August
2008

# The ibit Report

A PUBLICATION OF THE INSTITUTE FOR BUSINESS AND INFORMATION TECHNOLOGY

PROVIDING CUTTING-EDGE KNOWLEDGE TO INDUSTRY LEADERS

# Wireless 1.0

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*This new form of communication could have some utility.*
Guglielmo Marconi, 1899
(inventor of practical radio communication)

# Introduction

Why was Google, an internet search provider, so interested in the results of the FCC 700 MHz spectrum auction? A decade ago, business professionals were forced to quickly learn about the Internet. Modems, servers, the World Wide Web and e-commerce became part of the business lingua franca. We believe that now it is vital for business to learn about *wireless*. Just as pigments of paint permeate a canvas, wireless signals are now beginning to permeate the atmosphere.  Wireless concepts and technologies such as 3G, Wi-Fi, WiMAX, RFID, navigation systems, and municipal wireless networks will transform the way organizations do business and become a core component of the global economy. Traditional wired technologies will be relegated to legacy niche applications and consumer demand will expand as users migrate from fixed Internet access to lower cost ubiquitous access. By 2012, IDC expects nearly 75% of the U.S. workforce and 80% in Japan to be mobile. According to the Wi-Fi alliance and In-Stat, about 300 million Wi-Fi chipsets were shipped in 2007, and In-Stat expects 700 million devices will ship with Wi-Fi on board by 2010, and by that time Wi-Fi enabled devices will exceed notebook shipments. In short, Google and other firms realize that we are sitting on the cusp of another technology-fueled business revolution, one that will require creative exploitation and harnessing of the capabilities of wireless.

This paper is a first attempt to treat the current set of wireless technologies as an integrated concept. We refer to this state of wireless development as Wireless 1.0 and present an integrated layered model that organizations can apply to develop new capabilities and innovative new products and services. A new perspective is needed for managers because wireless has the potential to disrupt existing business operations and models and also to create new forms of business opportunities and industries. Why is wireless 1.0 so important? Consider the following three trends:

> Wireless 1.0 provides a model that organizations can apply to develop new capabilities and innovative new products and services.

The increasing virtual firm: The structure and conduct of business is changing rapidly in even the most traditional organizations. Business operations are increasingly conducted by workers sitting in airport lounges using BlackBerry's. Elaborate corporate offices are being replaced by hotelling. Newer flatter entrepreneurial firms now meet in coffee shops to conduct business. They don't have PBX telephone exchanges and run the business from their cell phone. Many professionals such as doctors are essentially mobile workers, they increasingly consult, diagnose, and prescribe from multiple locations and wireless can change their practice to anytime anyplace. The supply chain and distribution channels are at their most basic the process of managing objects that move from one place to another. When UPS maintains your inventory using wireless as a linchpin; the concept of traditional warehousing, starts becoming obsolete. Finally, the financial justification for installing a wired infrastructure is increasingly problematic. It is likely that wired and wireless infrastructures will co-exist in the immediate future, the challenge is identifying where each makes the most sense. Understanding wireless 1.0 is now more than ever a critical requirement for the increasing virtual firm.

The convergence avalanche: The technology, telecommunications, and media industries are at a collision course. The idea of convergence where the computer becomes ubiquitous and becomes indistinguishable from the phone and the television is being implemented today. The distinctions between voice, data, and video are quickly becoming obsolete. The Apple iPhone is just the start of an avalanche of new convergent products and services that are being envisioned. These convergent products and services will require a ubiquitous high bandwidth wireless infrastructure. Wireless 1.0 represents tremendous challenges and opportunities for venture capitalists, managers of technology, telecommunication, and media firms, and legislators.

Is cutting the wire, the next great source of competitive advantage?  Wireless 1.0 realized to its full potential is a disruptive technology. Just like the railroads or the telephone changed competition by forming physical linkages, wireless will change the landscape by affording new business models by cutting the wire. Cutting the wire requires rethinking our basic assumptions. The firms who are nimble enough to realize the opportunities afforded by wireless 1.0 will likely be the market leaders of tomorrow.

Just like the telephone or Internet connectivity is now part of every industry, wireless will be part of even the most unlikely industry. For example, Progressive Insurance is offering wireless monitoring devices that plug into consumer automobiles and influence pricing, while coffee shops now need to consider Wi-Fi access in their standard business model to remain competitive.

The main purpose of this paper is:

1. The wireless 1.0 model affords managers an analytical tool for thinking about the feasibility and role of cutting the wire in their industry.
2. Wireless technologies are immature and the physical characteristics of wireless fundamentally complicates decision making. The wireless 1.0 model identifies the most important issues.

# Background

A key long term enabler in the evolution of wireless 1.0 is that governments in several nations made certain bands in the radio frequency (RF) spectrum available for use by cellular providers and other users. These RF bands are used for cordless telephones, remote-controlled keys on cars, wireless LANs, and of course cell phones. The emergence of related wireless technologies is also enabling new capabilities. Bluetooth enables short range interconnection among devices so that for example, cell phones can automatically exchange directory information with on-screen automobile navigation systems. RFID allows applications that remotely update pricing and specifications on products while they are sitting in a truck on its way to a distribution center. Cellular 3G networks could soon offer near ubiquitous connectivity. There is a view that a new kind of convergence is underway that will impact all forms of communication including the wired telephone, cellular, television, and wired Internet access, so that all connections will eventually be supported via the same (interoperable) wireless infrastructure. Entire new generations of multi-mode products are now possible, such as handheld computing-communication-entertainment devices that use Wi-Fi, LAN, Cellular, and Bluetooth to provide near universal connectivity. The processors, packaging, screens, storage, power cells, and software to produce innovative new products and services have improved greatly; it is the lack of a ubiquitous, coherent, compatible, competitive, and integrated wireless infrastructure that is keeping new products such as the Apple iPhone from being much more useful to consumers and organizations.

Emerging wireless technologies are complicated. The development of wireless is not dictated by a central controlling authority or industry. Instead, the wireless landscape is being shaped by government (de)regulation, political lobbying, technological discoveries and improvements, changing consumer needs, industry alliances to create standards, availability of the radio-frequency (RF) spectrum, and the often divergent competitive strategies of computing firms, traditional telephone companies, consumer electronics, and the entertainment industry. These forces have led to a bewildering array of choice-sets for fulfilling different kinds of requirements. In a recent global survey traditional e-mail was selected as the most frequent use of wireless, even though the respondents said that their focus was to develop and use completely new wireless applications and services[1]. We believe this is because current models make it difficult for organizations to fully analyze the capabilities and potential afforded by wireless.

The wireless 1.0 model presented in the next section has five underlying themes and assumptions: 1. Wireless connectivity is more useful if it is ubiquitous. 2. Wireless technologies are more useful if integrated together. 3. All wireless technologies will migrate to Internet centric data connectivity. 4. For the short term, wireless technologies will need to connect with the wired world. 5. Wired technologies such as Ethernet are now relatively stable and can be treated like a black box. In the future, wireless technologies will reach the same status as wired, and papers like these will become less important.

A new kind of convergence is underway so that all connections will eventually be supported via the same interoperable wireless infrastructure.

The material presented in this paper is based on: (a) research and laboratory testing experience with RFID (Asif and Mandviwalla, 2005) and wireless, (b) writing the business case for the Philadelphia municipal wireless project (Jain, Mandviwalla, and Banker, 2007), (c), analysis of the needs and preconceptions of 110 potential users of wireless (Jain, 2006), (d) an analysis of municipal wireless networks (Mandviwalla et al., 2008), (e) a global survey of 82 corporate users on wireless applications (Mandviwalla and Jain, 2006), and (f) wireless industry analysis conducted for and with a venture capital group. Our approach is deterministic and rooted in specific technologies that will be relevant in the next three years. We believe new organizational capabilities and innovation can come from deep insights of available resources, and wireless is one type of resource.

# Wireless Layer Model

| | |
|---|---|
| Layer 5 | Competitive Environment |
| Layer 4 | Architectures |
| Layer 3 | Management |
| Layer 2 | Devices |
| Layer 1 | Spectrum |

**Table 1: Wireless 1.0 Layer Model**

We present an abstract layered model of wireless (see Table 1). The model is loosely based on the well known seven layer Open Systems Interconnection Basic Reference Model (also known as the "OSI model"). The OSI model is useful for technical personnel who need to design and build networks; the model presented below is oriented toward managerial decision makers. Each layer provides critical services to the layer above and is dependent on the layer below. The layer concept is useful because it provides a way to separate the many different complex issues that impact wireless. Since each layer builds on each other, the model also provides a way to holistically consider the entire ecology of wireless.

The first layer refers to the wireless spectrum. Analyzing the spectrum is important for assessing the basic capabilities and limitations of wireless. Wireless devices are analyzed in the second layer. Layer three focuses on how wireless technologies are operationally managed. In the fourth layer, the capabilities and limitations of wireless architectures are discussed. The fifth and final layer analyses the complex competitive environment of wireless.

# Wireless Spectrum

The wireless spectrum layer is based on radio frequencies, channel usage, and bandwidth. Radio frequencies impact the available channels for connectivity, channel usage refers to different techniques for getting data into and out of the radio frequency spectrum, and bandwidth is the amount of data transmitted in a given time period through the available wireless spectrum.

## Channel Availability

The "distribution channel" for wireless is nature's radio frequency spectrum[2]. Frequencies tend to specialize by application. For example, lower frequencies are less absorbed by objects and obstructions and are used for submarine and subterranean communications, and higher frequencies are less likely to be reflected by the ionosphere (see Table 2). The wireless spectrum is typically managed by national governments and by international agreements

| Name | Frequency | Typical applications |
|---|---|---|
| (Various low frequencies) | 3–30000 Hz | Submarine & subterranean communications, avalanche sensors, heart rate monitors |
| Low frequency (LF) | 30–300 kHz | Time signals, AM long wave broadcasting, RFID |
| Medium frequency (MF) | 300–3000 kHz | AM medium wave broadcasts |
| High frequency (HF) | 3–30 MHz | Shortwave broadcasts and amateur radio |
| Very high frequency (VHF) | 30–300 MHz | FM and television broadcasts |
| Ultra high frequency (UHF) | 300–3000 MHz | Television broadcasts, mobile phones, wireless LAN, Bluetooth, ground-to-air and air-to-air communications, RFID |
| Super high frequency (SHF) | 3–30 GHz | Microwave devices, wireless LAN, Radar |
| Extremely high frequency (EHF) | 30–300 GHz | Radio astronomy, high-speed microwave radio relay, RFID |

**Table 2: Radio Frequency Spectrum[3]**

brokered by the International Telecommunications Union (ITU). Active management is required because wireless signals travel through open space and can easily interfere with each other. This is a key difference in analyzing the advantages and constraints of wireless as compared to wired. In the U.S., the Federal Communications Commission (FCC) agency regulates private sector use of the spectrum through regulations and multi-billion dollar auctions for available frequency. Most of the frequencies listed in Table 2 in the U.S. have all been already allocated for governmental, licensed, and unlicensed applications (see Office of Spectrum Management, 2003). For example, 88 MHz to 108 MHz is allocated for FM radio. If a nearby "pirate" radio station starts using a frequency allocated to a local station, then you will hear the pirate station, not the local station you selected on your radio. Governing organizations have set guidelines for frequency use including purpose, location, and the amount of power (signal strength), as well as penalties for misuse.

Some frequencies have been made available for unlicensed usage meaning that any manufacturer can develop and market devices that operate in those frequencies and their customers do not need to get a usage license. In the U.S., 900 MHz, 2.4 GHz and 5.8 GHz are available for unlicensed use and known as the Industrial, Scientific, and Medical (ISM) bands[4]. Cordless phones, and RFID tags use the ISM bands and most home wireless LAN routers use the 2.4GHz band. The unlicensed frequencies are thus increasingly crowded and face reliability challenges. Interference management is one of the ways that manufacturers can differentiate themselves with devices that operate in the unlicensed frequencies.

Wireless has unique properties that influence range and bandwidth. (a) Signals degrade over distance and at a much higher level when higher frequency bands are used. For example, with all other aspects being equal, signals in the 3.5GHz band (which is targeted for WiMAX) will be received at 20 times less power than signals in the 800MHz band (currently used for cell phones) (Andrews et al., 2007). (b). Signals further degrade when they encounter trees and buildings. This type of degradation is impossible to accurately predict and brings significant variability into predictions of reliability and range. (c). Signals get reflected and changed by various surfaces and slightly different versions arrive at the intended destination. Therefore, a portion of the signal is lost or fades. Signals at higher frequencies fade more than signals at lower frequency bands.

What is striking is that it is therefore virtually impossible to estimate the range and bandwidth of each frequency in advance. Atmospheric conditions, interference from objects, terrain, presence of other signals, and even the salinity of water create significant uncertainty[5]. There are formulas available that can calculate propagation (range) and signal to noise ratio (interference) but they cannot fully account for the environment. One implication is that wireless transmissions will in the short run be inherently more difficult to manage and guarantee than wired. Engineers and firms that have real world experience in specific geographic regions on particular frequencies will have a significant advantage over new entrants.

All of the above means that certain frequencies are considered more valuable than others. That is the reason for the recent intense interest in the 700 MHZ FCC auction. The 700 MHZ frequency range is known as "beach front property" because it has desirable physical properties and tradeoffs for achieving reasonable range and high speed *and* there is a knowledge base of people and technologies already available (it has been used for many years for television broadcasting).

Whoever controls the available and most desirable frequencies essentially controls the "right of way."

In the short run, frequency availability will continue to be a problem. Wireless products will have to opt for increasingly sophisticated interference avoidance schemes that require costly components to provide good performance in the freely available unlicensed bands. Alternatively, wireless firms will need to seek new bands through expensive acquisitions or legal processes and fund the development for basic electronic components for these new bands. Manufacturers are also working on more cost efficient multimode components that allow one device to work with multiple frequencies. This may allow creative exploitation of available frequencies.

To summarize, a wireless connection can only occur if a frequency or path is available for the signal to go through. There are only a limited number of frequencies available and the current structure creates a potential bottleneck for new technologies. Whoever controls the available and most desirable frequencies essentially controls the "right of way." Creative partnerships with existing owners of relevant bands may provide an interesting alternative and opportunity for new products and services.

## Channel Usage

The previous section analyzed the availability of channels to transmit data, this section focuses on *how* the data is sent and received, i.e., how the channel is utilized. Imagine that a highway represents an available frequency range from the previous section and the lanes on that highway represent the channels. Continuing that analogy, if the goal is to send as many people as possible through the highway, then the kind of vehicle used (small vs. large) is the "modulation" scheme, and "multiplexing" is how multiple vehicles are sent on the same lane.

Modulation refers to the process of manipulating a signal so that it carries a message[6]. Sophisticated modulation techniques have been invented to pack even more data into a signal and continue to be improved. Multiplexing is how multiple signals containing different messages can be sent without interference through a single channel. Varying time and frequency are the basic elements of most forms of multiplexing; however they are often used together or with other schemes. Multiplexing is needed because a single signal uses only a fraction of a channel's capacity and there are only a limited number of channels (frequencies) available[7]. Wireless applications require multiplexing to support multiple users, as well as to support multiple data streams for the same user (e.g., streaming video and web browsing).

Whether one form of modulation or multiplexing is superior to another is a debate for scientists and engineers. The more obvious schemes have already been implemented and future improvements will require complex mathematical techniques and sophisticated and costly components that can handle ever more subtle changes in the signal to differentiate between a 0 and a 1. Modulation and multiplexing are important in analyzing how data is transmitted. However, existing techniques such as OFDM[8] have been shown to be superior in many different contexts, and variations are now prevalent in most current wireless architectures; the performance differences are now minor. Unless a dramatic new invention occurs, managers can treat the performance characteristics of the techniques as black boxes.

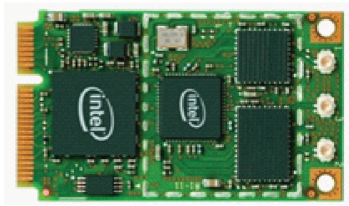
The most relevant managerial issue then is the actual performance realized by combining available channels with various channel usage techniques. Performance is typically referred to as bandwidth and is measured in bits per second (bps)[9]. The actual speed in which data is transferred is dependent on several factors including the efficiency of the modulation scheme, and how tightly packed the data is. There is also a difference between theoretical bandwidth and realized performance, also known as "throughput." All wireless signals experience interference and degradation in real world conditions. For example, 802.11g Wi-Fi supports a theoretical bandwidth of 54 Mbps while actual throughput is much lower at 7-15 Mbps.

Another important managerial issue is interoperability. Manufacturers and wireless providers have mapped out their distinct highways on frequencies they control and the vehicles for data sent through these highways are

**Key Wireless Spectrum Issues**

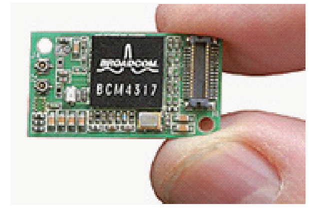
1. There is only a fixed, limited range of frequencies available in nature.
2. There is a relationship between available frequency bands and desired usage. Range, bandwidth, and other factors such as the ability to pass through buildings vary by frequency band.
3. Wireless transmission varies unpredictably by frequency, environmental conditions, and intended use. Experienced users have a significant advantage.
4. A major focus of wireless engineering is the efficient use of the spectrum. The pace of innovation has slowed down and new significantly more efficient modulation and multiplexing schemes are unlikely.
5. A more recent focus is the creative business model exploitation of existing frequencies through pay-per-use and other schemes.
6. A scientific breakthrough related to the above limitations will completely change the wireless ecology.

**WiMAX client**
(source: airspan.com)




**Wi-Fi 802.11n chipset and card**
(source: intel.com)

**iPhone**
(source: Apple.com)




**Wi-Fi 802.11b Single chip**
(source: Broadcom)

**Figure 2: Wireless Clients**

incompatible with the ones used on other highways. That is one of the reasons why the current wireless infrastructure affords limited interoperability. Nor will this situation change any time soon. The choice of frequencies and the scheme to physically transmit signals is made at the chipset level, so there are no “software” upgrades that can be applied to increase interoperability.

# Devices

## Clients

In the wireless 1.0 model, the first important type of device is a client. A subscriber station or more simply client is the term for a device that connects to available channels (see Figure 2). For instance, a laptop equipped with Wi-Fi is a subscriber station in a Wi-Fi network. The actual hardware required for connectivity is typically found on a “chipset” - a set of chips that work together and are placed on cards, motherboards, inside cell phones, or RFID tags. A small antenna that is either embedded inside the device or protrudes out connects to the chipset and transmits/receives the signals. Chipsets are generally limited to a particular set of frequencies, so for example, a 2.4 GHz Wi-Fi chipset can never transmit/receive on the 1900 MHz band used in the U.S. for cell phones. With increased cost and complexity, it is possible to embed different chipsets that operate on different frequency bands into the same client device. For example, many laptops now come with both the Bluetooth and Wi-Fi chipsets.

Chipsets determine the key attributes of wireless devices including the channel, channel usage (the modulation and multiplexing schemes), bandwidth, range, power draw, and form factor[10]. Wireless components account for a major portion of the power consumption in portable devices (Pering et al., 2006). Power management is therefore a very important attribute of any wireless client. Form factor refers to size and shape and impacts usability and functionality, which in turn impacts the final footprint of wireless devices such as the “thinness” of a cell phone. As a technology matures, manufacturers produce single chip products that embed all relevant functionality on one chip. Figure 2 shows a single chip implementation of Wi-Fi. These single chip designs tend to require less power, are easier to use in creating new products, and enable even smaller devices. Availability of such single chips will heavily influence the form factor and portability of all new emerging wireless hardware.

The client devices also require software drivers for basic operations and applications to utilize the connectivity. The drivers are typically embedded into operating systems (e.g., Windows XP) and for mature technologies such as Wi-Fi; they are relatively stable and transparent to the user. The drivers only tend to be an issue early on in the stage of a completely new standard. Wireless clients designed for Internet access such as laptops, PDA’s, and some cell phones include multi-purpose operating systems with integrated applications such as Windows Mobile or the Symbian mobile operating system. Cellular, Wi-Fi, and WiMAX include software designed to support connectivity, while Bluetooth and RFID also include application software embedded into the hardware. Bluetooth for example, includes software that allows two clients to automatically negotiate a connection and share data as well as data definitions; this is how your Bluetooth enabled phone can automatically show your phone directory in the car LCD screen. RFID includes limited special purpose instructions that allow for automatic identification and authentication.

Our analysis indicates that most wireless clients compete on connectivity and attributes such as reliability (“can you hear me now?”) or bandwidth. The Apple iPhone arguably raises the bar by also competing on applications and usability enhancements that leverage wireless beyond simple connectivity. Managers also need to understand that in theory, the chipsets and software are available today to create a multipurpose device that could access the full

**Access Point**

**RFID Reader**
(source: Psion)

**Cell Phone Tower**
(source: www.verizon.com)

**Figure 3: Wireless Base Stations**

frequency spectrum. This "do everything" device could provide AM/FM service, access the CB radio network, tap into GPS signals, receive television broadcasts, access Wi-Fi hotspots, connect to Bluetooth devices, read and write RFID tags, and of course operate as a video and voice phone. Such a device may not be practical today because it will require different chipsets resulting in high costs, complexity, high power requirements, and a relatively large form factor[11]. A scientific breakthrough in power cells or in chipset design could suddenly make such devices much more feasible and completely change the wireless world. A single programmable chipset and associated software that can "dial into" any available frequency could also make such a device practical. It is unclear if such a device is needed, and even if there was demand for such a device, it would still need a ubiquitous, reliable, high bandwidth network.

## Base Stations

The second major type of device is the base station and the underlying network. A base station, also known as an access point, is the device that communicates and provides services to a subscriber station (the client) (see Figure 3). For instance, the Wi-Fi access point in figure 3 is a base station in a Wi-Fi network. In cellular telephony, the base station is owned and managed by the cellular service provider and typically referred to as the cell phone tower. In RFID, base stations include stand alone readers or larger fixed installations such as toll booths. The base station must be able to transmit/receive at the same frequency as the client. Base stations typically include a software based management and operating interface. Base stations in the form of an access point for Internet access cost less than $100, while cellular base stations are approximately $200,000.

**Key Device Issues**

1. A scientific breakthrough in chipset or battery design can completely change the wireless ecology.
2. The availability of chipsets significantly influences the availability, portability and usefulness of current and future devices.
3. Innovation in antenna design is more likely to lead to substantial improvements in wireless bandwidth.
4. Chipsets are specialized by frequency. There are no general chipsets available that will allow a manufacturer to switch from say Wi-Fi to WiMAX.

Clients include antennas; however, antennas tend to be more important in base stations[12]. A superior antenna design can improve the reliability and performance of base stations, this is an area where vendors can compete with each other given that the underlying wireless chipsets for mature technologies rapidly become commodity items and are available to any vendor.

Base stations only create a local network and are only useful if they have a larger network to connect to such as the Internet. In RFID, the network is typically limited to a brief link between base and client to exchange data, while an access point can provide sustained connectivity to a larger network such as the Internet[13]. Our analysis indicates that small mobile client devices tend to have small batteries and antennas which limit their effective range. Restrictions in the clients thus determine the range of a wireless network. The restrictions also influence upload bandwidth because in general (a) it takes more energy to transmit than to receive and (b) it takes more energy to send a signal over a longer distance at a higher speed. In effect, most base stations have limited ranges often of a few hundred feet, and they need to be close to the clients.

# Management[14]

Organizations with a large wireless user base will need specialized network management tools that can monitor, track, and configure the overall network and all connected devices. Such tools and the associated personnel needed to manage the wireless network are a significant cost associated with wireless. In this section, we outline issues specifically related to managing wireless 1.0 network's (it is beyond the scope of this article to cover general network management concepts). These issues take into account the constraints and opportunities afforded by wireless devices and the availability of wireless spectrum, i.e., the other layers of the wireless 1.0 model. They also incorporate the concerns and interests of corporate IT management. The latter is based on a global survey of corporate IT professionals (Mandviwalla and Jain, 2006)[15].

## Standards and Maturity

Standards are a key determinant of wireless adoption and use. More than 80% of survey respondents said that the maturity and standardization of wireless technology is driving adoption decisions, and more than 90% said that compatibility with existing infrastructure was an important consideration. Further, the future of most wireless architectures is dependent on the development of key standards. The Institute of Electrical and Electronics Engineers (IEEE) is a non-profit professional association of engineers that has pioneered many of the networking standards in use today[16]. This is in contrast to the rest of the computer industry where standards are often based on market forces. However, the open and consensus based approach of IEEE is now under criticism for being too slow (Garretson, 2007). The Wi-Fi alliance and WiMAX forum are newer industry led organizations that certify wireless products and have reduced the importance of IEEE since they are willing to certify standards even at the draft stage. But they are membership driven, and future success is dependent on the goodwill of all their industry members. One powerful company could derail the process as exemplified by the HD DVD vs. Blu-ray video disc rivalry. The long term future of standards development is therefore a substantial risk and may require a complete overhaul to support ubiquitous wireless services. For example, standards groups may need to work at higher

| Architecture | Frequency Bands | Power draw | Range | Bandwidth |
|---|---|---|---|---|
| Cellular | (varies per region and country) | <100mW – 700mW | 300 – 3000ft | 40Kbps – 1 Mbps |
| Wi-Fi | 2.4GHz or 5GHz | 300 – 1000mW | 30 – 300ft | 2 Mbps – 25 Mbps |
| WiMAX | 2.5GHZ or 3.5GHZ | 10 – 500mW | 1000 – 3000ft | 10-20Mbps |
| Bluetooth | 2.4 GHZ | 250uW - 2.5mW | 3 – 30ft | 50Kbps – 1 Mbps |
| RFID | (varies) 13.56 MHZ for passports and smart cards | 30 – 200mW | 1 – 10ft | 1 - 100Kbps |

**Table 3: Wireless Architectures**[22]

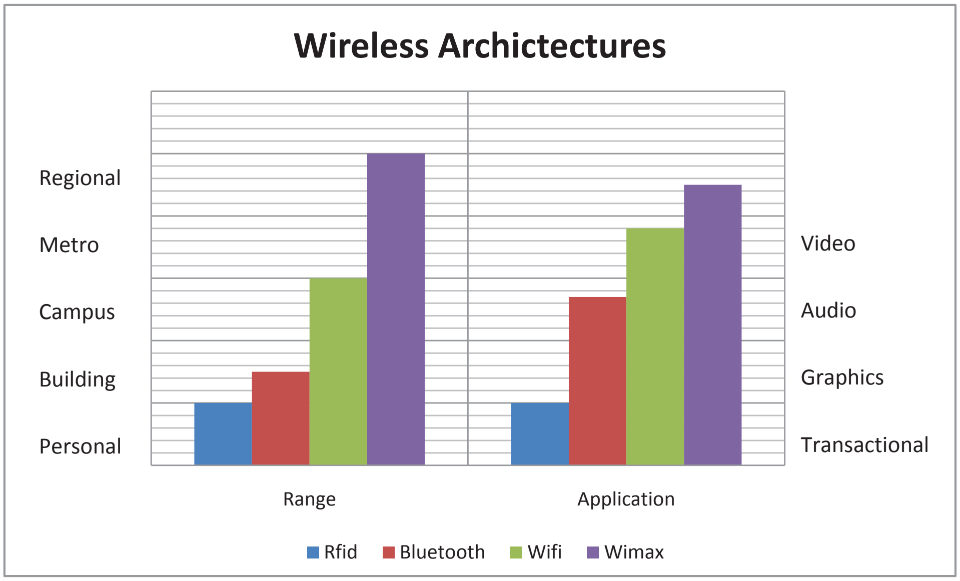



**Figure 4**

levels of abstraction and consider models like wireless 1.0. A further challenge for managers is standards proliferation and churn. Market forces increase pressure to roll out new standards, yet too many new standards mean ever changing and potentially incompatible products.

## Quality of Service

From a Quality of Service (QoS)[17] perspective there are five different kinds of traffic: gaming, voice, streaming media, data, and video. Each kind of traffic has different characteristics such as real time versus asynchronous, streamed versus cached, bandwidth needs, and tolerance for delay (see Andrews et al., 2007 for additional analysis). QoS is a relatively well understood area in networking and though wireless has unique characteristics such as the need to conserve power and handoff (see below), most of the concepts from the wired world are applicable. The challenge for application in the wireless 1.0 model is that most of the current wireless standards do not support QoS. Another challenge arises when wireless traffic crosses network boundaries, because different networks may offer different tiers of QoS.

| Generation | Traffic Type | Description and Data Options |
|---|---|---|
| 1G | Primarily voice | Analog signals between clients (phones) and base stations (towers) |
| 2G | Primarily voice | Digital signals between clients (phones) and base stations (towers). Global System for Mobile Communications (GSM) is the dominant cellular standard around the world. Code Division Multiple Access (CDMA) is popular in the U.S. |
| 2.5G | Voice and data | There are two options for data: 1. General packet radio services (GPRS) provides 35 Kbps average bandwidth. 2. Enhanced Data rates for GSM Evolution (EDGE) provides 75-135Kbps (may be categorized as 3G). |
| 3G | Voice and data | There are two competing options for data: 1. Universal Mobile Telephone Service (UMTS) with bandwidth of about 220-320Kbps and HSPDA provides download (only) bandwidth of 400-700Kbps. 2. Evolution Data Optimized (EV-DO) with realistic bandwidth of about 500Kbps – 800Kbps (upload bandwidth limited to about 100Kbps). |
| 4G | Voice and data | Under development. Expected to provide data communications at speeds of 100Mbps for mobile systems and 1Gbps for stationary systems. |

**Table 4: Cellular telephony standards and generations**

## Security

Network security typically involves a tradeoff between access and security. Because wireless networks are often accessed from scattered areas they can be more susceptible than wired networks to attacks and interceptions. Network security is also a well understood and researched area in the wired world and most of those concepts apply to wireless. For example, security for wireless includes encryption, authentication, and message integrity verification[18]. Large scale wireless networks will require crossing multiple layers of the wireless 1.0 model to support levels of authentication and encryption. Such layers can for example, provide open access to some kinds of devices in public areas, while other kinds of traffic require higher level of security and access.

## Roaming and Handoff

Roaming and handoff[19] works well in the cellular voice domain but is only recently being considered for Wi-Fi and other forms of wireless data. A seamless wireless network must allow users to maintain their connection while moving from one location to another even if it is serviced by a different base station. At the backend, such aggregated services will require complex coordination among multiple service providers in the areas of billing, security and QoS. From the perspective of the wireless 1.0 model, there are some daunting technical challenges. For example, what if the frequency used by the next base station is not supported by the client? Roaming and handoff capabilities will be one of the major differentiating factors of wireless in the future and are required if large scale wireless networks are to be considered viable replacements for corporate wired networks.

# Architectures

Wireless architectures are analyzed below as specific collections of technologies available for deployment. In Table 3, and below, we apply the wireless spectrum, device, and management layers introduced in previous sections to analyze each architecture[20] (See Appendix I for how we created Table 3). Figure 4 further highlights the differences among wireless architectures[21].

## Cellular

The cellular network is the oldest most widely deployed wireless network and it continues to expand at a very rapid pace. However, it generally offers low bandwidth and since it was originally designed for voice, Internet related traffic is usually second priority[22]. The total number of cellular users is expected to hit 3 billion by 2010 (Wakefield, et al., 2007). The architecture of cellular consists of base stations (cell towers) that are linked to specialized switching equipment and gateways that provide access to the public switched telephone network. The generations of cellular telephony are summarized in Table 4. 3G networks typically operate in the 1.7 to 2.1 GHz frequency band. 3G or 4G networks are not standards, they are part marketing labels and part "generally accepted" collections of technologies.

3G networks are typically accessed via special wireless access cards in laptop computers or through built-in chipsets in PDA style cell phones such as the Apple iPhone. The response to 3G has been slow. Proponents of competing technologies believe that (a) data is a low priority for cellular vendors whose current revenue is based on voice, (b) there are too many arbitrary restrictions on usage, (c), and the fees are too high. It is currently not possible to roam between different kinds of 3G networks. Nevertheless, the higher bandwidth of 3G is fast enough to support most organizational tasks. Applying the wireless 1.0 model

**Key Management Issues**

1. Standards are currently falling behind the pace of new product introductions and the prospects of interoperable devices in the short run are poor.
2. Active quality of service (QoS) management is hard to achieve in the wireless world.
3. Roaming and handoff represent the next frontier in wireless access. Firms that can implement seamless roaming and handoff among disparate networks may gain a unique advantage.

to cellular shows that every layer is fully realized and available, and therefore, despite the slow start, we conclude that the cellular networks may in the end turn out to be the only widely available wireless architecture.

## Wi-Fi

Wi-Fi (Wireless Fidelity) is the name of the wireless local area networking standard based on the IEEE 802.11 specifications. Wi-Fi architecture consists of a client that connects to an access point which is typically connected to the Internet through a wired connection. Table 5 outlines the most relevant Wi-Fi standards. The 802.11b/g standards do not support QoS and all users accessing a single access point share a fixed amount of bandwidth whether they fully utilize the bandwidth or not.

The original versions of Wi-Fi also had limited security[23]. The challenge is that many devices such as PDAs still only support the early versions of Wi-Fi which creates a security hole if those devices are given access to the corporate wireless network. Products based on the 802.11n draft 2 proposal are being introduced in 2008 even though final IEEE ratification is not expected till 2009. 802.11n draft 2 is secure, supports QoS, and supports new antenna designs to provide much higher bandwidth. 802.11n is the first Wi-Fi standard that offers a credible alternative to wired networks. It may now be quicker and cheaper to use wireless in a new branch office than to install traditional wired networking. There are also opportunities to rethink traditional office design so that employees are no longer tied to formal cubicles and can collaborate and work anywhere. The IEEE is working on a number of improvements will further enhance Wi-Fi (see Appendix 2).

Mesh, also called multi-hop networking, refers to connecting Wi-Fi access points together using bridges or nodes to form a larger overall network[24]. Mesh networks are suitable for municipal wireless networks (MWNs) that cover city-wide areas. The 802.11s and the 802.11v specifications will in the future provide a mesh networking standard and centralized management of clients and base stations. However, meshing is an afterthought; Wi-Fi was not originally intended to be meshed and this leads to several compromises. In wide area deployments, Wi-Fi mesh networks have been found to have unacceptable levels of delay (latency) and difficulties with signal strength, leading to decreased performance. There are also interference problems because Wi-Fi operates in the unlicensed 2.4GHz band, and has to share spectrum with a large number of other applications, including other Wi-Fi networks. Finally, unless a booster antenna is used, the signal strength of mesh networks is usually not strong enough to penetrate buildings. In sum, proprietary Wi-Fi based mesh networks are useful for the short term but they will likely be replaced by new standards and by WiMAX (see below).

| Standard | Achievable Bandwidth | Range | Frequency and Interference risk |
|---|---|---|---|
| 802.11b | 5Mbps | 150 feet | 2.4GHz, high |
| 802.11g | 20Mbps | 150 feet | 2.4GHz, high |
| 802.11n (draft 2 products available in 2007) | 40-50 Mbps | 200-300 feet | 2.4, 5GHz, varies |

**Table 5: Wi-Fi Standards**

## WiMAX

WiMAX - Worldwide Interoperability for Microwave Access is a standard based on the IEEE 802.16 specification. The original 802.16c standard operates in the 10GHz-66GHz frequency range at a tradeoff of 70Mbps or 30 miles. Signals at such high frequencies are easily absorbed by buildings, relegating practical implementation to fixed line of sight applications. 802.16e, termed Mobile WiMAX, is currently targeted for frequencies around the 2.5 GHz and 3.5GHz bands, bandwidth of 1-4 Mbps, range of about 1-2 miles, and support for outdoor usage, in a moving vehicle, or inside a building, and includes QoS and channel usage enhancements. Mobile WiMAX can challenge cellular networks with its long distance broadband non-line of sight capabilities.

WiMAX is more efficient, more secure, and better engineered than Wi-Fi for large scale broadband wireless implementation[25]. In other words, for each layer of the wireless 1.0 model, we conclude that WiMAX is technically superior. WiMAX chipsets needed to manufacture clients and base stations are now becoming available in 2008. However, Wi-Fi is already installed in millions of clients. Therefore, in the short term, large scale wireless projects such as municipal wireless networks tend to use meshed Wi-Fi for hot zones, while employing WiMAX for last-mile connectivity and backhaul. A fully deployed regional or national Mobile WiMAX network would look very much like the current cellular voice network in which the client is any device with the requisite chipset and base stations are analogous to cell phone towers spread over a region. The key difference is that the current cellular network is optimized for voice while WiMAX is engineered for the Internet. Sprint is deploying Mobile WiMAX in the 2.5GHz band and calling it “4G” and expects to roll out service by the end of 2008.

## RFID

RFID (Radio Frequency Identification) refers to a set of technologies that was originally conceived in World War II to identify friendly aircraft. RFID today is used to identify and track objects as well as niche applications such as replacements for tool booth collectors on freeways. RFID is not designed to enable Internet access; instead RFID enables communication to objects such as products. The architecture of an RFID system includes clients (called tags that are placed on or embedded into products), base stations (antenna and readers), and the software to control the tags and readers. The tags can typically store up to 10 Kbits of data and are differentiated by intended use, size, and shape and whether or not data can be written to them (see Figure 5). The bandwidth of tags and readers is generally low and ranges from 1 Kbps to about 120 Kbps.

**Figure 5: RFID Tags (Clients)**
Source: www.ti.com

One challenge for managers envisioning global inventory management applications is that the frequencies authorized for RFID vary across countries so a tag and associated frequency that is legal for use in the U.S. may not comply with European regulations. Further, until the cost of tags goes down to a few cents, RFID will likely not be cost effective for tracking low priced goods and will remain useful only for pallets or higher value goods (e.g., controlled substances, passports). Since the tags operate without human intervention and by their very nature are simple devices, security and privacy concerns will remain a challenge.

RFID on the surface is completely different from Wi-Fi or WiMAX. Yet, at a basic level, RFID is still a radio transceiver with clients and base stations. It is not difficult to envision a future where RFID like capabilities are integrated with other wireless technologies to create new services. For example, RFID like functionality may be embedded into devices for authentication and identification purposes, while other chipsets are used for actual communication. Envision a product manager sitting at a cafe, who needs to change the pricing of a product on a store shelf across the world. The message goes through the Wi-Fi at the cafe using a virtual private network (VPN) to travel through the public Internet, and arrives at the corporate headquarters, receives automatic authentication, and is then sent through the corporate secure WiMAX network to the individual store, where it is transmitted on the store Wi-Fi to the RFID reader/writer attached to the specific shelf, which then updates the price, and sends confirmation back so that the databases of the manufacturer and store are updated.

In the future, inventory management applications of RFID seem promising assuming the tags continue to go down in price. The future for consumer or other specialized applications is less clear. Richer applications will require more expensive and higher power draw chipsets. It then might make more sense to implement RFID like functionality in software and on top of general purpose existing architectures such as Wi-Fi or WiMAX. Over the long run RFID is expected to replace identification systems such as bar codes and magnetic strips on cards, and eventually there may exist dozens of RFID radios inside all kinds of unique objects such as keys, credit cards, cell phones, toll booth cards, store identification cards, rail passes, and others.

## Bluetooth

Bluetooth was originally conceived as a cable-free alternative to connect headsets and operates over the 2.4GHz frequency band. IEEE 802.15.1 is now the current Bluetooth standard architecture which involves connecting ("pairing") clients together. In theory, Bluetooth supports point-to-multipoint connections but in practice today it is typically used to connect two clients together such as a cell phone to a wireless headset. Unlike other wireless technologies, the Bluetooth specification also provides a control interface so that one client can control another such as using a wireless Bluetooth headset to control cell phone functions. Bluetooth 2.1 offers a bandwidth of 2 – 3 Mbps with a range of about 300 feet.

The next generation of Bluetooth is based on a merger with another standard called Ultra-Wideband (UWB) – the merger is known as the WiMedia alliance. This new generation could provide bandwidth of up to 480 Mbps and potentially displace the use of Wi-Fi in the home. This new high bandwidth fully integrated technology can disrupt the wireless 1.0 layer's by reducing the distinction between hardware, software, and management. In Bluetooth, the software and hardware is all integrated. The WiMedia alliance also includes a technology called Wireless USB whose original goal was short-range high bandwidth connectivity that would provide a wireless equivalent to the now ubiquitous USB 2.0 connectors found on many devices. The chipsets supporting WiMedia, Wireless USB, and Zigbee (yet another similar technology) are becoming available in 2008. Bluetooth is on the surface a niche wireless technology. Yet, the unique control characteristics and low power requirements of Bluetooth could make it suitable for interesting new wireless applications. For example, a police officer walks past a warehouse and senses movement, so she sends a query through a cellular data link to the warehouse owner. In response, the owner sends a security code to the officer so she can use the local Bluetooth link to remotely view and control a security camera inside the warehouse.

**Key Architecture Issues**

1. The current cellular network is more likely to provide near ubiquitous lower bandwidth connectivity in the short run.
2. Wi-Fi has the largest penetration in homes and offices but faces significant architectural, security, and QoS challenges.
3. Municipal wireless networks (MWN) based on Wi-Fi and Mesh will likely be supplanted by WiMAX or other technologies. MWNs represent the best hope for low cost, metro based ubiquitous and high bandwidth connectivity.
4. WiMAX is a superior architecture for high bandwidth, ease of management, openness, interoperability, and low cost. Yet, rollout and deployment is slow.
5. RFID and Bluetooth and other specialized wireless architectures will gain more features and bandwidth and may compete with other architectures for certain applications. RFID and Bluetooth could also be supplanted by "software" implementations of their functionality within Wi-Fi or WiMAX networks.

# The Competitive Environment

According to Christensen, et al. (2004) "… although wireless technology *could* have been disruptive, today's incumbent telephony companies co-opted wireless technologies in a way that sustained their existing business model." (p. xxii). The analysis is still relevant in 2008 for voice; it is unclear however if it will remain so for data. The signals of change exist in all of Christensen et al.'s customer groups, including undershot, overshot, and non-consumers, and in the actions of nonmarket players. The intense interest in the Apple iPhone indicates a willingness by undershot customers to pay more for multimedia and usability enhancements. Firms continue to try and move into higher profit tiers by introducing incremental innovations such as mobile ESPN or pay-per-use navigation features in cell phones. The relative success of the no frills low cost low bandwidth Juno internet service and the growth of prepaid cell phones indicate that there are also overshot customers. The interest in municipal wireless networks and the focus on economically disadvantaged urban residents bring non-consumers into the market. Perhaps the most interesting signal of change is Google's desire to influence how the frequency spectrum is auc-

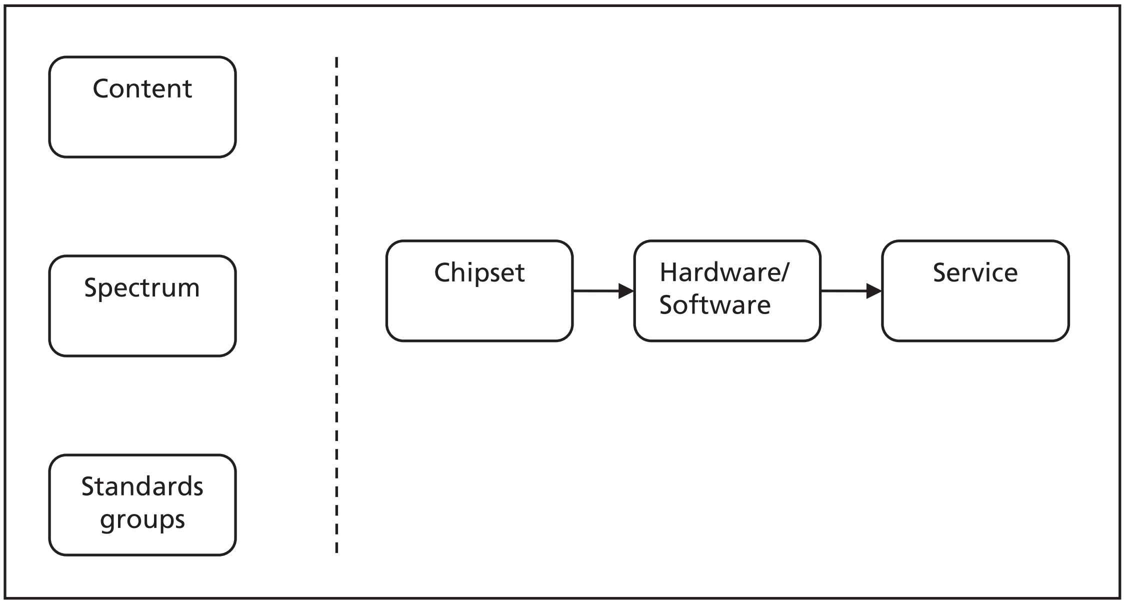



**Figure 6: Wireless Value Chain**

tioned and used. At the architecture level, the introduction of standards based WiMAX as a potential replacement for the traditional cellular phone architecture will create the modular interfaces that Christensen et al. believe are important for disruption. All of these signals suggest that it is important for managers to have a sense of the wireless competitive landscape, which we analyze below as the wireless value chain.

The wireless value chain consists of chipsets that are used to produce hardware, which in turn is the basis for software applications, and the combination results in various wireless services. The radio frequency spectrum, backhaul, standards, and available content provide the "raw materials" for the construction of chipsets, hardware/software, and services. Each element of the value chain and its competitive environment is discussed further below using the concepts developed in the spectrum, device, management, and architecture layers.

Chipsets. Chipsets are the first and most basic element of the wireless value chain. It takes several years to design, test, and manufacture a chipset. Chipset manufacturers are large semiconductor firms such as Texas Instruments and Intel and boutique chipset designers such as Atheros. Chipset manufacturers can dramatically change the wireless competitive environment by 1. Lowering the cost of chipsets so that they can be embedded into more and more devices (e.g., a major reduction in the price of RFID tags could supercharge adoption), 2. Reducing the size and power requirements of chipsets to increase the mobility of devices, and 3. Creating new multipurpose chipsets that can operate on multiple cellular, RFID, Bluetooth, and Wi-Fi frequencies and architectures. The combination of all or even two of the innovations above would enable completely new kinds of products and services. It is unlikely that existing chipset manufacturers will be displaced, but the manufacturers have the potential power to introduce disruption for other parts of the chain.

Hardware and Software. Hardware and software firms utilize chipsets to create actual products. Manufacturers include traditional firms such as Motorola and Samsung, that design cell phones, consumer electronics firms such as Yamaha, that are embedding Wi-Fi and Bluetooth into their product lines, Microsoft which is competing with Symbian to control the future of wireless device operating systems, and also working on hardware devices such as smart phones, Apple with the iPhone, traditional telecommunications manufacturers such as Cisco and D-link that manufacture wireless routers and client cards, special purpose devices such as RFID readers, and even gaming manufacturers such as Nintendo that are embedding Wi-Fi into their consoles and designing new games that leverage wireless connectivity. Hardware and software manufacturers can change the competitive environment by: 1. Integrating chipsets, new battery technologies, and highly usable software to create a "killer" application or device (e.g., the "Dick Tracy" Watch). 2. Establish de-facto standards by introducing a new breakthrough technology early and gaining quick acceptance (e.g., Dell started offering 802.11n Wi-Fi in its notebooks before the standard was fully approved), 3. Create a compelling software application that leverages wireless and drives the market for customized hardware. There is room for new entrants because existing firms lack the skills and orientation to think of wireless in a holistic manner. On the other hand, and as mentioned earlier in the section on spectrum, each wireless frequency faces unique interference and reliability challenges that provide firms with experience with a particular frequency, a unique advantage.

Services. The final element in the wireless value chain is the actual service (application, content, and capabilities). Service providers integrate hardware and software with connectivity to provide a service to end users or organizations. Providers include firms such as Verizon with their voice and data services, aggregators such as Boingo, which offers flat rate Wi-Fi at more than 100,000 hot spots worldwide, RFID solutions from IBM which offers consulting, implementation, and specialized software for product tracking, integrated products such as the Blackberry which bundles a device and connectivity service together, specialized consumer applications such as the Bluetooth speakerphone feature offered in luxury automobiles or the EzPass toll service offered in the U.S., and content centric mobile applications such as the ESPN streaming video service offered on cell phones. Service providers can change the value chain by vertically integrating and controlling the chipset, hardware, and software, and type of service offered. Providers who control valuable content or applications (e.g., Google) have the market and financial power to implement vertical integration. The likelihood of new entrants is very high because chipsets and hardware and software quickly become widely available commodities. There is also room for a kind of horizontal integration in which an aggregator integrates and resells services. For example, imagine a worldwide Internet access provider that has a single logon and seamless handoff among existing cellular networks, municipal wireless networks, and hot spots.

Content. Content generators and information providers include organizations that need to share information or communicate with employees or customers/suppliers. For example, sending alerts to sales people in the field about recalled products, or enabling customers to check the status of their account. They also include entertainment and knowledge production firms such as the television and movie industry, news media, education, publishers, and information search (e.g., Google) or aggregation (e.g., My.Yahoo) firms. Some content may be so unique or valuable that providers may refuse to provide it as "raw material" and choose to vertically integrate direct to the consumer. For example, the UPS device which records the delivery signature is a single purpose wireless device in which the chipset, hardware and software, and the service is all designed for one type of content. It is beyond the scope of this work to go into all the different content providers, but once content is available in digital form then wireless becomes a potential distribution channel. Availability of new content or the withholding of existing content can thus disrupt the complete value chain, resulting in new devices (e.g., Amazon's new Kindle reader for books) or creating new demand for existing content (e.g., Google Maps on the Apple iPhone has arguably created a new distribution channel for maps).

Spectrum. The wireless spectrum cannot be expanded by the addition of new frequencies. Unless there is a major electronics breakthrough, the desirable frequencies like prime real estate will continue to appreciate in value and resulting conflict over use and application. Therefore, any discussion of spectrum availability is a discussion on how it will be allocated and regulated[26]. Acquiring a license to use a frequency is an expensive and time-consuming process. The approach of simply granting exclusive access to each potential user causes problems because there are too many potential applications/users and not enough frequencies. To make matters worse, a significant part of the existing allocated frequencies are unused for large portions of time (Steenstrup, 2005). According to Steenstrup, a frequency may be allocated to a service that is not yet active or may be suboptimal for the desired use. Therefore, control of a desirable frequency or frequency range is akin to holding the "right of way" to build a road to your customers using the easiest and most desirable path. Peha (1998) argues that the problem of frequency availability can be addressed by new ways to share and reuse existing frequencies. Peha (2007) suggests integrating economic concepts such as applying ideas from land rights management that allow subdivision and expiration of rights, with technical approaches such as new forms of micropayments which allow "pay per use."

An interesting example is the FCC auction of the UHF TV (700 MHZ) spectrum (FCC, 2007). The 700 MHz spectrum is particularly valuable because signals can travel a long distance and go through walls and it is a well known frequency band since it was used for analog TV for many years. The winning bidders will get access to the spectrum in February 2009. At one point, Google stated an intention to bid at least $4.6 billion on these frequencies. Google required that networks using the spectrum be "open platforms". Open platforms must support any device, any software such as browsers, and networks which can connect with each other. Also, it would be necessary for providers to lease capacity to other providers. The FCC agreed to open devices and software, but has not agreed to the connection and capacity lease requirements. More than 266 bidders including Google, Verizon, and AT&T, submitted applications. Google eventually dropped its bid. The big winners were traditional telecommunications corporations, such as Verizon. One implication is that those traditional firms who have capital will end up controlling the spectrum and leave little room for competition.

Another important recent governmental development was when the U.S. Supreme Court reached a decision in *Nixon v. Missouri Municipal League* which confirmed that municipalities could set up municipal wireless networks (MWN) and sell access to the public. At that time, there were already approximately 100 MWN projects in various stages of progress around the country. However, all of these were in small municipalities. The Supreme Court judgment encouraged much larger municipalities to consider MWN projects. All this interest and activity at the state level has prompted the U.S. Federal Government to initiate an overhaul of the Telecommunications Act of 1996 to address MWNs and other similar local-level broadband Internet access efforts.

At the state and local level, there are also regulatory challenges for wireless. Kim (2007) suggests that more than 100,000 new cell sites are needed to meet future cellular phone growth alone. About half of these sites will require new towers because they are in rural areas where few suitable tall structures are available. Communities react negatively to such structures based on aesthetics, property values, and increasingly health concerns. Communities then tend to enact local ordinance and zoning laws as deterrents or simply place projects on hold because they have no applicable laws. Kim suggests various solutions such as co-location, use of public property, financial incentives, and pre-emptive federal laws. Any regional or national wireless infrastructure regardless of architecture (Wi-Fi, WiMAX or cellular) will require base stations arranged in some kind of cellular grid. However, there are no easy or regionally consistent solutions available to deploy such stations.

Standards. Standards are considered a universal good because they drive down prices and enable interoperability. Yet, according to Pucker (2006) wireless standards are more complex because they: (a) commoditize technology, (b) create market alliances among participants, (c) allow one participant to embed their intellectual property into the standard for future gain, and, (d) block or postpone the introduction of a particular technology. There are more than 15 organizations that create standards at different points in the wireless value chain and they exhibit all of the above characteristics. The end result is a proliferation of standards. Therefore, competition in wireless will not only occur over specific products or firms but also between groups of vertically or horizontally related firms that support particular standards (Pucker, 2006). Competition over standards is healthy because the existence of a standards group indicates that there exists a business case for that particular configuration of technologies. Managers will therefore have to become aware of not only the technical merits of particular standards but also their "competitive" role in the industry.

**Key Competitive Environment Issues**

1. The wireless value chain is fragile. New entrants can enter the industry relatively easily and can cause significant change and disruption.
2. The tension between established telecommunication providers and innovative new application users will increase. We will see more network blackouts and brownouts and legal action as a result of content users riding on the networks of established firms.
3. Regulation and legislation will likely increase given the increasing interest in ubiquitous Internet access and new issues such as "net-neutrality."

# Applying the Model

The purpose of the five layer wireless 1.0 model is to enable managers to think about wireless in a holistic manner so that they can make informed decisions. Toward that end, the model represents a checklist of issues to consider. Each layer in the model should be considered a major question with the individual items within each layer providing secondary level questions.

A relatively simple example and application is internal organizational deployment of wireless to enable Internet access for employees and customers. At the spectrum layer you will need to consider available channels (frequencies) and how they will be used. If you have major electronic interference issues in your area then the modulation scheme used by the vendor may have a major impact on your realized bandwidth. The modulation scheme may be a function of the chipset used at the device layer, which may impact quality of service decisions and guarantees at the management layer. Quality of service requirements will consequently impact the choice of architecture. For example, WiMAX or cellular data may turn out to be superior to traditional Wi-Fi. Finally, the competitive environment at the fifth layer will indicate how to best source the product and whether it makes sense to invest now or wait.

A more complex example is a content provider such as a news organization that is considering the challenge of reaching customers that ignore traditional outlets such as print and TV. These customers instead consume information in small doses through cellular data enabled smart phones while sitting on a train or video game consoles at home (e.g., the Nintendo Wii has a news channel enabled through Wi-Fi). For this kind of organization, the most important entry point in applying the model is to consider the competitive environment chipset manufacturers, hardware and software vendors, and service providers. These firms are potential partners, or the news organization may decide to control more of the value chain by integrating some of the elements together. If the goal is national rollout on a large scale then maturity of standards at the management level may influence the choice of wireless architecture. Further, experience with particular frequencies at the spectrum layer may help in determining the best partner or backhaul provider. The availability of partners will help decide on a hardware only custom solution versus a software client that operates on existing devices. The Amazon Kindle book reader device is an interesting example of a content distributor that has applied a systematic and holistic approach to wireless 1.0. The wireless connection is provided by Sprint but the end consumer never considers access issues or costs and only interacts with the distributor.

A third application is the health care industry. The healthcare industry is complex and includes many stakeholders who all need to interact. Consider doctors; they increasingly use wireless devices such as Smartphone's to access reference material or to display information needed to make a diagnosis. For example, some firms are now marketing portable devices that can instantly display an X-ray in any location and with enough underlying bandwidth that the images show at a usable resolution. These devices are used in multiple environments as doctor's move from room to room and facility to facility. These environments can dramatically influence the availability of the wireless spectrum in terms of interference and reliability – the first layer of the wireless 1.0 model. Yet, the scope for creating new devices such as "electronic charts" that support mobile work is tremendous. These devices will however have to consider size, form factor, power draw, available chipsets, and all the other issues identified in the second layer of the wireless 1.0 model. Further, at the third management layer, the issues in terms of security and quality of service are even more important for healthcare related information. The architecture issues at the fourth layer are just as critical especially in terms of interoperability. Different healthcare facilities may end up supporting incompatible architectures that do not work with each other; this would result in chaos for doctors used to working in multiple hospitals and clinics. Finally, at the competitive layer, given that the healthcare industry is large and seen by many as having access to immense resources; it is highly likely that the competition will be intense. It is entirely possible that vendors may create unique chipsets, hardware and software, services, and content, and competing standards to service the industry. The competitive pressures may end up dictating all the other elements of the wireless 1.0 model.

# The Future

What will wireless 2.0 look like? What are current and future challenges for wireless? In this section, we present a list of questions that will determine the future of wireless.

*What will future wireless devices look like?*

Will the iPhone grow into the Alan Kay "Dynapad" – a portable do everything communicator, computer, and entertainment device or will the future consist of many different wireless devices co-existing with each other and sharing information with each other?

*What will a ubiquitous wireless infrastructure look like?*

Will large telecommunication firms deliver on a universal, low cost, high bandwidth, easy to use, and reliable ubiquitous national or international wireless infrastructure? Or will other firms or governments who control different parts of the value chain seize the opportunity? Will this infrastructure be provided by one monopolistic firm or a collection of firms that will create standards to interoperate?

*Are highly integrated convergent wireless devices technically feasible?*

Is it feasible to create a general purpose chipset that can be "tuned" to different frequencies? (Or an electrical interface that allows swapping in one chipset for another). Without such a breakthrough, manufacturers will be forced to use multiple chipsets in the same device, resulting in higher power draw, requiring larger batteries, larger form factors, interference problems, and longer and costlier development cycles.

*Is it feasible to create a design framework and application programming interface that affords developers the tools to build applications on top of highly integrated convergent wireless devices?*

Prior to the development of the browser, client server applications required development of versions for multiple computer and operating system architectures. As the browser and other "write once – run anywhere" technologies were developed applications could run in a browser environment and run on multiple devices supporting multiple service levels. There is no "write once – run anywhere" technology available which crosses the spectrum of wireless technologies. The Google Android project is a promising start because it creates an abstraction layer that includes drivers for wireless architectures such as Bluetooth, and Wi-Fi (GSM will remain hardware dependent), libraries to manage media and data, and a standard operating system level application framework. However, Android is a software only project which is still waiting for the hardware and chipsets to catch up.

*Is there demand for more wireless devices or highly integrated convergent devices?*

Will users accept and adopt complicated integrated wireless devices that do everything? Will they continue buying and using more and more wireless devices in general? Are there adoption and usage challenges that are unique to wireless devices?

*What is the impact of the extreme multitasking afforded by highly integrated convergent devices on user behavior and productivity?*

Will such devices increase or reduce productivity? Will users be able to take advantage of extreme multitasking?

*What is the business model for manufacturing, selling, and maintaining wireless devices in the future?*

The wireless value chain shows that there is no obvious industry or firm that has a unique advantage in the marketplace. Is a traditional large telecommunications service provider with a large infrastructure base, best qualified to be the front line of corporate and consumer use? Or are hardware and software firms better qualified and able to handle the challenges of producing compelling applications? Will the killer application come from a content firm or be enabled and best imagined by a chipset manufacturer?

*Can the wireless spectrum be used and managed for greater good and impact?*

Are their faster and cheaper ways to manage spectrum and make it available to innovative new firms and ideas? Should new allocation schemes be created? Should spectrum allocation become privatized?

*What is the appropriate locus of research on wireless devices?*

Wireless devices enable mobility of people and objects, commerce, communication, entertainment, tracking, infrastructure avoidance, and distribution of computing power. What is the appropriate future locus of research on wireless devices? Concepts that sit between technology and use such as "mobile computing" or "mobile commerce" are useful for looking back and understanding application and usage. However, since they are not tied directly to technology, they do not fully afford all the potential capabilities and constraints. In 2000, the hype about mobile e-commerce was very high with both industry analysts and academics proclaiming new paradigms and new frameworks for thinking about technology. Yet, the underlying usability and wireless connectivity options of cell phones and other related devices was poor, for all practical purposes mobile e-commerce was never realized as originally envisioned. However, usage of wireless devices has continued to explode. We need lively debate on the how to best build and study wireless.

# Conclusion

If one were to trace the trajectory of developments in wireless since the mid-nineteenth century, it is astonishing how much progress has been made in so short a time. Each progressive generation of wireless technology has made unique and far-reaching contributions to enable business.

As the lines between different kinds of networks blur, as different kinds of devices turn out to be essentially the same black box driven by different kinds of software and content, as seamless multi-device handoff and roaming become taken for granted we will enter into a new age of wireless. The changes may be conceptualized as a series of tensions that will pull wireless in different directions. The tensions include debates regarding centralization vs. decentralization, hardware vs. software, more vs. less regulation, network backbones that comprise the "real" network vs. peer-to-peer guerilla networks that piggy-back on the "real" network, growing existing architectures vs. making way for new architectures.

To summarize, the contributions of this paper include (a) providing a comprehensive and comprehensible analytical model of Wireless 1.0, (b) generating new insights on the emergence of the next generation of wireless opportunities and challenges, and (c) providing a model that managers and researchers can use to conceptualize and study wireless in the future.

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# End Notes

1 When asked about wireless applications, about 66% chose e-mail, the next most popular choice was CRM at about 30%. In contrast, 76% said that they adopted wireless to develop applications and uses. For more information see Mandviwalla and Jain (2006).

2 Radio waves are electromagnetic waves that travel through space as sine waves. Data is encoded on to radio waves as zeros and ones by manipulating their basic characteristics such as amplitude and frequency. A sine wave varies over time and is repeated in cycles. For each cycle the amplitude starts at zero, increases to its maximum positive value, returns to zero, and decreases to its maximum negative value before returning to the zero value.

3 The table is based on the frequency allocations of the FCC Office of Spectrum Management (2003). The number of complete cycles in one second is the frequency and is measured in hertz (Hz) where 1 Hz is one cycle per second. Wireless frequencies are typically measured in MHz (1 million cycles per second) or GHz (one billion cycles per second).

4 A band is a block of frequencies, for example, the 2.4 GHz band ranges from 2400 MHz to 2483.5 MHz. A band is typically divided into channels. For example, the Bluetooth specification divides the 83.5 MHz bandwidth available in the 2400 to 2483.5 MHz range into seventy nine channels of 1 MHz each (some of the range is used for control purposes). The actual physical transmittal of data then occurs over one of these channels.

5 For example, a phenomenon known as tropospheric ducting can bend a local signal due to changes in temperature and create a "duct" that will transmit over 800 miles!

6 For example, amplitude modulation (AM) is the process of using a low voltage signal to represent a 0 and a high voltage signal to represent a 1. If the carrier wave operated at 1200 Hz, and noting that each hertz is equivalent to one cycle per second, then the theoretical data transmission rate would be 1200 bits per second (BPS). However, this simplistic technique is not used by devices today. Transmission occurs at higher speeds because much more data is packed into the signal, for example, rather than varying the signal between two voltage levels, it could be varied among four voltage levels. Quadrature amplitude modulation (QAM) and quadrature phase shift keying (QPSK) are common modulation techniques and de facto standards.

7 For example, in frequency division multiplexing (FDM), different signals in a single channel are assigned different frequencies so that they avoid interference with each other. In time division multiplexing (TDM), multiple signals are given time slots within the same channel so that the channel can support multiple connections simultaneously.

8 Orthogonal frequency division multiplexing (OFDM) is increasingly used in wireless applications; a key characteristic of OFDM is that the carrier frequencies are chosen so that they are orthogonal to each other. The orthogonality of the signals resists interference and distortion.

9 The technically correct usage of the term bandwidth is to refer to a range of frequencies. For example, the Bluetooth specification calls for a bandwidth of 83.5 MHz between 2400MHz to 2483.5MHz. Continuing with the technically accurate meaning, a bandwidth of 83.5MHz is wider and can pack in more data than a bandwidth of only 1MHz. In this paper, we continue with the common interpretation of bandwidth to mean the overall speed of transmission and assume it summarizes issues of frequency width, speed, density and so on.

10 Range is how far the device can operate from a base (see next section), power draw is the amount of electricity consumed during standby and while in use.

11 Modu has found an interesting way to overcome these challenges. Their "jacket" concept allows a single very small device to "wear" many different feature sets. See http://www.modumobile.com/ for more information.

12 Omni-directional antennas broadcast a signal in all directions along the horizontal plane making it easier for users to access. However, Omni-directional antennas are inefficient because they radiate in all directions. Directional antennas broadcast a signal along a narrow corridor in one direction and are useful for relay purposes, e.g., to support point-to-point links to carry a signal over a long distance. Smaller antenna sizes typically require additional energy per bit to maintain reach. Similarly, if there are obstacles that absorb the signal, e.g., walls inside a building, then the signal needs more energy per bit to maintain reach. New kinds of antennas are under development. Multiple/input multiple output (MIMO) refers to a set of approaches that increase the number of transmitting and receiving antennas to increase reliability, range, and achieve higher bandwidth. The premise for MIMO is that the slight variations in which different antennas receive and transmit can be used to amplify signal strength or pack more data into channels. MIMO is considered very important in realizing higher wireless bandwidths (Andrews et al., 2007).

13 This kind of sustained connectivity to a larger network is called a backhaul.

14 We use the term "management" here analogous to how the term "network management" is used, i.e., to refer to operational issues related to controlling, deploying, and securing wireless transmissions.

15 The respondents were asked to identify issues

governing adoption and usage of wireless in their organizations. We received 82 responses, which represented a range of industries, size (about 40% had annual revenues greater than $100 million), spread around the world (about 45% were in North America).

16 See Wakefield et al., 2007, chapter 1 for a summary of all the different standards groups.

17 QoS is the ability of a network to differentiate and prioritize between the needs of different traffic going through the channels. For instance, live video needs high priority (a gap delay would reduce the quality of the experience), whereas textual email usually needs lower priority (a few seconds delay is acceptable).

18 Encryption is a process whereby the content of a message is coded using an algorithm and a key. Even if some unauthorized entity listens to the message, they will not have the key code to unlock the message. Authentication is a process whereby the network is able to confirm that an entity using the network is authorized to do so.

19 Roaming is the movement of a client from one base station point to another without losing connectivity. Handoff refers to the process whereby different kinds of networks can pass signals to each other while maintaining the connection for the user and without requiring a new login.

20 See Dekleva et al., 2007 for a trend analysis of wireless architectures.

21 The usable range of the radio signals is charted based on personal space (e.g., connect a cell phone to a Bluetooth headset), a building such as a home or office, a set of buildings or campus, metropolitan area, and a geographic region. The application of the architecture is charted based on transactional data (mostly text), graphical data that is the norm on websites, audio applications such as two-way calls, and video streaming and conferencing.

22 The internet is packet switched and the need to interoperate with the internet will ensure that all future wireless networks look like packet switched networks. Packet switching is when the data is divided into small packets at the source, transmitted separately, and then reassembled in the correct order at the destination. If there are multiple paths between the source and destination, then different packets may take different paths to get to the destination. Sometimes, packets will get destroyed or corrupted en route and the destination will re-request the missing packets from the source. All of this happens fast enough that in most cases, the end-user at the destination will be able to receive complete information in near real-time conditions. Standard telephony and cellular voice is circuit switched because a dedicated connection is set up between two speakers. However, two speakers talking over the telephone use only a tiny fraction of the connection's capacity. During such a conversation, information is transmitted one-way most of the time (wasting at least half the capacity of the connection's two-way transmission capabilities), and the carrying capacity of such a connection far outstrips the capacity required to carry human voice. The advantage of a dedicated connection is very little delay in the conversation as compared to packet switching. .

23 Wi-Fi security was originally implemented using a standard called wireless equivalent privacy (WEP). However, WEP is inadequate and was eventually followed by the much more secure Wi-Fi Protected Access (WPA2). WPA2 is based on the IEEE 802.11i standard but was introduced by the Wi-Fi alliance prior to final approval in response to market needs.

24 Mesh networks have dynamic path configurations and are self-healing. If one node fails, transmission can take place along alternative paths. Further, if there is spare capacity in some part of the network, the network can re-route packets along that part, thereby balancing itself.

25 WiMAX uses an adaptive scheme so that users' bandwidths can be increased (or decreased) to compensate for conditions such as noise or low signal strength. It is difficult for the small antennas in mobile devices to capture a long wavelength signal effectively. WiMAX's adaptive bandwidth allocation scheme makes it possible to use wider bands when a device is stationary and narrower bands when the device is in motion. All WiMAX base stations are required to include dedicated processors so that security-related processing does not adversely affect transmission.

26 See Estache et al., 2006 for a summary of the impacts of regulations at the national and social levels.

# Acknowledgements

We would like to thank Jeff Smith and Sankaran Somasundaram for their work on previous versions of the paper. Mart Doyle provided valuable feedback and helped come up with the layer model described in this paper. Pat Lyons did some of the basic research on wireless technologies and his work was the basis for Appendix I.

Kent Seinfeld, former CIO, Commerce Bank, and E. Carey O'Donnell, President, Mesa Technical Associates provided valuable feedback on this document.

# Appendix I

There is no one source that provides reliable and comparable data on real world wireless usage. We had to create estimates using small real world tests or by integrating many different sources. The numbers in Table 3 are provided in a range. The lower number is based on typical poor conditions and the higher number is based on typical good conditions. We do not report theoretical maximum or minimum numbers. Further all the numbers are reported from the client device perspective or what is known in telecommunications as consumer presence equipment (CPE). For example, in cellular, power draw would be very different for a cell phone vs. the access tower. We focus only on the client (cell phone) numbers.

We focused on the following versions of the specific architectures. The numbers reported in the Table are averaged across the versions listed below.

- Cellular: 2.5G and 3G architectures (GPRS, EDGE, UMTS, HSPDA, and EV-DO)
- Wi-Fi: 802.11b, 802.11g, and 802.11n
- WiMAX: 802.16e
- Bluetooth: Class 1 and 2
- RFID: Passive or semi-passive tags used for tracking packaged goods.

**Range**

The correct concept for assessing range is propagation. Propagation refers to how well and how far a wireless signal can travel between nodes. However, we were more interested in what is commonly known as "range" – i.e., what is the typical best and poor distance that a signal can travel to a client device using each of the respective architectures. The low number in the table is thus a typical poor distance followed by a typical good distance. We created the following two conditions for assessing range:

1. Under ideal conditions which include flat terrain, no buildings, low population density, low volume, ideal environmental conditions, what is the maximum distance that the frequencies and architectures can reach?
2. Under poor conditions which include hilly terrain, steel and concrete structures, high population density, high volume usage, what is the best distance?

Additional sources included:

- Bluetooth: http://bluetooth.com/Bluetooth/Technology/Basics.htm#5
- Wi-Fi: http://www.wi-fi.org/retailer_technical-information.php

**Bandwidth**

The correct term for what we report in the table is throughput. However, consistent with popular usage we report data rates and throughput using the term bandwidth. The reported ranges are an approximation where the low number is based on typical poor conditions, and the high number is based on typical good conditions. The numbers were estimated after assessing the results of the following questions:

1. What is the maximum theoretical data rate in bits per second possible for the following frequencies and architectures? Assume ideal "laboratory" theoretically perfect conditions including flat terrain, no buildings, low population density, low volume, and ideal environmental conditions. Please ignore historical usage precedents. For example, the medium frequency band has been used for AM radio with low data rates. Assume you have full control over that frequency range and within reason can blast a powerful signal on that frequency range. Also assume (if you need to) you can spec your own chipset design to get the best data rate.
2. What is a "reasonable" "real world" data rate in bits per second for the following frequencies and architectures? Assume real world conditions such as typical interference from other signals, obstructions, urban environment, high population density, varying environmental conditions.

**Power draw**

The range is based on idle (low), typical, and high usage. It was calculated by evaluating the specifications of components available at electronic component distributors including Mouser Electronics (http://www.mouser.com/), Digi-Key Corporation (http://www.digikey.com/), and Newark (http://www.newark.com/). For each architecture, components from well known manufacturers were examined based on the following questions and guidelines:

1. What is the minimum and maximum power usage requirement in milliwatts for each architecture? Please answer this question from the user device perspective.
2. We don't care about the power requirements for the towers/routers/nodes that the user devices will connect to.
3. We need a range for each architecture so that readers can distinguish the power requirements among the different architectures. We understand that the answer for each architecture will vary based on the available specific chipset and other device specific parameters. So if needed, pick the most well known or popular chip set as a reference and cite that. If you do pick a chipset please include a discussion of whether the power requirements can be reduced over time through improvements in chipset design and what the theoretical minimum could be.

Additional sources included:

- Wi-Fi: http://www.rfcafe.com/references/electrical/wireless_comm_specs_new.htm
- Bluetooth: http://bluetooth.com/Bluetooth/Technology/Basics.htm (we combined numbers for Class 1 and Class 2 devices)
- RFID: Wireless Dynamics at http://www.sdid.com/products.shtml. The numbers for RFID were estimated using a specific reader/writer and an active tag (i.e., powered tag).

# Appendix II

| Specification | Description |
|---|---|
| 802.11k | Improved network optimization. |
| 802.11r | Fast handoff - maintains user authentication so that the connection is maintained each time the user roams from one base station to another. Expected in 2008. |
| 802.11s | Mesh networking standard (see below). Expected in 2009. |
| 802.11u | To internetwork with external networks such as cellular. Expected in 2009. |
| 802.11v | Wireless Network Management - defines common commands and protocol messages for the management of large scale networks. Expected in 2009. |
| 802.11w | Protected Management Frames - Protects against network disruption caused by malicious systems. Expected in 2008. |

**Table 1: Upcoming Wi-Fi Improvements**

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As executive director of the Institute for Business and Information Technology, Mandviwalla leads a full service institute that engages with industry at multiple levels including research and human capital development, and provides faculty and students with funding, scholarships, contacts, and professional development. As the founding chair of the department of Management Information Systems, Mandviwalla leads the research and teaching activities related to information systems for the Fox School of Business. He holds a BSc in Systems Engineering from Boston University, a MBA from the Peter F. Drucker School of Management at Claremont Graduate University, and a Ph.D. in Management Information Systems from the Programs in Information Science at Claremont Graduate University.

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Paul has held numerous management positions at CIGNA Corporation including Corporate Systems and CIGNA's technology research organization. In 1984, Paul was named Vice President, CIGNA International Life and Group Systems, based in Reigate, Surrey, England, and managed staff in England and Japan, developing and deploying systems worldwide. Paul joined Aetna in 1991, to run Aetna's healthcare administrative systems organization. In 1994, he returned to CIGNA as Senior Vice President, Managed Care Systems. Following this assignment, Paul became responsible for the technology component of CIGNA's eCommerce strategy, focusing on the development of integrated employee benefits services.

Paul's teaching interests include emerging technologies, the integration of object oriented technology and business structures, and the management of information systems organizations. Paul is a member of the Information Systems and Technology Council of the American Management Association (AMA). The Council is a group of CIOs which helps develop the strategy for the AMA's course and publication offerings in IT. Paul serves on the Ben Franklin Technology Partners' technology review board and is also a member of the EMBA faculty of Temple University, Japan.

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