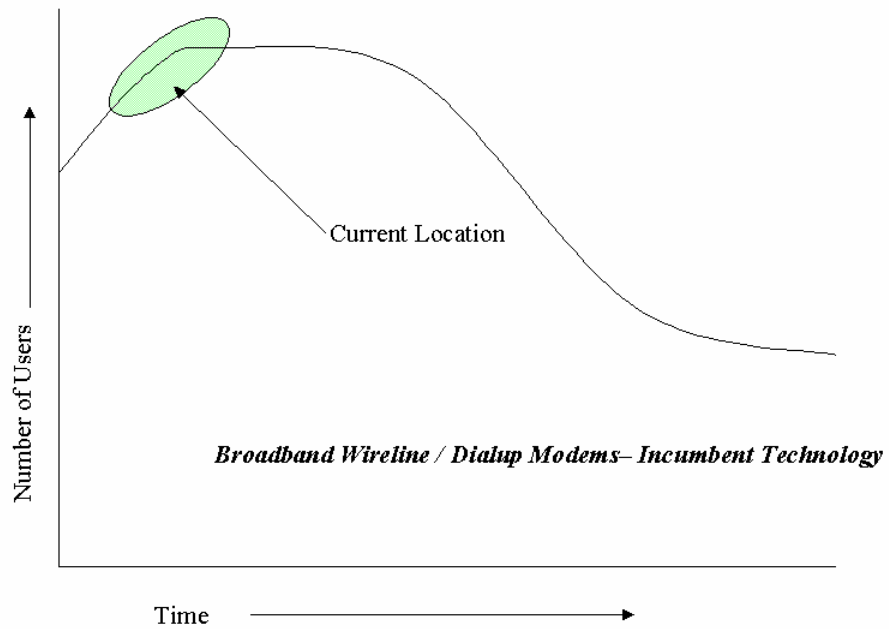
Figure 62. Change in the Number of Users of Wireline /
Dialup Over Time

Please note that these figures are not to scale and only represent trends. Interestingly, this is very similar to the trend that is predicted by the Lotka-Volterra model shown in Figure 48 where the wireless technologies surpass the wireline technologies in terms of number of users in 2007.

RECOMMENDATIONS AND CONCLUSIONS BASED ON MODELS

5.1 Incumbents Should Consider Subsidiary Organizations

One strategy supported by Christensen [135] and others is the need for threatened incumbents (i.e. prey) to respond to a truly disruptive innovation by "spinning off" or creating subsidiary organizations. These smaller, more nimble organizations are more readily capable of pursuing radical new ideas without feeling encumbered by the larger organization's politics and bureaucracy [136], and need for large returns to make a project feasible. This need for a large return is often seen in financial literature as reasoning why it is possible for mutual funds to become too large.

There are arguments as to whether the many technologies researched and discussed in this paper are truly disruptive. For example, Christensen et al.'s vision is that 802.11 technologies are not disruptive because they fail the litmus test of whether it can improve and march up or across market [137]. In this case, they argue that many wireless technologies are sustaining to the telecom incumbents because most require a wired infrastructure and can be co-opted by the incumbents.

To counter this assessment, consider that perhaps they were too narrow in their vision of the future of broadband wireless. Many areas outside of the United States and Western Europe do not have an up-to-date wired infrastructure in place on which to piggyback broadband data transfer as was mentioned earlier in the paper. Some areas such as South America and China do not have this wired infrastructure and have started to adopt broadband wireless solutions that do not depend on it. It must be more cost effective for them to adopt truly wireless solutions. This assumption was not researched in depth, however launching point for further analysis is provided later in this chapter. While near-term solutions in the U.S. may be classified as sustaining, long-term solutions may very well be disruptive – not relying on wired infrastructure and therefore disruptive to today's

incumbents. To effectively handle these disruptions, spin-offs may indeed be better situated to take advantage of the opportunities. Knowing when the fluid stage of innovation has peaked will be critical for incumbents so that they can more accurately assess when a spin-off is required and when the churn has subsided enough that the spin-off will be financially viable on its own.

5.2 Entrants Should Develop an Iterative Strategy: Conserve Resources

According to Christensen, *"Research has shown, in fact, that the vast majority of successful new business ventures abandoned their original business strategies when they began implementing their initial plans and learned what would and would not work in the market. The dominant difference between successful ventures and failed ones, generally, is not the astuteness of their original strategy. Guessing the right strategy at the outset isn't nearly as important to success as conserving enough resources (or having the relationships with trusting backers or investors) so that new business initiatives get a second or third stab at getting it right. Those that run out of resources or credibility before they can iterate toward a viable strategy are the ones that fail. [138]"* Applying this framework thinking to existing wireless broadband technologies results in Figure 63.
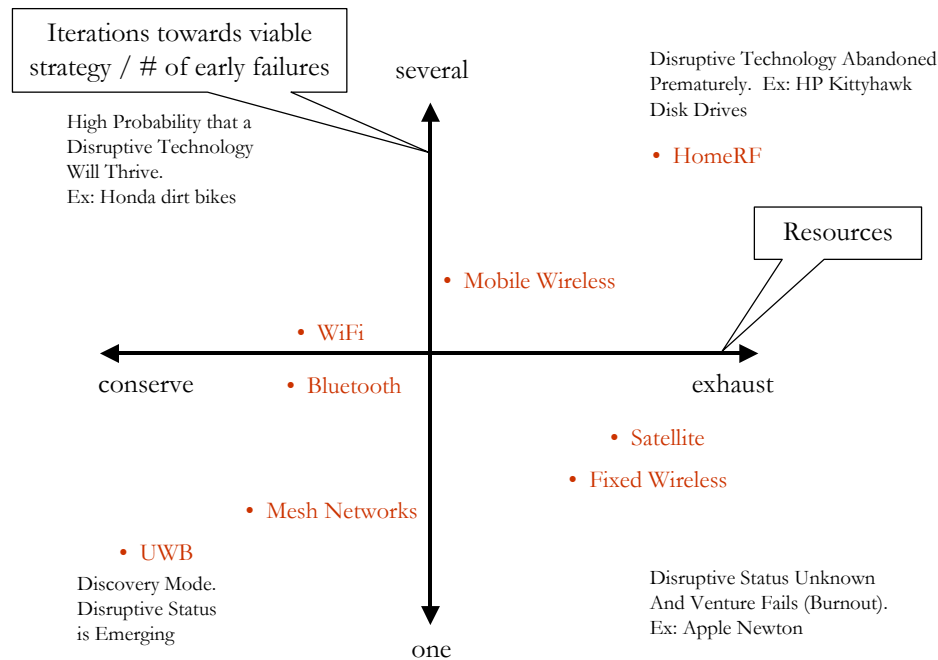
Figure 63. Relationship Between Strategy Iterations and Resources

Just as it will be vital for incumbents to know *when* it is necessary to spin-off a smaller subsidiary, it will be very important that they know *what* to spin-off. Technological churn is something that Utterback describes happening in the fluid phase of innovation, which is the phase that best describes the current state of broadband wireless [139]. The many competing standards and technologies for different market needs points to a state of flux in wireless broadband. In order to survive and not waste limited resources, it would be wise for companies not to base their entire survival on the acceptance of one particular technology. While significant investment and bets can be placed on one technology, research should continue in other areas with money held back in case the currently chosen technology does not pan out as the eventual dominant design. As the adage says in gambling, "only bet with what you can afford to lose."

This is even truer in the high stakes wireless broadband arena. Some companies are making significant investments in one area, such as what Intel has done with the recent introduction on their Centrino microprocessors with 802.11b capabilities imbedded. However, the solvency of Intel does not rest solely on the acceptance of the Centrino chips. Likewise, it is important for current telecom incumbents such as BellSouth, Sprint, Verizon, Worldcom, etc., to continue with forays into many different areas of broadband, both wired and wireless. If they can stay in touch with many different approaches, they should be better positioned to move more quickly into the market with products that the public wants once a clear "winner" is identified. If they do not have offerings with the technology that eventually emerges as the public's choice, they could be placed in the unenviable position of playing catch-up to other incumbents who did, as well as the new entrants that chose correctly.

Diversification of resources is a wise choice for incumbents. Research and advanced development needs to continue even in poor economic times. Unfortunately, often during tough economic times, this advanced research is cut and the flow of new products is slowed considerably. This has been done many times in many industries. Buying your way in, once a dominant design is identified *may* be possible, but as Utterback points out, the late entrants may never catch up.

5.3 Beware of Making Large Investments in Existing Technology

It is very tempting and even logical for incumbent players to attempt to capitalize on their existing investments in infrastructure, people, and knowledge to try to push their technology further. This is precisely what sets up the dilemma Christensen discusses so thoroughly in his book. The problem with this logic is that is doesn't lead to long-term competitiveness against a *disruptive* technology. For example, in the harvested ice industry, major investments were made in better ice cutting technology and techniques – none of which were needed when mechanical ice-maker technology was introduced [140].

Similarly, the advent of the Personal Computer made all the investment in coming up with a better typewriter or word processor a waste over the long term. If broadband wireless were truly a disruptive force in the marketplace, it would be dangerous for the incumbents to put all their eggs in one basket and invest heavily in existing technologies like DSL and fiber due to the risk of not receiving a good return on their investment. The key for the incumbents is to make sufficient investment in the process arena so as to provide better value to the end user while keeping an eye on the disruptive technology and its progress. This will ensure sufficient inflow of revenue through sales of the incumbent technology while allowing strategic investment in the area of the disruptive technology so as to be in a good position when the market starts to turn. This will also be a winning strategy in the most likely scenario for the medium term when wireline and wireless broadband services would have a symbiotic relationship by ensuring that the player would have a presence in both key service areas. This scenario is most likely in major population concentrations due to the inherent advantage provided to use existing infrastructure for the wireline services to provide a relatively inexpensive solution to the customer with the wireless services piggybacking on to this market to provide the added flexibility and features that the consumer demands.

5.4 Rural Market Opportunities

As mentioned previously and following from the previous examples, if Acee, Christensen and others are correct then one idea for a new entrant to get started in the wireless broadband industry is in rural areas. Typically, costs for wired broadband providers are lowest in highly populated areas. This has given rise to wireless voice providers such as Sprint PCS to cover approximately 250 million people in the United States with their system - leaving a full 50 million people on the "outside looking in." This may prove to be a real opportunity for an upstart to begin providing simple wireless access in remote locations, where infrastructure also tends to be poorest. Some analysts feel that simple connectivity and communication services attract more current spending than 'glamorous' content such as the entertainment, news, and shopping information that the current providers are currently using to try to pull their customers up-market. A 'simple' wireless solution in an outlying area would gain the benefit of being the first entrant in the area,

learning the needs of the area, gaining the trust of the local customers, and working out the initial troubles inherent in a new technology. Incremental or sustaining innovation would potentially drive the technology into the current mainstream market as Christensen suggests. Having a proven product in the market with satisfied customers (even if they are out of the mainstream) also helps integrate the technology into the urban marketplace more easily where even a small misstep or less than desirable performance trait could drastically reduce the chance for success.

5.5 Summary of What the Models are Saying. What do they have in Common?

5.5.1 Christensen's Performance versus Market Demand Model

The customer analysis in Chapter 1 clearly shows that the needs of business customers outpace those of consumers. This is illustrated using a slight modification to Christensen's framework shown in Figure 64. Businesses need more performance and are willing to pay for it more readily than consumers.
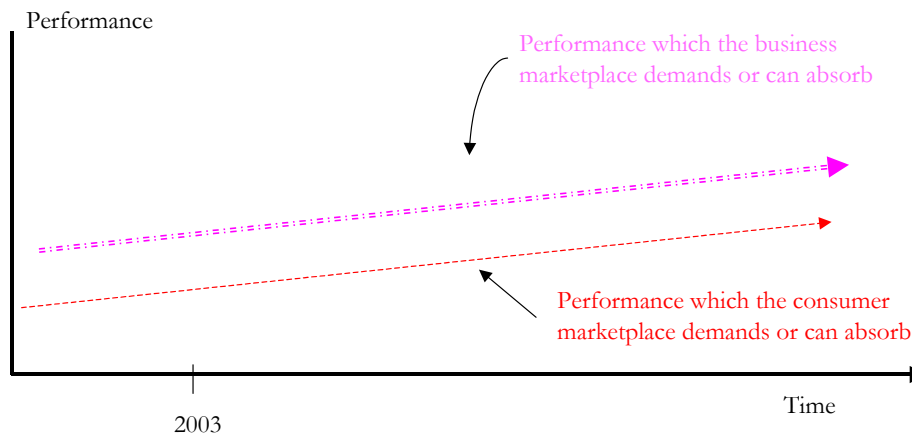
Figure 64. Performance Demands of Businesses and
Consumers

As stated in Chapter 2, the performance traditional criteria for broadband wireless are coverage, price, range, speed, and security. Mapping these five performance criteria to the framework in Figure 64 yields the curves and summary shown in Figure 65.

119
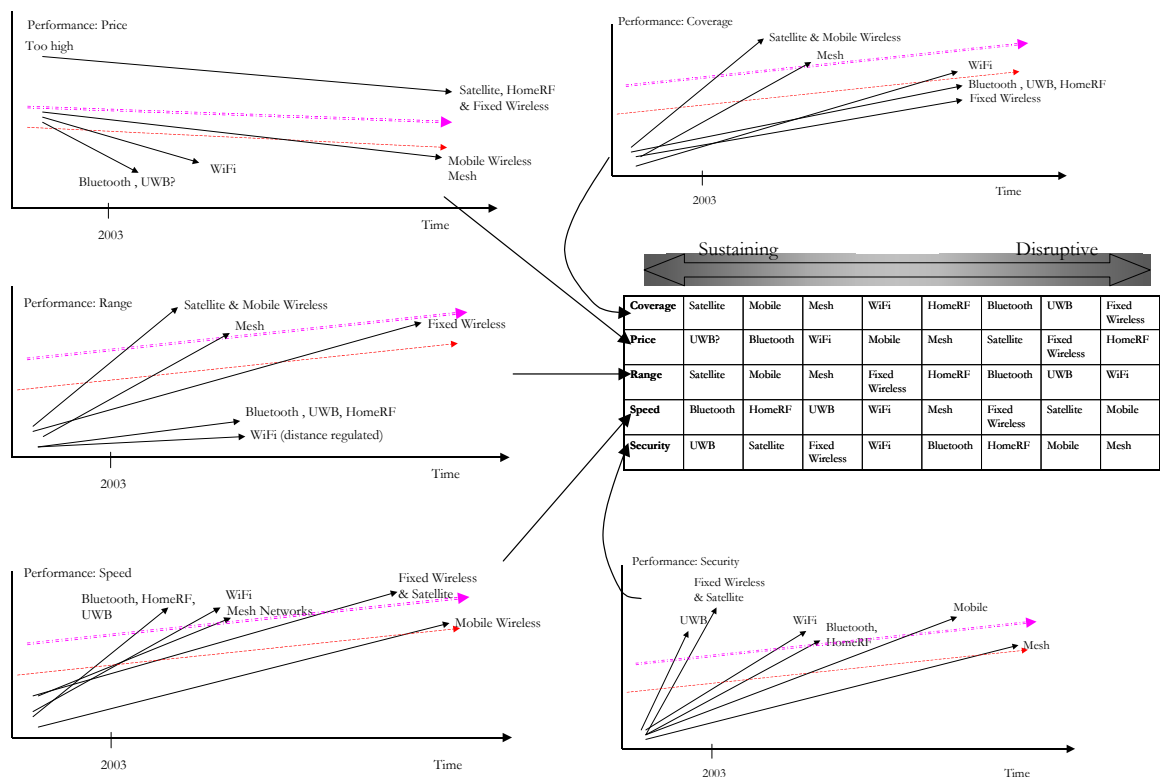
Figure 65. Performance of the Eight Broadband Wireless
Technologies in Each of the Five Performance
Dimensions, and a Summary of their Disruptive
Potential as Defined By Christensen's Framework

According to Christensen, these curves can help assess the disruptive potential of a technology. This potential is also summarized in Figure 65, which begs the question: **Which performance dimension (or dimensions) matter the most in the long term?** Clearly the answer to this question is imperative if one is to use these models to determine the technology most likely to be adopted because no single technology appears to be disruptive in all categories. For example, if a firm believes that the **coverage** provided by satellite and mobile technologies is currently overshooting the coverage demanded by the market, then coverage of fixed wireless technologies, over time, will disrupt. **If all five performance criteria are thought to be about equal in long-term importance, then**

this model suggests fixed wireless technology is the most probable to disrupt -- otherwise it is hard to tell.

5.5.2 Sustaining versus Disruptive Innovations

Recall previous discussion about the differences between sustaining and disruptive technologies from which a framework was created for evaluating technologies based upon these criteria. Here we will apply this framework, also taken from Christensen's book [141], to the broadband wireless technologies under consideration in this thesis to determine where each might be classified.

In Figure 66, each broadband wireless technology is classified by the degree to which it fits Christensen's criteria for being a sustaining technology. By this analysis, **fixed wireless, mobile wireless, and satellite technologies** appear to be the most likely to be classified as sustaining.

	Sustaining Technology	Bluetooth	Fixed Wireless	HomeRF	Mobile Wireless	Mesh Networks	Satellite	Ultra Wide Band	WiFi
Technology qualities	Incremental improvements		✓		✓		✓		✓
Market	Predictable - can be modeled and forecast			✓	✓		✓		
Information	Quantified, accurate estimates		✓		✓		✓		
Sr. management perception	Business as usual		✓		✓		✓	✓	✓
Customer needs	Addresses important customer needs		✓		✓	✓	✓	✓	
Profit	Positive impact				✓				
Management Tendencies	"Wait until market is large enough to be interesting"						✓	✓	
Dependencies	High dependence on existing resources, supply chains, & products		✓		✓			✓	✓
Value network	"Fits" within existing	✓		✓	✓				
Application and uses	Completely identified		✓	✓			✓		

Figure 66. Degree to Which each Technology Seems to
Support Sustaining Characteristics

Figure 67 shows the broadband wireless technologies most likely to be disruptive in nature, which appear to be **Bluetooth, Mesh, and WiFi**.

	Disruptive Technology	Bluetooth	Fixed Wireless	HomeRF	Mobile Wireless	Mesh Networks	Satellite	Ultra Wide Band	WiFi
Technology qualities	Simpler, more reliable, more convenient	✓		✓		✓		✓	
Market	Unknown & orders of magnitude larger than "expected"	✓				✓			✓
Information	Pure speculation - none exists			✓					✓
Sr. management perception	Distraction from business as usual	✓		✓		✓			
Customer needs	Niche needs at best	✓		✓					✓
Profit	Negative Impact		✓						✓
Management Tendencies	Entrepreneurial	✓		✓		✓			✓
Dependencies	None or very few dependencies	✓		✓			✓		
Value network	Totally different and usually not obvious or apparent					✓		✓	✓
Application and uses	Not apparent or foreseen	✓			✓	✓		✓	✓

Figure 67. Degree to Which each Technology Seems to
Support Disruptive Characteristics

Two different frameworks taken from the same author in the same book, give different and even contradicting results! So what might be useful is to find consistencies *between* these two frameworks to help guide a strategy. For example, both models show that WiFi and Mesh technologies are showing signs of becoming disruptive.

5.5.3 Modes of Competition and Mobility Segments

Intersecting the *modes of competition* and *mobility segments* in the broadband wireless space produces Figure 68, which was first presented in back in Chapter 4. This figure shows that the technologies under investigation are not all competing with each other. Rather, each one possesses performance characteristics making it most suitable for users in a particular market segment, as shown in Table 12. From this perspective one can surmise that the technologies within each segment are competing to become part of the dominant design for use within that segment.

A	B	Symbiosis B→A= + A→B= +	Predator (A) Prey (B) B→A= + A→B= -	Predator (B) – Prey (A) B→A= - A→B= +	Pure Competition B→A= - A→B= -
Wireless Technology	Wireline Technology	WiFi router plus DSL line	Satellite replacing dialup in rural areas	Highly sensitive business system; very large data volumes	Cell phone substituting for POTS line
Short Range Wireless	Cables, cords, etc.	N/A	Bluetooth, HomeRF, Ultra Wide Band	N/A	N/A
Stationary, Long Range Wireless	Dialup	Fixed wireless or Satellite with dialup backup option	Satellite replacing dialup in rural areas	Poor wireless QoS and no other alternative	Equal wireless QoS and no other alternative
	DSL, Fiber, COAX	Base stations require large wireline backbone connection	Poor wireline QoS and comparable pricing	Poor wireless QoS and wireline services available	Equal QoS, little price difference, and all available
Nomadic, Medium Range Wireless	Station Wiring	N/A	WiFi router installed in new construction	N/A	Wireless is not an option due to corporate policy or interference issues
Mobile, Ubiquitous Wireless	Dialup	Packages that offer free dialup as backup	3G wireless PC cards	Poor 3G QoS or 3G too expensive	N/A
	DSL, Fiber, COAX	Base stations require large wireline backbone connection	Truly mobile users who rarely dock to a landline	Poor 3G QoS or 3G too expensive	N/A
	WiFi	Forthcoming chipsets like Intel's Centrino	N/A	Nomadic users that have enough access to hot spots	Vertically integrated wireless applications and platforms

Figure 68. Modes of Competition in the Broadband
Wireless Space

Short Range	Stationary, Long Range	Nomadic, Medium Range	Ubiquitous, long range wireless
•Bluetooth •HomeRF (lost) •Ultra Wide Band (emerging) •WiFi	•Fixed Wireless •Satellite •WiFi (emerging)	•WiFi	•Mesh •Mobile •WiFi (emerging)

Table 12. Classification of Competing Technologies by
Mobility Segment

Using Utterback's framework to further analyze the modes of competition between the technologies yields the examples found in Table 13.

Competition Mode	Symbiosis	Predator – Prey	Pure Competition
Relevant Examples	WiFi + Wireline WiFi + 3G WiFi + McDonalds WiFi + Starbucks WiFi + Chip Makers WiFi + Airline Travel WiFi + Hotels Mesh + Mobile (Devices)	Ultra Wide Band → Bluetooth WiFi → All	Fixed Wireless Vs. Satellite Vs. DSL & COAX For the "last mile"

Table 13. Example Modes of Competition

Clearly, WiFi is attempting to become the dominant transmission delivery mechanism for every market segment and is doing so primarily by symbiosis. WiFi boosts the demand for wireline hot-spot connections and attracts customers to restaurants, hotels, and airliners (forthcoming) that provide access. **This analysis concludes that WiFi is showing strong signs of becoming the dominant design for broadband wireless transmission technology.**

5.5.4 Lotka-Volterra Models

The *pure competition* column in Table 13 was also analyzed in Chapter 4. The Lotka-Volterra analysis showed that the number of broadband wireless subscribers would equal the number of broadband wireline subscribers in 2031. Given the existing distance limitations and regulations, only satellite and fixed wireless technologies can be used as the basis for comparison because historical data is required for this modeling technique.

If companies' historic commitments to, and marketplace adoption propensity of new broadband technology is any indication of time frames required, then looking at recent

examples could prove useful. DSL technology was invented in 1988, 15 years ago. By 1998 most RBOCs had acknowledged the market and made commitments to the technology (10 years later), and in 2002 there were almost 18 million DSL subscribers in the US [142]. The 802.11b WiFi standard was released in 1997, and by late 2002, 18 million people had used it (5 years later) [143]. Assuming similar timelines and increasing clock-speeds and adoption rates for the existing broadband wireless technologies means that a commitment from the large firms in 2002 will produce millions of subscribers by 2007, 24 years earlier than 2031. If the Lotka-Volterra model in Figure 49 *is* correct, it is telling us that **fixed wireless and satellite technologies will probably not become widespread** because 24 years is almost five times longer than the historical example of DSL, and surely one of the other technologies will take its place.

5.5.5 Motability Framework

The motability framework lumps all wireless technologies together into the "looking for the target" classification, meaning the motivation is there to pursue the technology but the money is not. This tells us that the government could change the playing field by injecting money into wireless technologies or by providing financial incentives to the players in the wireless space. Since neither of these appears likely to happen at the magnitude required to effect a change, the technology with the least cost risk may weigh more heavily to the providers than other performance criteria such as speed, range, etc. **This framework thus seems to support WiFi and Bluetooth.**

The commonality within all of the models is that all of the technologies are pushing in the same direction but that the ones that can reduce the cost and increase the bandwidth the quickest will be the survivors. Figure 69 depicts the relative cost and bandwidth of the different broadband wireless technologies, with the arrows indicating the general direction and speed with which the technology is progressing. The question for mobile wireless is whether the chasm separating it from WiFi is too large to cross quickly enough in order for it to compete. Its only hope might be forthcoming chipsets promising to support both 3G and WiFi networks.
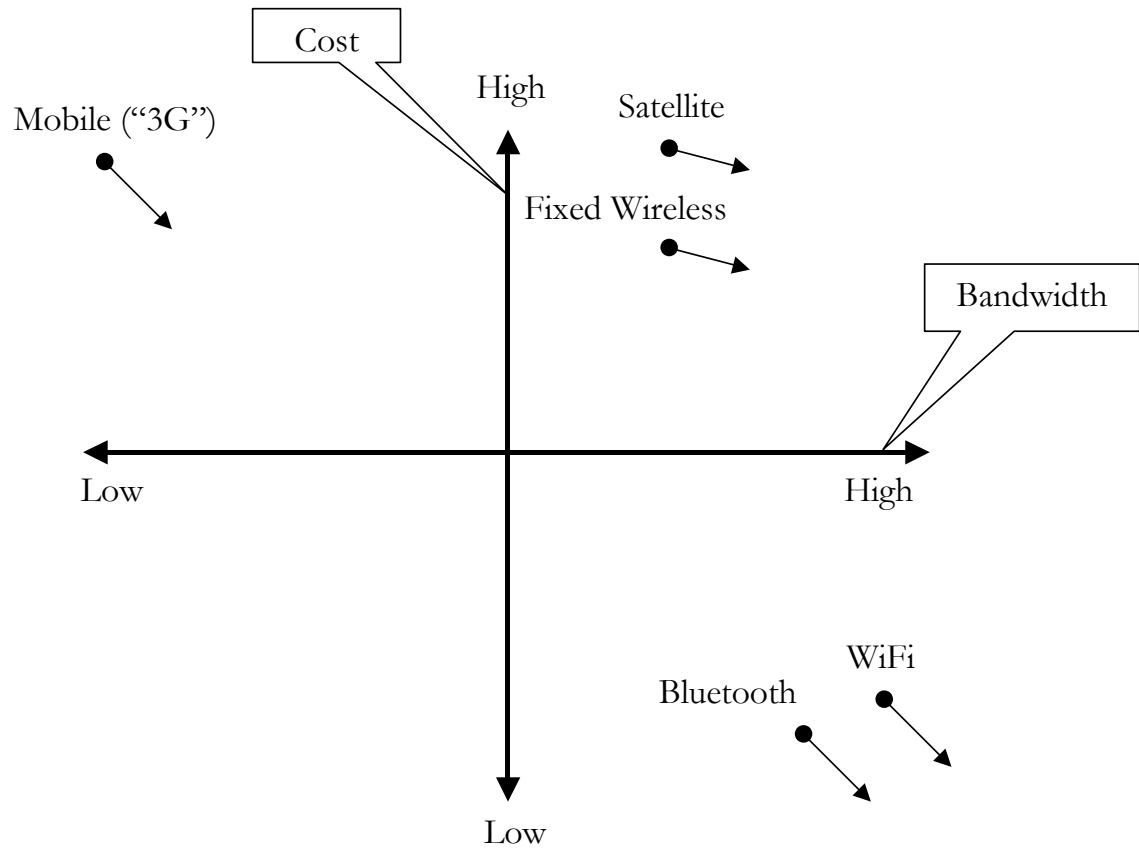
Figure 69. Relative Cost versus Bandwidth and
Direction of Improvements

Table 14 summarizes the different models considered in this thesis and the resulting technology that seems to be supported or challenged by each model. The reader will quickly notice that WiFi dominates the list, suggesting that it will emerge as the dominant transmission standard in the broadband wireless arena. As the range of WiFi increases with emerging standards such as 802.16, one can surmise that every device will be enabled with a WiFi chip and the proliferation of innovation will quickly switch from product to process-oriented as the providers scramble to address issues of IP address mobility, billing, and interoperability.

Model	Supports	Challenges
Performance v. Market Demand	Fixed Wireless	*Not apparent*
Sustaining v. Disruption	Bluetooth Mesh WiFi	Fixed Wireless Mobile Satellite
Modes of Competition	WiFi	All others
Mobility Segments	WiFi	All others
Lotka-Volterra	*Not apparent*	Fixed Wireless Satellite
Motibility Segments	Bluetooth WiFi	*Not apparent*
Value Network / Signaling	Symbiosis between the four technology categories: 4 dominant designs emerging	A single dominant design that serves all segments completely

Table 14. Summary of Which Technologies each Model
Supports or Challenges

5.6 Which Models Should We Believe and Why?

"All models are wrong, but some are useful." This is George Box's statement that allows us to answer the question about which models to believe by saying, "it depends." The Utterback-Abernathy product-process evolution framework is very useful for analyzing the broadband wireless market because its description of the emergence of a dominant design seems to be exactly what is happening in this space: a plethora different players, standards, and technologies vying for acceptance in the marketplace. This describes the existing atmosphere and provides direction to those firms interested. Once the dominant design, or any architectural piece of it begins to emerge, the market may swiftly usher the others out.

Christensen's models are only useful for analyzing disruptive technologies using his somewhat narrowly defined definition of *disruptive*. If the reader thinks broadband wireless fits within Christensen's disruptive framework, i.e. products that evolve starting with the need for more performance in a dimension valued only by niche users followed by moving up-market and attacking incumbent players, then his models should be updated frequently and examined closely, since they do not yield consistent results today.

Intersecting Utterback's modes of competition and mobility market segments allows us to quickly see that each broadband wireless technology competes with the others based primarily upon the *range* dimension. This may be an obvious conclusion to some even without the models, lending credibility to them.

Taken from the study of population dynamics, Lotka-Volterra provide a method to analyze the case of pure competition, where one technology substitutes for another. Given some historic data about the growth rate of the predator and the prey and making some assumptions about the context of the market, this model can be useful in predicting if and when one technology will overtake another. Since the technologies are so new and not deployed extensively, it is difficult to find historic data about broadband wireless adoption rates. It is hard enough to predict markets a few years out, let alone 30 years, so the results provided by this model are limited.

Regulation, or lack thereof, plays a vital role in the emergence of broadband wireless technologies. The motability matrix is a useful framework for classifying policy and can be used as the basis for assessing the results of policy decisions at a high level.

5.7 Wireless versus Wireline: Decision Making Process

Deployment and adoption of broadband wireless is also dependent upon the availability and cost of wireline infrastructure. Availability has two dimensions: the wireline infrastructure itself, and the length of time required to acquire new services utilizing the infrastructure, which is generally referred to as the *provisioning cycle time*. The availability of infrastructure might depend on the location and/or the country. The effect that wireline (existing) has on wireless (emerging) was not in the scope of this thesis, however there

128

must be causal relationship that would play into a decision whether to use wireless instead of wireline technologies. This assumption could help explain the slow adoption of broadband wireless in the US because there is an abundance of wireline infrastructure in place, and only 15 percent of the fiber in the ground is "lit," meaning 85 percent is in place and not being used [144].
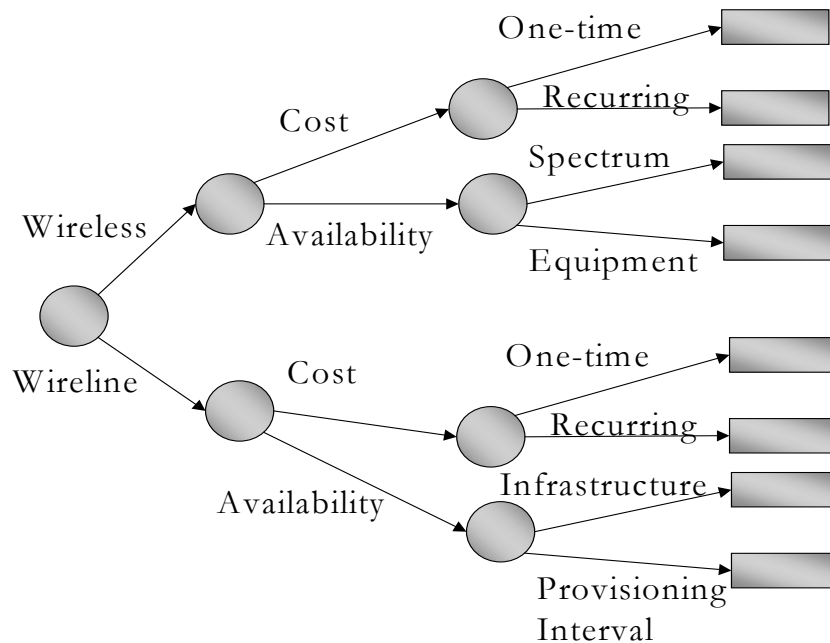
Figure 70. Sample Decision Tree for Analyzing the
Deployment of Broadband Wireline versus Wireless

A simplified decision tree is shown in Figure 70, illustrating the point that wireline infrastructure plays into the decision making process. An interesting extension of this thesis would be to explore this decision in more detail.

5.8 Response Framework

Given the specific results stemming from the application of these models, the next step is to formulate a response or strategy. If the reader doesn't agree with the results, he needs only to change the assumptions and reexamine the models before proceeding with a

strategy. It is also important to note that sustaining technologies should not be ignored. Most new technologies *are* sustaining in nature and provide value to customers and profits to firms. What is important for firms to understand is that given a particular classification, it is critical that they respond appropriately in the way they organize, strategize, and manage the technology. Moreover firms who continue to invest in sustaining technologies should pay careful attention to disruptive technologies becoming predators in the future and rendering their products obsolete. Table 15 provides a framework for formulating a response to a sustaining technology versus a disruptive one and comes from both Christensen's <u>Inventor's Dilemma</u>, and Utterback's <u>Mastering the Dynamics of Innovation</u>.

Response to Sustaining Technology	↔	Response to Disruptive Technology
Listen to customers	Interaction	Watch customers and observe customers using products
Disciplined managers	Leadership style required	Entrepreneurial leaders
Execute a well planned strategy	Strategy and planning	Learning and discovering via fluid strategy
Actions follow plans	Strategy and planning	Plans follow actions
Listen to their customers	Marketing	Discover market opportunities
Budgets: revenues and costs known	Investment	Venture / unknown
Not a significant indicator of future performance or competitiveness	First mover advantage	Significant advantage if technology is successful
Viewed as career enhancing opportunities	Employees	Viewed as risky; must be gratified by small successes
Clearly defined measurements along valued dimensions	Product metrics	Totally different; must be normalized to compare to existing
Sustain existing market share and try to move upmarket	Market strategy	Grab small, sub-markets first; move up -market and attack
Management by objective	Leadership processes	Learning organization
Hierarchical - command and control	Organizational style	Separate business unit with different objectives
Interview industry experts, trend analysis, economic modeling	Forecasting methods	No traditional (for sustaining) methods work at all

Table 15. Framework for Formulating a Response to
Sustaining versus Disruptive Technology

To illustrate the application of this generic framework it will be applied it to the findings. The output of over half of the models and frameworks used in our research suggests WiFi

is emerging in disruptive and symbiotic ways. According to the framework in Table 15, if a firm believes this result is correct (or even possibly correct), they should setup a separate subsidiary organization for WiFi and hire an entrepreneurial management team to run it. Employees within the incumbent firm who are reluctant to leave and join the subsidiary company should not be forced or convinced because they are probably not going to be successful. The new organization should be given a reasonable budget and be given latitude to develop their own strategy and performance metrics, ensuring resources are conserved for future iterations. Their initial strategy should be viewed as a starting point for attracting small sub-markets of customers who could most benefit from the strengths and ancillary performance metrics provided by WiFi. Their overarching goals should be to remain flexible to product changes, amenable to short-term dynamic strategies, and to be sure that each small victory ultimately leads to perfect timing when the mainstream market accepts WiFi.

Firms competing with WiFi and those who view it to be a sustaining technology should watch WiFi closely and be ready to change. Research has shown that once a technology moves up-market to the point where the early majority is adopting it, it is nearly impossible for the incumbent firms who ignored the technology to catch up [113].

When I began this research nearly one year ago, I knew virtually nothing about wireless technologies or markets. My initial intent was to deliver a thesis about fixed wireless products because they appeared to be the most promising. Once I started researching and learning more about wireless products in general, I found plenty of material already written about fixed wireless – and every other wireless – technology. I quickly learned that there were an enormous amount of analyses, research studies, data, and opinions about wireless technology already available.

What I could not find was a document that focused *less* on making specific conclusions about specific technologies, and *more* on how to analyze the technologies and how to build strategies for them. I wanted to create a roadmap that wireless companies could use to assess wireless technologies holistically.

I was very surprised by the results. Now that I've completed this thesis, it is clear to me that WiFi technologies have the most potential – not fixed wireless or 3G mobile as I initially believed. It is also clear that one can change the underlying assumptions made here within, and come up with very different conclusions. Therefore, companies need to be very skeptical about what they are told, and take the time to understand the underlying assumptions and methodologies that support recommendations.

Ultra Wide Band technologies are also showing promise, another surprising result. While I did not formulate a strategy for UWB, this doesn't mean companies should not be seriously looking at it – they should.

Given these results, I firmly believe companies should embrace WiFi and UWB by creating subsidiary organizations and following the framework presented in Table 15. Section 5.8 provides other guidelines for this organization – they must respond with adaptive, not purely technical, solutions. This is a complex, dynamic space in which to formulate a strategy, and parent organizations tend to stifle the creativity that is needed for long-term success.

Some important questions that I now have, specifically about WiFi, have to do with the inconsistencies and extremes we're currently seeing. Rural markets are one of the best opportunities for wireless and WiFi is the most promising technology, yet it is only capable broadcasting 300 feet. How can this inconsistency be overcome? Today, there are free, non-profit, and for-profit WiFi hot spots. How can telecommunication companies make money on WiFi given these extremes? Under which scenarios would the competitors bail out? How would spectrum openings impact the cost and adoption strategy of WiFi? Which part of the value chain is most likely to make money on WiFi and should telecommunication companies consider partnerships to improve probability of profitability?

If there is one overarching theme I have learned at MIT, especially through this research, it is *how* to think not *what* to think. Many of the underlying issues facing the broadband wireless industry are not new. Successful wireless companies will combine historical information about a wide variety of industries with current needs for value and profit into frameworks that assist them in how to adopt and deploy new wireless technologies.

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