The Technological Fundamentals of Successful Wireless Applications

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Preface

This report is the culmination of many different experiences that have spanned a variety of technology-focused endeavors during the past 17 years of my career. Despite the varied sources, the report has a singular focus on the reoccurring theme that I have heard: that being the relationship between technology and business, and in particular for me, the dynamics in how wireless technology can be used to implement successful applications and businesses. In addition, through my various career endeavors, which include engineering positions at a wireless technology startup (Uniplex Corporation) and an established telecom equipment provider (ADC Telecommunications), as well as a wireless analyst position in the investment banking industry (with RBC Capital Markets/Dain Rauscher Wessels) and various consulting assignments, I have often been surprised by the diverse levels of wireless technology knowledge that exist among individuals participating in the industry in one facet or another. As a result, I have long believed that the industry could use a better analysis that has a dual focus on explaining wireless technology in straightforward terms while conceptually connecting that technology to relevant business aspects that drive the commercial success of applications and businesses. That is the objective of this report.

Ultimately, however, achieving that objective is quite difficult. Certainly from a practical standpoint, the industry has had many knowledgeable and experienced people attempt and fail at well thought-out and well financed wireless ventures that had, at their core, the similar objective of leveraging wireless technology into a successful commercial enterprise. Fortunately, though, the industry has also had a great many successes that allow the driving factors (both technological and business) of the successes and failures to be compared, contrasted and ultimately filtered down to a set of core fundamentals that are worth remembering in regard to the planning and assessment of wireless initiatives. Ultimately, there is no precise method of deriving those fundamentals and it is the combination of an empirical industry analysis, principally derived from the numerous companies and industries I studied while in the investment banking business, and my own technology industry experience that forms the basis of the material for this report.

Finally, there is no doubt that a characterization of all the factors driving successful wireless ventures would be a highly complex analysis and would ultimately still include significant unknown factors from the continually shifting landscape of the marketplace. This report should not be interpreted as that all-encompassing. While an understanding of the material presented in this report certainly does not guarantee success, it does, I believe, point one in the right direction, based on time-tested technological fundamentals, and further represents the elementary building blocks of wireless applications and the corresponding success drivers of businesses built on those applications.

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Introduction

It is usually quite easy to observe an industry retrospectively and identify the successful applications, and marginally more difficult to identify the principle characteristics that drove those successes from a high-level application, product or business perspective. An analysis of the more detailed aspects can sometimes be quite difficult. However, this type of market and application analysis is often used with the intent of deriving those core success factors so they may be reapplied to new application initiatives and, in turn, result in new success. While it would be nice if the equation for success were that straightforward, the reality is considerably more difficult. In technology industries in particular, a layered market or application analysis can go quite deep into difficult technological issues that require highly specialized knowledge and are far removed from business and market concerns. As a result, a conceptual gap can develop in the formulation of core success factors between the details of technology and the application/business issues — i.e., the classical engineering-marketing disparity. This can often result in new technology products that do not meet the application or business expectations and ultimately result in product failure.

This also is certainly true of the wireless industry, because it can be difficult to identify the more detailed technological factors that drive successful applications, products and businesses. For wireless communications, these difficulties can often be attributed to the inherent nature of wireless and the common view that product implementations and successful applications are often more art than science. That view is not exactly true, however, and this report's intent is to derive a set of technological fundamentals that have held true through time and across applications, and that can be used as general guides in the pursuit of leveraging wireless technology into successful applications and businesses.

While these fundamentals can be technologically complex, the report will focus on high-level conceptual knowledge for both the technical and non-technical reader. Ultimately, however, these technological fundamentals are fairly tangible, in both concept and application, and can be applied to the entire chain of wireless technology, products and services and leveraged into such activities as product conceptualization and planning, business development, competitive research, market opportunity assessment, business strategy and investment analysis.

The report is divided into four sections. The first is a wireless market analysis that focuses on the empirical derivation of the technological fundamentals based on real market examples. The following three sections address those technological fundamentals in more detail as they apply to the general application characteristics of coverage, performance and product implementation/usability. The report overall, though, focuses on the technological fundamentals as they apply specifically to applications. In the wireless industry, growth companies, after all, are built upon successful applications. Growth markets, in turn, are built upon a group of successful companies capitalizing on a common opportunity, and growth industries are built upon the mutual success of those markets. From a very basic perspective, the technological fundamentals for wireless applications are the root source from which growth sprouts to all levels.

Fundamentals for Success

Determining the fundamentals that drive success in any industry is far from an exact science. In fact, this report will focus on an empirical analysis of the wireless market and a top-down approach to developing the technological fundamentals. This top-down approach will start by framing the wireless market within the larger communication industry and as a result, focus on the high-level characteristics that drive the wireless market overall — i.e., the wireless golden rule. The remainder of this section will use a divide and conquer approach to separate the wireless market into segments that exhibit similar technological and application characteristics. Application examples will then be used to illustrate the key technological drivers of successful applications and to show deficiencies in applications that may not have succeeded to the extent initially expected. Ultimately, however, the objective is to derive the technological fundamentals that most impact the general application characteristics of coverage, performance and implementation/usability from a non-sector specific perspective. In this way, we can establish a set of guiding principles that are applicable across sectors and to new applications and wireless initiatives. These technological fundamentals are listed at the end of this section under the respective headings of coverage, performance and product implementation/usability and reference the corresponding, more detailed sections later in the report.

The Golden Rule of Wireless

Before delving into the detailed market analysis, it is important to understand the general competitive landscape in which wireless communications operates and the high-level characteristics that drive the wireless industry overall. After all, wireless communications is simply one medium in the entire universe of communication technologies and must therefore compete with other technologies in the broader information communication marketplace. In surveying wireless communications through history and across sectors, it becomes clear that every successful wireless application leverages unique capabilities and benefits of non-wireless technology that establish those solutions as the winners in the market. At a high level, there are two fundamentals of wireless that define these unique capabilities and benefits and thus drive successful applications. These fundamentals are 1) mobility, and 2) advantageous deployment economics. Mobility refers to the extent to which applications use the inherent untethered nature of wireless. Advantageous deployment economics refers to an application's ability to use wireless to implement communications easier, more cost effectively or faster than other communication mediums or simply communicate where other mediums cannot go. ***Simply stated, the golden rule of wireless is that successful wireless applications must leverage mobility, advantageous deployment economics, or both, into unique communication solutions — otherwise, the benefits of wireless are lost.*** In fact, if a wireless application does not leverage one or both of these characteristics, it is most likely destined for failure in the broader communication marketplace because it will likely encounter competition from superior solutions that leverage a different communication technology.

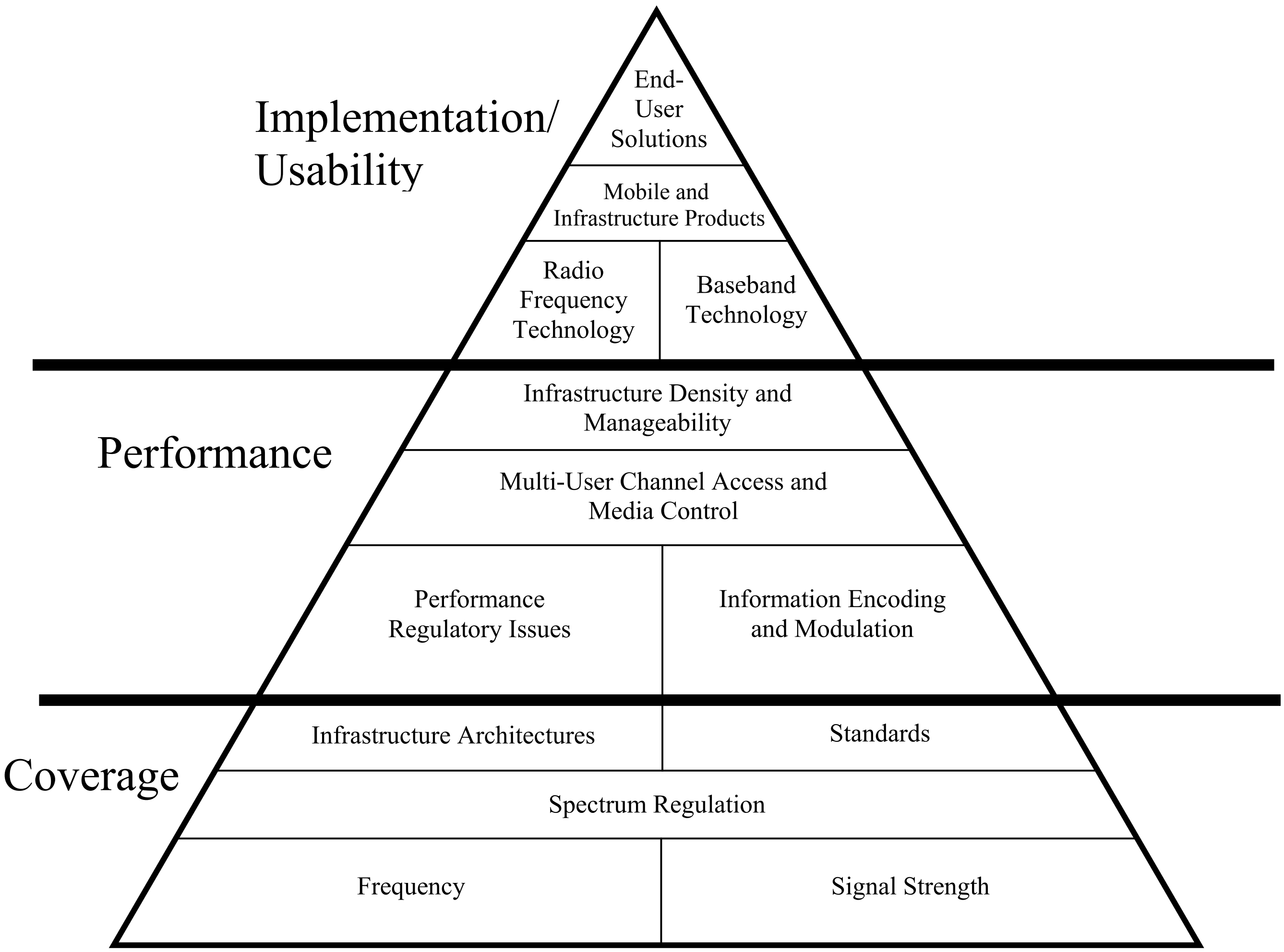
In addition, there is an implied priority order to the two fundamentals of mobility and advantageous deployment economics and the extent to which each drives successful wireless applications and differentiates from competition from other mediums. Mobility is obviously the more important driver and leverages unique characteristic of wireless to communicate in an untethered fashion. Solutions from wired mediums cannot effectively compete with this characteristic. Advantageous deployment economics is clearly a secondary driver and encompasses all other application characteristics that are not driven by mobility. Applications such as fixed wireless communications and semi-mobile or nomadic wireless communications are typically driven by advantageous deployment economics. However, applications driven by deployment economics carry additional risks because they are more prone to direct competition from other communication technologies. In these applications, wireless technologies typically deliver solutions that are slower and more expensive than wireline equivalent solutions and as a result must focus on application characteristics such as quicker deployment, lower overall cost (in not having to deal with connecting wires) or simply communicating through a wall or some other special circumstance where wireless is the only solution. Ultimately, it is a complex combination of technology, product or service characteristics focused on meeting a market demand that determines if an application will be successful. But mobility and advantageous deployment economics are clearly the two defining, high-level fundamentals of the capabilities and benefits that make wireless applications successful.

Wireless Market Analysis

The principle objective of this market analysis is to arrive at a set of technological fundamentals proven to be the core drivers of successful applications by conducting an empirical analysis of market examples. Those fundamentals will then be related to the general application and business issues that drive success in the market. To achieve that, this analysis uses a methodology that examines the general characteristics of wireless applications across industry sub sectors and emphasizes the technological features responsible for the specific application attributes that drive success. These technological features are then distilled into the general technological fundamentals that can be applied across all sectors, and thus generally applicable as market-proven drivers of success.

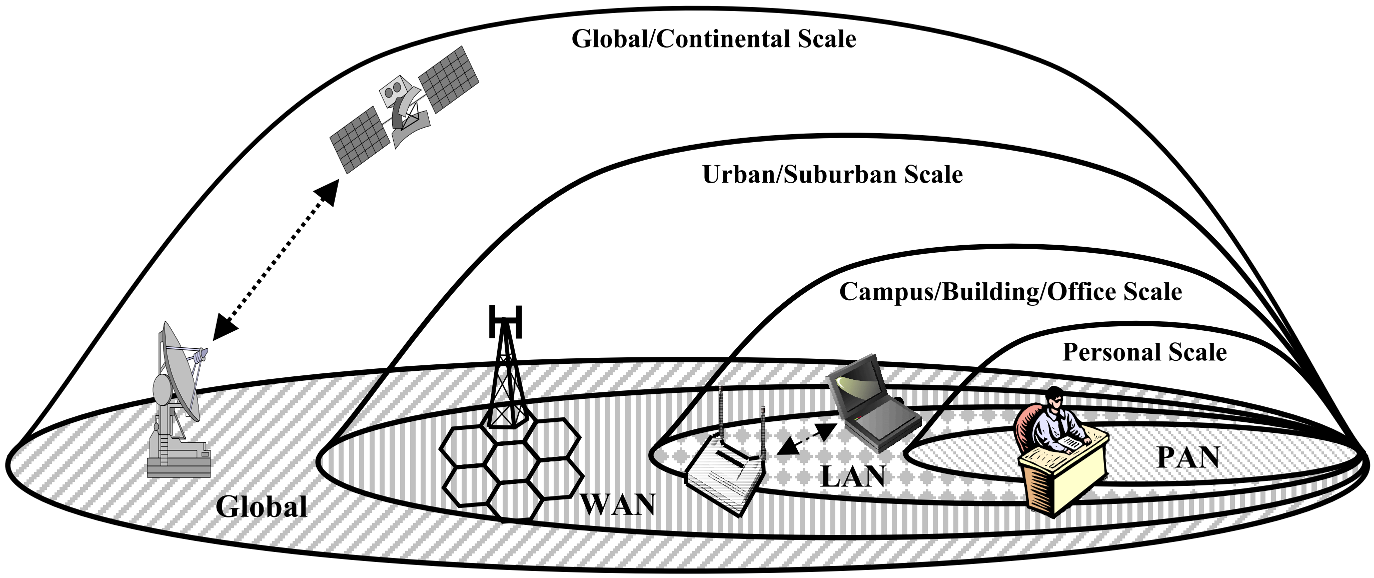
This analysis will focus on three general applications characteristics: coverage, performance and implementation/usability. Figure 1: Technological Fundamentals Pyramid, is a pictorial representation of these three application characteristics and the topic within each that will be addressed in this report. Coverage is a characteristic that refers to the geographic area over which wireless communications is available and is unique to wireless in terms of the extent to which the untethered capabilities of wireless enable communication and mobility. Performance is a classical characteristic of any communications application, but for wireless applications in particular, it refers to not only data rate and throughput performance, but also to multi-user access and subscriber capacity performance. The last general application characteristic encompasses a wide variety of application attributes associated with the customer-facing issues regarding product implementation/usability. At first glance these may seem like separate categories, but the two are closely related. Product implementation is ultimately guided to a large extent by how the product will be used, and usability includes not only product features but also service features and system integrated solutions. In total, these three general characteristics are designed to encompass all pertinent features and capabilities of an application and categorize the defining application attributes from which the technological fundamentals can be discerned. This information is included in Figure 1 as a pictorial outline of the detailed explanations of the technological fundamentals presented in the last three chapters of this report.

Figure 1: Technological Fundamentals Pyramid



The industry sectors across which the three general characteristics will be analyzed are focused on applications — i.e., the industry as categorized by application. The most effective technique to dissect the industry by application is via coverage. As will be presented in the analysis of the sectors, applications grouped according to similar extents of coverage generally also have similar application objectives. Figure 2: Wireless Application Segments, shows a commonly used diagram that groups the industry applications into four sectors according to coverage: personal area networks (PANs), local area networks (LANs), wide area networks (WANs) and global networks, with the names of each sector implying the communications coverage. Figure 2 also lists some representative successful applications and the significant coverage, performance and implementation/usability attributes for these industry sectors.

Figure 2: Wireless Application Segments



Global Network

Successful Applications
- Satellite television and radio.
- Global Positioning System.
- Can be driven both by mobility and advantageous deployment economics.

Coverage
- Designed for communications and broadcast to far-spanning points on the globe.
- Able to cover large geographic areas.

Performance
- Can use extensive amounts of bandwidth for broadcast services and thus have very high overall performance capabilities.
- Other services performance characteristics can vary.
- Multi-user high performance uplink capabilities can be difficult to implement on a mass scale.
- Latency can be an issue.

Product Implementation and Usability
- Satellite based, which accounts for the high cost of technology in this market.
- Deployment costs are substantial
- Can compete directly with other wireline-based mediums, so the cost dynamics and business models must make sense.
- Great for broadcast functionality but struggles with two-way communications and thus has difficultly capturing a mass interactive customer base.

Wide Area Network (WAN)

Successful Applications
- Cellular telecommunications.
- Paging applications.
- Point-to-point fixed wireless.
- Largely mobility driven — i.e., cellular applications, though fixed wireless is clearly driven by advantageous deployment economics.

Coverage
- Metro basis and beyond. Cell sizes and communication ranges can vary greatly, but will typically be on the order of miles.
- Very standards oriented — enabling interoperability and extensive mobility and roaming.

Performance
- Initially delivering voice circuit switched communications, but now transitioning to moderate speed wireless data (20 kbps to more than 200 kbps).
- Multi-access/multi-user capacity performance is a key factor.

Product Implementation and Usability
- High integration on mobile/CPE devices, less integration on base stations.
- Deployment costs are typically quite high. High pricing and cost pressure as service providers struggle with deployment costs/business models.

Local Area Network (LAN)

Successful Applications
- 802.11a/b/g.
- Initially used as mobility driven solutions in vertical market applications, but now used in many different applications driven both by mobility and advantageous deployment economics in horizontal markets.

Coverage
- Moderate coverage range: can be more than 500 feet, though systems can be combined in ad hoc cellular architecture to achieve wider coverage.

Performance
- 802.11x systems deliver maximum 11 Mbps and 54 Mbps, with real throughputs of 3 to 5 Mbps and 10 to 30 Mbps.

Product Implementation and Usability
- Technologies: 802.11x, some cellular/PCS in-building applications, etc.
- Highly competitive tech suppliers in this market.
- Deployment costs are getting less costly all the time.
- Applications expanding exponentially as volumes rise and costs go lower.

Personal Area Network (PAN)

Successful Applications
- Bluetooth.
- Principally used as a wire replacement and thus competes on advantageous deployment economics. Mobility is not much of a factor.

Coverage
- Very short range — five feet to 50 feet, generally confined to a single or few users/devices in a very localized area.
- Standards: Key to product/device interoperability. Bluetooth standard set, others like Ultra Wide Band (UWB) are emerging.

Performance
- Typical wireless PAN links communicate in the 1 Mbps to 2 Mbps range, though future applications may require considerably higher data rates and throughputs.

Product Implementation and Usability
- Applications: typically wireline replacements around a person or the desk and office environment — i.e., mobile device synchronization, etc.
- Highly integrated solutions.
- Competes directly with wired solutions, so cost dynamics must be competitive — i.e., applications require very low component costs.
- Technologies: Bluetooth, Ultrawide Band (UWB) WLANs, infrared, RF ID technology, etc.

Wireless Personal Area Networks

Wireless Personal Area Networks or WPAN applications are generally designed to cover very small areas — e.g., one's personal area — be that simply around their body (e.g., a mobile phone communicating to an earpiece) or around a desk environment at work (e.g., synchronizing a PDA to a computer). Typical communication distances for PAN devices are in the five feet to 50 feet range and are typically intended as short wire replacement solutions. As such, PAN applications are driven more by advantageous deployment economics (i.e., not having to connect a wire) than by mobility. PAN applications can certainly be used with mobile devices such as a mobile phone or a PDA and can even be used in mobile applications such as connecting a wearable computer to a headpiece or a hand-held tablet device. Even RF ID applications tend to be WPAN implementations principally driven by mobility. But to a large degree, WPAN applications are generally not primarily driven by applications where one transceiver is mobile around the other. The most successful applications in this segment are centered on Bluetooth technology, a standard originally developed by Ericsson in 1998 and initially endorsed by Nokia, IBM, Intel and Toshiba and subsequently endorsed by many others. A market report by Instat/MDR in August 2003 placed the 2002 Bluetooth chipset shipments at 35.8 million units, an increase of 245 percent more than 2001 and projected compound annual growth of 74 percent between 2002 and 2007.

From a coverage perspective, WPAN applications are intentionally designed for short-range communications, typically with very low transmit power specifications and minimal antenna requirements and generally use unlicensed frequency bands. Bluetooth applications in particular are limited to 100mW of output power, but typically transmit less because most applications do not require further transmission distances and lower transmit power enables prolonged battery life in the remote connected device. These lower transmit power levels limit the coverage of Bluetooth communications to the five feet to 50 feet distance enabled by the basic transmitter-receiver transmission distance. In addition, most WPAN and Bluetooth applications do not typically use any type of infrastructure to extend coverage beyond that distance. Antennas are typically embedded in the device and do not deliver considerable signal gain to improve that signal's transmission distance. Bluetooth applications use the 2.4GHz unlicensed band, which delivers reliable point-to-point short-range communications but can be obstructed fairly easily (i.e., easier than lower frequency communications) by objects such as walls, filing cabinets, etc. Theoretically, Bluetooth and WPAN applications could use higher frequency bands (i.e., other unlicensed frequency bands in the 5GHz and 10GHz frequencies), because higher frequencies will propagate shorter distances (consistent with the definition of WPAN applications) due to the inverse relationship between propagation distance and frequency. But there is a trade-off with higher frequencies — implementations will also need to factor in additional cost that can materialize due to increased costs of higher-frequency components (which is inconsistent with the low-cost requirements for WPAN applications). In addition, unlicensed frequency applications must share the band with other applications, which is generally not a problem for highly localized communications. The obvious advantage for unlicensed band applications is the ease of user deployment, which has proven to be a significant factor driving market adoption and commercial sales. After the product manufacturer has obtained FCC approval for unlicensed band operation, users of Bluetooth devices, for example, do not need to get an FCC license to operate the transmitter (which is something typically required for higher power transmitters). Standards tend to be an important aspect of these applications principally from an interoperability perspective. This technology can be embedded in a wide variety of devices from different product suppliers, and multi-vendor interoperability among these suppliers is key to market adoption and commercial success. As mentioned previously, Bluetooth is the current dominant WPAN standard. Other emerging standards include ZigBee (a short-range, low data rate solution predominately designed for industrial applications) and Ultra Wide Band (UWB) a very high data rate (100 Mbps to 200 Mbps) next-generation WPAN solution, as well as other standards focused on more vertical applications like RF ID implementations.

Performance aspects of WPAN applications and Bluetooth devices in particular tend to be fairly minimal and focus on simplicity of implementation as opposed to maximizing the bit rate, throughput and bits-per-hertz communications. As a result, the modulation schemes used in these applications are fairly simple and tend to be more robust in the presence of interfering noise. The data transmission performance of Bluetooth devices is currently 1 Mbps, but has provisions in the specification for higher data rate options. The 1 Mbps data rate seems to be adequate for most Bluetooth applications today, but future applications may require considerably higher data communications. UWB is largely considered the next-generation solution for very high data rate WPAN applications. UWB has the potential to deliver 100 Mbps to 200 Mbps over short ranges of 10 feet to 15 feet. Since WPAN and Bluetooth applications are generally designed for highly localized communications, multi-user performance and multi-access protocols are also quite minimal. Again, these multi-access protocols are kept simple because most applications in a localized area do not require sophisticated multi-access techniques to support a significant number of simultaneous communications. This also keeps implementation simple and leads to economical implementation of chipsets.

Product implementation is probably the most significant issue for WPAN applications. As principally a short wire replacement solution, WPAN and Bluetooth applications must compete on an advantageous deployment economics basis with wired alternative solutions — i.e., the short communications cable. So the convenience of not having to connect the cable must outweigh the extra cost that typically accompanies a wireless connection (above the cost of the communications cable). Even mobility-driven applications like RF ID solutions need to be extremely cost effective in the applications in which they are used (i.e., principally implementing smart ID/barcode replacements). Accomplishing a low-cost implementation is not easy and takes time in terms of developing highly integrated solutions. While the Bluetooth specification was initiated in 1998, only during the last year or so have highly integrated chipsets been available on the market at the right price to generate enough industry interest to ramp volumes to the point where Bluetooth can compete with the wired alternatives. The additional benefit of the focus on highly integrated solutions is in terms of enabling long battery life for the remote connected devices. This can be a significant usability factor for a device like a mobile phone that may have Bluetooth synchronization capabilities and depend absolutely on battery power for user operation.

Wireless Local Area Networks

The Local Area Network (LAN) wireless application segment (often termed WLAN for Wireless LAN) is the one segment of the four that has recently experienced the most dramatic transformation and growth. LAN-type wireless applications, generally categorized with coverage distances in the 500 feet to 1,500 feet range, have existed for quite some time and have used a variety of technologies. In fact, even the genesis of the current WLAN market can be traced back to an FCC rule implemented in 1985, which allowed a communication technique called spread spectrum modulation (used in the 802.11b standard) to be used in the Industrial, Scientific and Medical (ISM) unlicensed frequency bands. Current WLAN applications focus on the 802.11 standards (generally referred to as Wi-Fi) and use the 2.4GHz ISM band for 802.11b (delivering up to 11Mbps raw data rate) and 802.11g (delivering up to 54 Mbps raw data rate), and the 5 GHz ISM band for 802.11a (delivering 54 Mbps raw data rate). Adoption of these standards has been key to the market growth for Wi-Fi applications. These applications have gone from being a vertical niche market to the mainstream horizontal mass market. Market estimates vary, but most currently place Wi-Fi unit shipment growth at well over 50 percent annually.

Coverage aspects of Wi-Fi applications vary depending on the specific standard and technology. For example, 802.11b uses the direct-sequence spread spectrum modulation technique, while 802.11a and 802.11g use an Orthogonal Frequency Division Multiplexing (OFDM) modulation technique. The 802.11b and 802.11g standards, using the 2.4GHz band, will in general transmit further than the 802.11a standard in the 5GHz band simply based on the inverse relationship between propagation distance and frequency — i.e., the "b" and "g" basic link transmission distances should be approximately twice as far. In addition, the OFDM modulation technique is more complex than the direct-sequence technique, so while the "g" and the "a" standards deliver considerably higher data rates, those techniques trade transmission distance for higher-speed communications. Even though "b" and "g" both operate in the same frequency band, "b" will generally transmit further at its maximum data rate due to the lower-complexity modulation scheme and the resulting better noise immunity. Regulatory rules for WLAN systems vary around the world, but most Wi-Fi applications in the 2.4GHz band transmit approximately 100mW of power and can use antenna gain of approximately 6dB, which results in a basic Wi-Fi link transmission distance in the 300 feet to 600 feet range. Wi-Fi systems in the 5GHz band typically use only 50mW of output power and realize transmission distance of 50 feet to 300 feet. Finally, as Wi-Fi systems have evolved, more sophisticated infrastructure capabilities have become available. Many Wi-Fi applications are able to expand coverage beyond the basic transmitter-receiver transmission distance by using microcells and roaming from cell to cell. This effectively leverages infrastructure solutions that enable the geographic reuse of frequencies and coverage expansion.

Wireless LAN performance characteristics also continue to evolve. Early wireless LAN applications provided raw data rates in the 1 Mbps to 2 Mbps range and real throughput rates in the 300 kbps to 750kbps range. Current applications provide 11 Mbps of raw data rate and 3 Mbps to 5 Mbps of real throughput (for 802.11b) and up to 54 Mbps raw data rate delivering some 10 Mbps to 25 Mbps of real throughput (for full speed 802.11a and 802.11g). In addition, some systems will enable multiple Wi-Fi channels to be used simultaneously and thus enable maximum data rates of 108 Mbps. All of these implementations operate within the same general distance-speed trade-offs — i.e., the more complex modulation schemes transmit shorter distances at full speed due to the higher signal strength required by the complex modulation schemes. So each of these Wi-Fi technology implementations will exhibit decreasing speed as transmission distance increases and will thus scale back the transmission speed in order to enable further distance. In addition, the multi-access performance capabilities of Wi-Fi applications continue to improve. While many early applications would only realistically support 10 to 20 users per access point or microcell, newer systems are using advanced media access control (MAC) functionality to enable the support of hundreds of simultaneous users. In addition, newer MAC implementations are enabling better quality of service (QoS) capabilities and are thus enabling more real-time services like voice communication over wireless LANs and video transmission. Many of these access control capabilities are being combined with innovative infrastructure solutions to provide better high-level management of users and media dependent communications.

The implementation/usability characteristics for wireless LAN applications have undergone the most radical transformation as the industry has evolved. Early product implementations in this segment were designed to provide basic stand-alone, localized coverage for mobile devices and a data-only interface into a traditional wired LAN. These initial products were first used in applications that required mobile or nomadic (mobility between stationary periods of communications) data communications, such as bar code scanning applications in warehouse, industrial or retail situations and were thus principally driven by mobility because they were too costly and slow to compete on a wire replacement basis. However, during the past five years, this segment has experienced a dramatic transformation with the new standards, higher data rates, more integrated technology solutions, dramatically lower product prices and innovative applications. Adoption of the 802.11b standards in 1999 jumpstarted the industry with a higher data rate solution that finally exceeded the 10 Mbps Ethernet barrier. This also allowed integrated circuit and system suppliers to pursue a common implementation and relieved users of the burden of buying proprietary solutions. Wi-Fi technology suppliers also were able to leverage the new integration technologies at both the RF and baseband integrated circuit level to realize highly integrated solutions. This resulted in more economical solution implementations that further fueled higher-volume sales. These trends have continued to the point where product prices have come down so dramatically that these systems can even leverage advantageous deployment economics into competing on a wire replacement basis. As a result, the addressable opportunities for Wi-Fi applications have expanded significantly and are being designed into applications that previously would have not been considered. In addition, more advanced Wi-Fi solutions are even looking more like “carrier-class” equipment, enabling capabilities such as data encryption, access security, voice over IP communications and network management — typically functions found in considerably more sophisticated telecommunications and networking systems. In fact, wireless LAN extensions to 3G data communications is one of the most active market applications for Wi-Fi systems, and potentially opens up an entirely new usability realm with wireless LANs serving as publicly accessible networks and leveraging the combined services of WAN cellular and the Internet.

Wireless Wide Area Networks

The Wide Area Network (WAN) wireless application segment typically addresses communications coverage on a metropolitan basis and beyond, but is generally limited to terrestrial-based systems. Within this segment there are a number of different markets that use different frequency bands and technologies and ultimately address different communications needs of users. In the United States, these include markets such as cellular and PCS communications (at 850 MHz and 1.9 GHz), fixed wireless communications (WCS/MMDS in the 2.1 GHz and 2.5Ghz bands and 3.5GHz band internationally, various point-to-point systems in the 10GHz to 40GHz frequencies and point-to-multipoint LMDS in the 27 GHz to 31 GHz frequencies), paging communications (at 35 to 36 MHz, 43 to 44 MHz, 152 to 159 MHz, 454 to 460 MHz, 929 MHz and 931 MHz), terrestrial television (54 to 87 MHz, 174 to 216 MHz and 470 to 806 MHz), terrestrial radio (535 to 1,700 KHz and 88 to 108 MHz) as well as more niche markets like wireless public safety networks (in the 800 MHz bands) used by municipal emergency services. These markets each address different needs of users and include both mobility-driven applications such as cellular and PCS communications, paging and public safety communications, as well as applications that compete more directly with wired alternatives such as the various fixed wireless markets. The mobility-driven applications have clearly been more successful, particularly in the cellular and PCS market, which offers fairly advanced communication services on a broad scale. Fixed wireless services, on the other hand, have historically not been as successful — some services and companies have failed outright, principally due to the market dynamics as a result of competing directly with wireline alternatives. But the cellular application is clearly the segment to analyze from a success perspective because it represents the world's most popular wireless application. Market estimates place worldwide cellular subscriber counts at approximately 1.4 billion subscribers by the end of 2003 and growing to more than 2 billion subscribers by 2007 or 2008. As a result, this industry exhibits the most extensive historical progress and development initiatives in term of coverage, performance and implementation/usability of any WAN wireless application.

Coverage is truly a key enabler of the cellular industry because without available wireless communications coverage, usage, and thus billable minutes of use (i.e., revenue for the service providers), is a moot point. As a result, this industry tends to use almost every important technological fundamental of coverage. Cellular and PCS systems around the world tend to use frequencies in the 800 MHz to 2 GHz range and coupled with various power output transmission levels and sophisticated antenna systems, realize basic link propagation distances anywhere from several miles to 50 miles, which make appropriate cell sizes. Actual cellular system implementation can use cell sizes much smaller than several miles and can even use special cell extension equipment for abnormal coverage situations (i.e., extending coverage behind a hill that obstructs transmission from the main cell transceiver, providing better signal quality inside buildings, etc.). In addition, cellular applications use infrastructure architectures to dramatically improve coverage by piecing together cells in a highly coordinated hierarchical fashion such that a user can move from one cell to the next and usually not lose communications. Furthermore, the implementation of standards has enabled extensive interoperability across independent systems, and combined with integrated intelligence in the infrastructure, enables roaming across vastly geographically diverse areas, which extends basic usability. Interestingly enough, fixed wireless systems also have played an important role in cellular coverage expansion in regard to providing backhaul communications from base stations. Base stations often need to be located geographically to provide the best coverage, which is not always a convenient location for connecting to the public switched telephone network. Fixed wireless systems have been used as a way to conveniently and economically connect the base station to the mobile switching center and/or to the local loop switch for the public wireline network. This is a perfect example of the utilization of advantageous deployment economics in the application of fixed wireless communications — i.e., it provides communications more conveniently than can be provided with a wireline solution.

The performance of WAN wireless communications varies greatly across the numerous applications previously mentioned, but no other application is experiencing more dramatic performance improvements than mobile cellular communications. Driven by worldwide mass popularity, cellular communications continually strives to improve both data rate and multi-access capacity to carry new service applications and support the continually expanding subscriber base. Cellular communications started out as principally a voice-oriented, circuit-switched communication network that tapped into the wireline public switched telephone network — i.e., serving as simply a mobile wireless extension to telephone services — but is now evolving into a converged voice-data network that provides not only voice but high-speed data communications and Internet access. Cellular communications performance can largely be viewed as a two-dimensional problem in terms of providing the most efficient use and reuse of frequency bandwidth. The efficient use of frequency bandwidth refers to how much information can be communicated in a given frequency band (i.e., the number of calls that can be supported or the number of bits that can be communicated per Hertz of frequency). The efficient reuse of frequencies refers to how well frequencies can be reused over a geographic area to support the dispersed user base. Efficient frequency use is determined principally by information modulation techniques and multi-access methods, which have driven the fundamental progression of cellular technologies from the legacy analog systems to the advanced digital technologies (GSM, CDMA, TDMA) and further to next-generation, higher-speed systems (cdma2000, WCDMA). Frequency reuse leverages those technologies into infrastructure architectures that reuse frequencies on a geographic basis to provide adequate service capabilities to the users. In reality, these aspects are closely related in that the higher-complexity modulation schemes can result in shorter transmission distance and influence the density of the infrastructure that needs to be deployed. Higher infrastructure density results in higher infrastructure costs, which is a financial problem that many cellular service providers are encountering as they deploy next-generation systems to improve performance and coverage.

Product implementation and usability have also improved quite dramatically for cellular systems overall as their popularity has multiplied. This pertains to not only handsets and infrastructure equipment but also to the services and applications that leverage those systems and products. For example, the handset market has evolved quite dramatically from the early days of the cellular industry. Huge economies of scale have allowed handset manufacturers to apply significant resources to realize dramatic improvements in integration for both the RF and baseband technologies. This has directly resulted in smaller, more attractive form factors and longer battery life, which both lead to improved usability. The integration benefits and the economies of scale combine in the manufacturing process and result in products with lower part counts and improved manufacturability, which in turn, directly results in lower cost and lower-priced handsets, further driving adoption. Infrastructure products are undergoing their own transformation as the delivery of cellular communications shifts from simply initial coverage (delivered with basic large base station equipment) to coverage everywhere. This has resulted in a variety of new infrastructure products focused on economical ways to deliver better signal quality and communications access to areas previously not served or obstructed (i.e., indoors, behind buildings, etc.). After all, coverage will still be the principle enabler of the delivery of core voice services. Finally, services and applications also have changes. While initially focused only on voice communications, cellular systems now deliver data communications and Internet access and continue to evolve with a plethora of services enabled by those capabilities and the additional convergence with other technologies, such as mobile/handheld computing, position location technologies, camera phones, etc.

Global Wireless Networks

The global wireless network application segment, as the name implies, is intended for communication between far-spanning points around the globe and uses various types of space-born satellite infrastructure. Applications that use satellite communication can be driven equally by mobility and advantageous deployment economics. For example, one of the more popular mobility-driven applications is GPS (Global Positioning System) positioning, where mobile receivers use a constellation of satellites to determine a longitude, latitude and even altitude position. Satellite based voice communications can be driven by mobility as well, in geographic areas or situations where there is no other telecommunications alternative (wireline or cellular). However, some of the most popular satellite applications actually compete on advantageous deployment economics basis, where satellites can be used to broadcast to very large geographic areas. Satellite based television services are the principle example of one-way satellite broadcasts covering large portions of an entire continent. This unique ability to transmit over a vast geographic area has enabled satellite television broadcasts to compete on an advantageous deployment economics basis with cable television and terrestrial broadcast services. In the United States, for example, an August 2003 release from the Satellite Broadcasting and Communications Association estimated that 20.36 million households, or one in five television households in the U.S., now receive their television programming through direct broadcast satellite services.

From a coverage perspective, the wireless link in broadcast satellite systems takes the form of a single, point-to-multipoint communications link from the satellite to a terrestrial-based receiver, and is thus concerned principally with the basic transmission link dynamics associated with that communications link. This transmission link and the quality of that communication is key to the services that are delivered and is thus a central issue to the businesses of broadcast satellite companies. Satellite communications typically use higher frequencies, which fundamentally transmit shorter distances and exhibit more propagation issues with obstructions. However, those problems can mostly be solved through the appropriate design of transmit power and antenna gain. The satellites can be designed to transmit enough power on the downlink to account for most atmospheric obstructions, and high-gain antennas (i.e., parabolic antennas) can be used on the receivers to add further signal strength improvement. Communication issues associated with the satellite link dynamics are potentially more problematic with applications that use mobile two-way satellite communications (i.e., applications where the ground-based transceiver is mobile). In these situations, the mobile device is often required to transmit at a relatively significant power level and typically uses a rather bulky, large antenna to transmit a signal that will reach the satellite. High transmit power levels result in either relatively large battery power mobile devices or short talk times, and when combined with the large antenna requirements, make for a less than optimal mobile device design.

The downlink performance for satellite broadcast television applications is typically not a significant issue in that most applications are allocated an adequate amount of bandwidth with which to transmit television channels. Still, satellite television service providers strive to make the most efficient use of the allocated bandwidth and thus often use encoding techniques to encode digital video prior to modulation and transmission, thus reducing the frequency bandwidth requirements for each channel and, in turn, allowing them to carry more channels. The more significant performance issue is encountered with two-way communications (both fixed and mobile applications) relative to the multi-access capacity performance of the uplink (i.e., the terrestrial transmitter to satellite receiver communications). While satellites are uniquely capable of simultaneously broadcasting down to a large number of users, the same cannot be said for the uplink communications. While some satellite systems enable two-way communications — for example VSAT (Very Small Aperture Terminal) satellite applications — most are not designed to support a large number of simultaneous users similar to what is supported on cellular systems. Fundamentally, the services offered by satellite systems suffer from asymmetric capabilities between up-link and down-link communications, which has generally limited large-scale wireless uses of satellite communications to broadcast applications.

Probably the most significant issue for satellite communications is the implementation/usability relative to leveraging the unique wireless capabilities that differentiate it from other forms of wireless and other communications mediums. The central issue here is concerned with the development and deployment of satellite communications and the related cost implications relative to the existing business opportunities. In particular, the extraordinary costs involved in developing and launching a satellite often outweigh benefits that can be derived from available opportunities. Satellite television is more of an ideally fitted solution, where even a very expensive satellite deployment can reap benefits when leveraged across the delivery of services to millions of potential customers. However, other applications like fixed and mobile telephony services have not been significant business opportunities for satellite communications because the implementation costs outweigh the potential benefits — particularly when those services compete with established global wireline networks and cellular services. Satellite telephony services typically only make sense in remote areas not served by any other wireline or wireless service, which makes for a relatively small addressable market opportunity (relative to the costs of satellite deployment). Furthermore, it could even be argued that GPS applications would not be financially feasible in a commercial sense if the U.S. government had not put up the satellite constellation for defense purposes. So satellite communication implementations must weigh the fundamental costs against the real business opportunities in determining financially feasible application opportunities.

The Technological Fundamentals

From the market summaries previously discussed, a number of reoccurring general technological themes emerge relative to applications and characteristics of coverage, performance and implementation/usability. First is the extent to which an application fits the wireless golden rule in leveraging the unique capabilities of wirelessness in the specific solution. This alone can often determine the level of success that an application will attain. It also is clear that the technological details of the basic wireless link cannot be glossed over relative to wireless coverage and the corresponding implications to the application and related business, and that spectrum regulations are not only a key part of that coverage dynamic but also can have significant impact on performance. In addition, infrastructure architectures can be key elements to both coverage and performance if used appropriately, but also can have significant cost implications. It also is worth noting that performance as applied to wireless applications is more than just a bits-per-second rating and can have a significant impact on the multi-access support of users and on businesses that derive revenue by charging subscribers based on their minutes of use. Finally, product and service implementation/usability can be determined by numerous technological factors that need to be considered early in the development process to produce applications that succeed in the marketplace. These general technological themes lead directly to the specific technological fundamentals that are listed below and are detailed in the following sections of this report.

The Wireless Golden Rule: Successful wireless applications must leverage either mobility, advantageous deployment economics or both, into unique communication solutions — otherwise, the benefits of wireless are lost.

Technological Fundamentals of Wireless Coverage

1. Coverage, the defining characteristic of wireless, dictates the geographic area over which wireless communications can occur for any particular application, and is determined by the basic link transmission distance, spectrum regulations, infrastructure architectures and the implementation of interoperable standards. Coverage ultimately relates to the central "golden rule" issues of enabling mobility and advantageous deployment economics and can thus influence a wide variety of application and business issues such as availability of communications, system deployment costs, product implementations, communication usability and popularity, and subscriber base growth. (See section entitled Coverage on page 18)
2. The transmission distance of a basic transmitter/receiver configuration serves as the principle factor in determining coverage for all wireless applications and directly influences an application's usability and the use of and cost of additional infrastructure for coverage expansion. At its most basic level, the wireless link transmission distance is a combination of the variables of frequency, transmit power, antenna gain and receiver sensitivity. (Please refer to the section entitled Basic Wireless Link Transmission Distance on page 18.)
3. Frequency of communications is inversely proportional to signal propagation distance — i.e., the higher the frequency, the shorter the propagation distance in any given transmit power level, antenna gain and receiver sensitivity situation. These signal propagation characteristics can thus, in part, define the usability of frequencies in terms of applications focused on mobile, nomadic or fixed usage. (Please refer to the section entitled Frequency on page 20.)
4. Transmit power is proportional to signal propagation distance, but not on a 1:1 basis. A 10-times boost in transmit power results in a little more than a three-times increase in transmission distance. (Please refer to the section entitled Signal Strength on page 25.)
5. The appropriate use of antennas adds gain bidirectionally, improves both transmit and receive signals and can be a very power-efficient way to improve overall wireless system signal strength. (Please refer to the section entitled Signal Strength on page 25.)
6. Receiver sensitivity is directly proportional to signal transmission distance and can thus have a significant impact on wireless coverage. But transmission distance improvements related to receiver sensitivity are sometimes not possible or not required depending on the background noise level and the application requirements, respectively. (Please refer to the section entitled Signal Strength on page 25.)

7. Spectrum regulation (i.e., FCC rules) directly influence coverage through regulations on transmit power limits, geographic licensing, antenna configurations and the flexibility (or lack thereof) associated with licensed and unlicensed usage. (Please refer to the section entitled Spectrum Regulation on page 28.)
8. Infrastructure architectures can be key to delivering wireless communication capabilities to the point of application, extending communications beyond the maximum signal propagation distance and enabling the geographic reuse of frequencies in expanding coverage area. Infrastructure density and costs, however, have an inverse relationship with signal propagation distance — i.e., the shorter the signal propagation distance, the more expensive the infrastructure to cover a given area. (Please refer to the section entitled Infrastructure Architectures on page 30.)
9. Standards can be the key factor in defining common approaches to wireless technology implementation and thus enable infrastructure mobility and wireless interoperability in general. (Please refer to the section entitled Standards on page 32.)

Technological Fundamentals of Wireless Performance

1. High-level wireless communications performance characteristics of successful applications focus on quality, availability, throughput and user capacity, which are in turn derived from technological fundamentals such as regulatory issues, information encoding and modulation, channel access efficiency and control, as well as infrastructure density and manageability. (Please refer to the section entitled Performance on page 34.)
2. It is the frequency bandwidth set by the FCC or regulatory agency that determines the maximum potential data throughput and/or the multi-user capacity of a wireless communication band. (Please refer to the section entitled Performance Regulatory Issues on page 34.)
3. Regulations pertaining to the licensed and unlicensed usage of frequency bands can have a significant impact on the performance characteristics of quality and availability of communications. Applications thus need to address the suitability of these types of communications on an application specification basis. (Please refer to the section entitled Performance Regulatory Issues on page 34.)
4. Information encoding functions prior to the RF signal modulation can improve the quality of wireless communications (usually by sacrificing throughput) as well as increase perceived throughput (via data compression) but typically not on a combined mutually exclusive basis. (Please refer to the section entitled Information Encoding and Modulation on page 36.)
5. Digital is better than analog; the noise immunity performance advantage is the fundamental reason why digital modulation performs better than analog modulation. (Please refer to the section entitled Information Encoding and Modulation on page 36.)
6. Higher complexity modulation schemes can improve performance by transmitting more data per given amount of frequency, but also may require a stronger signal environment and thus may reduce signal propagation distance. (Please refer to the section entitled Information Encoding and Modulation on page 36.)
7. Multi-user channel access techniques can enable the efficient use and sharing of wireless bandwidth among many users and thus have a significant impact on multi-user capacity and

communications availability performance. (Please refer to the section entitled Multi-User Channel Access and Media Control on page 39.)

8. Media Access Control (MAC) functionality can have a significant impact on the collision management and bandwidth utilization of a multi-access system, and thus can improve performance in terms of availability of communications, the associated multi-user capacity and the quality of communication services. (Please refer to the section entitled Multi-User Channel Access and Media Control on page 39.)

9. Infrastructure architectures can spatially distribute communication resources and thus improve the available bandwidth per geographic area, resulting in better multi-user capacity, increased data rate per user and general availability of communications. These benefits have a cost trade-off though, because higher density infrastructures require more equipment and can be more costly to deploy. (Please refer to the section entitled Infrastructure Density and Manageability on page 44.)

10. Infrastructure manageability can directly influence performance through diligent monitoring of maintenance and administrative tasks as well as through real-time traffic monitoring and throughput adjustments that result in better multi-user capacity and system throughput performance. (Please refer to the section entitled Infrastructure Density and Manageability on page 44.)

Technological Fundamentals of Product Implementation/Usability

1. The technological fundamentals behind implementation/usability can directly impact many key application and business issues such as product time-to-market, product costs, manufacturability and volume production, and competitive barriers to entry, as well as the more elusive usability-driven aspects such as product popularity (and thus product sales) and service minutes of use. (Please refer to the section entitled Implementation/Usability on page 46.)

2. RF technology implementation characteristics, which are highly dependent on the frequency used for communications, generally follow somewhat predictable macro trends, according to frequency across the wireless spectrum. These trends can be used as the technological fundamentals to guide RF product implementation. (Please refer to the section entitled Radio Frequency Technology on page 47.)

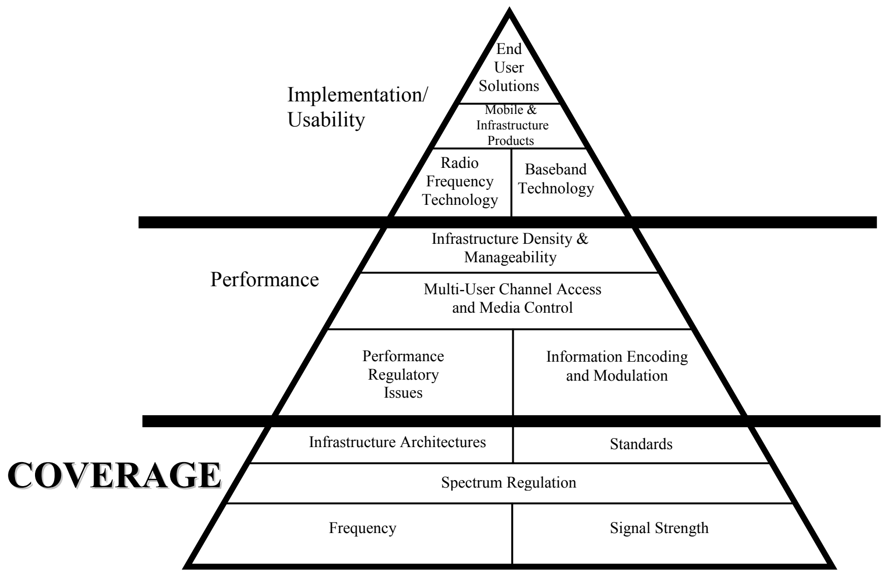
3. RF technology implementation can often embody valuable intellectual property and thus be used as a barrier to competitors, but must also factor in the increasing complexity as frequency increases (which can require additional design and development resources and lead to time-to-market delays), as well as the decreasing integration levels at higher frequencies, which can lead to lower integration and higher costs at the product design levels. (Please refer to the section entitled Radio Frequency Technology on page 47.)

4. RF technology implementation can be complicated by less readily available and higher priced RF components as the frequency of communication used for applications increases. When coupled with the complexity and integration trends, this also can lead to more manufacturability issue as well as higher cost and lower volume potential products. (Please refer to the section entitled Radio Frequency Technology on page 47.)

5. For baseband technology, the significant benefits of pursuing an integrated implementation usually outweigh the potential time-to-market development delays and can be used as potential barriers to competitors. Ultimately, these benefits include lower costs, better product manufacturability, higher volume potential, lower power consumption and better mobility usage. (Please refer to the section entitled Baseband Technology on page 50.)
6. For baseband implementations, programmability, technological convergence and customization can all be key implementation factors used as product and service differentiators to drive better sales volume, expanded geographic usability, enhanced overall product appeal and better usability resulting in higher service minutes of use. (Please refer to the section entitled Baseband Technology on page 50.)
7. Successful mobile products leverage integration into better manufacturability, attractive form factors and improved battery life, and focus on mobility and individualization in the convergence with other technologies, services and functions for consumer oriented products. (Please refer to the section entitled Mobile and Infrastructure Products on page 52.)
8. Successful Mobile infrastructure product implementations focus on delivering wireless coverage economically and/or enabling flexibility through network intelligence and the ability to incorporate additional product and service enhancements. These factors lead to better mobile usability and can drive service minutes-of-use. (Please refer to the section entitled Mobile and Infrastructure Products on page 52.)
9. Wireless infrastructure products that compete based on advantageous deployment economics must leverage the ability to go where wires cannot or deliver communications cheaper, faster or easier than wireline alternatives, and thus focus intently on product costs, which can single-handedly determine product sales volumes. (Please refer to the section entitled Mobile and Infrastructure Products on page 52.)
10. From a wireless network service provider perspective, successful end-user services are determined by customer usage, which is still largely driven by the primary end-user solution/service offering (i.e., the principle service driving network deployment), but are increasingly augmented with the delivery of secondary end-user solutions that focus on further enabling that usability, and in turn, on generating addition revenue. (Please refer to the section entitled End-User Solutions on page 55.)
11. Successful secondary end-user solutions leverage the capabilities of the underlying technologies and products into an end-application and usability-focused product or service that leverages distributed intelligence, standardized platforms and the individualization capabilities of wirelessness to drive new market applications and revenue sources as well as increased service usage, improved service popularity and subscriber base growth. (Please refer to the section entitled End-User Solutions on page 55.)

Coverage

Coverage is the probably most basic and defining characteristic of wireless applications, and is ultimately rooted in a number of fairly complex technological issues that vary depending on the type of application. By definition, it was the characteristic used in the segmentation of the market presented in the Wireless Market Analysis section on page 3 because it goes to the core issue of what wireless is all about and tends to categorize technologies, products and services into groups of similar characteristics.



Coverage is the defining characteristic of wireless — it dictates the geographic area over which wireless communications can occur for any particular application, and is determined by the basic link transmission distance, spectrum regulations, infrastructure architectures and the implementation of interoperable standards. Coverage ultimately relates to the central "golden rule" issues, enabling mobility and advantageous deployment economics and can thus influence a wide variety of application and business issues, such as availability of communications, system deployment costs, product implementations, communication usability and popularity, and subscriber base growth.

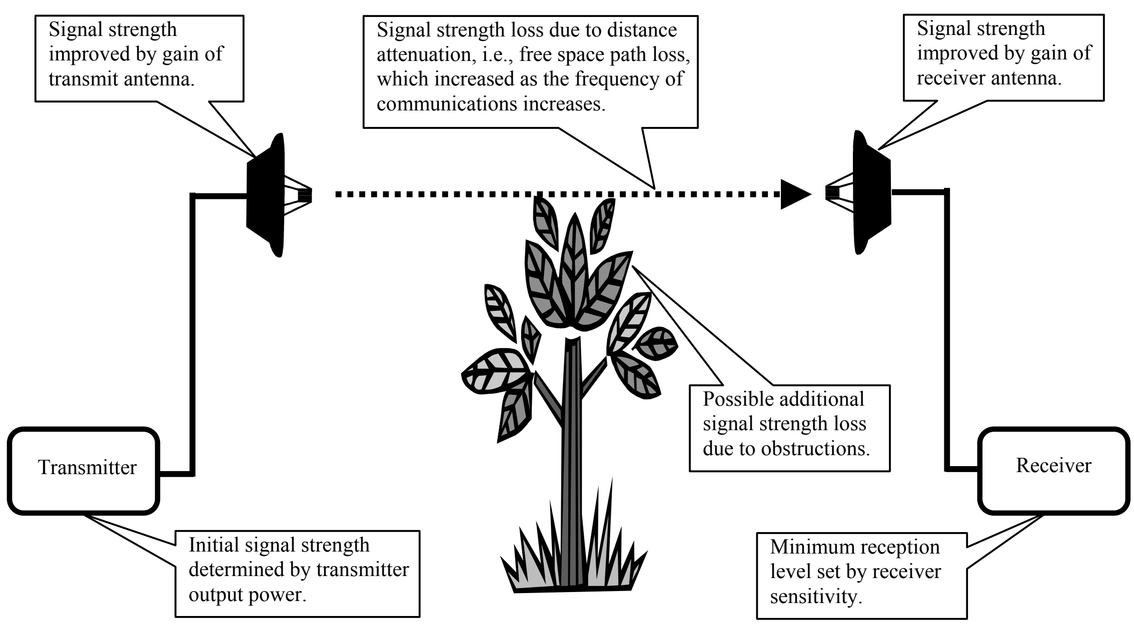
Basic Wireless Link Transmission Distance

The first step in understanding coverage for wireless applications is to grasp the basics of a simple wireless link, consisting of a transmitter and a receiver, and in gaining an applicable knowledge of the variables that affect that transmission distance. ***After all, the transmission distance of a basic transmitter/receiver configuration serves as the principle factor in determining coverage for all wireless applications and directly influences an application's usability and the use and cost of additional infrastructure for coverage expansion. At its most basic level, the wireless link transmission distance is a combination of the variables of frequency, transmit power, antenna gain and receiver sensitivity.***

Like most of these technical topics, the reality is that details of link transmission distance can become quite complicated. However, an applicable understanding of the basics of link transmission distance and how it influences the success of applications and ripples up into material business issues is actually fairly straightforward. Thus, this report and the sections that follow will focus on developing an intuitive sense for link transmission distance, how it changes with the basic variables and influences application and business oriented issues.

Figure 3: Basic Wireless Transmission Link Configuration, is a diagram of the basic factors of a wireless transmission link and indicates the most material issues that determine transmission distance. Ultimately, transmission distance is directly related to signal strength — i.e., transmitting, propagating and receiving adequate signal strength to meet the minimum reception level of the receiver (while also meeting any regulations and standards requirements). Initial signal strength is determined by the output power of the transmitter. This signal strength can then be improved some through the signal gain designed into the transmit antenna. From the transmit antenna, the signal strength will actually attenuate and lose strength as it travels to the receiver antenna. This is technically referred to as the free space path loss and is dependent on frequency. In addition, signal strength could be reduced further if there are obstructions between the transmitter and receiver antennas. Depending on the application, these obstructions could be anything from a tree, hill or building in an outdoor application, or walls, file cabinets and partitions in an indoor application. Signal strength can then be improved and strengthened by the receiver antenna in a similar manner as the transmit antenna. Finally, at the end of the transmission link, there must be a minimum amount of signal strength remaining in order for the receiver to interpret the transmission. This minimum receiver signal strength level is referred to as receiver sensitivity, which is largely receiver design dependent. So, from a maximum coverage and link distance perspective, the transmitter and receiver can be separated by the longest distance, such that the received signal strength does not go below the minimum receiver sensitivity level. From a conceptual perspective one can view this wireless link transmission configuration as having five different variables: frequency, transmit power, antenna gain, obstruction loss and receiver sensitivity.

Figure 3: Basic Wireless Transmission Link Configuration



While that description represents the basics of what one needs to know about the distance a wireless link can communicate, in reality it can be much more complicated. Depending on the application, cabling between the transmitter/receiver and the antennas may cause additional signal attenuation. In addition, most applications will require more than just the minimum level of signal strength available at the receiver. A higher signal strength level can be required due to a number of additional variables. Rain, snow, leaves on trees during summer but not winter, people walking by the transmitter or receiver, etc., are all other obstructions that can cause additional signal attenuation and need to be taken into account if the link is to work through such "temporary" disturbances. This additional signal strength required to overcome these more occasional and random situations is referred to as the link margin. Finally, there are other aspects that can affect wireless transmission distance. Most are more detailed than those discussed here, and while they may have a notable effect on the coverage and transmission distance in actual deployments, they are of less concern when it comes to the aspects that drive the fundamentals of applications and business issues.

Frequency

The frequency of communication is probably the most fundamental characteristic of coverage and link transmission distance because the signal propagation distance at any particular frequency (with similar transmit power, antenna gain and receiver sensitivity) is largely determined by factors beyond what can be significantly altered with technology and product design choices. This is principally due to what is commonly referred to as spreading loss, or the attenuation of the wireless signal (actually the attenuation of the wireless signal strength density) as it spreads to a larger and larger sphere as it propagates further and further away from the transmitter. The radiated energy simply becomes more dispersed (and attenuates on a logarithmic scale), similar to how light from a bulb gets less bright as one moves further away. This spreading loss and the wireless signal power at a receiver can be computed with a path loss equation called Friis' free-space equation.[1] An interesting effect embodied in this equation is its direct dependence on the frequency of communications, which is actually as a result of the frequency's dependency on the reception aperture of the receiving antenna relative to the wavelength of the propagating signal. ***The net result is that the frequency of communications is inversely proportional to signal propagation distance, i.e., the higher the frequency, the shorter the propagation distance in any given transmit power, antenna gain and receiver sensitivity situation.*** In addition, the important applicable takeaway is an intuitive understanding for the approximate transmission distance at the various frequencies. This intuitive understanding is quite valuable in matching the required communication distances of wireless applications to the fundamental signal propagation characteristics of the various frequencies. ***These signal propagation characteristics can thus, in part, define the usability of frequencies in terms of applications focused on mobile, nomadic or fixed usage.***

Figure 4: Propagation Charts, applies Friis' free-space path loss equation to show the approximate propagation distances for frequencies between 500 KHz and 50 GHz. Due to the wide range of frequencies (i.e., five orders of magnitude) and the logarithmic rate of signal

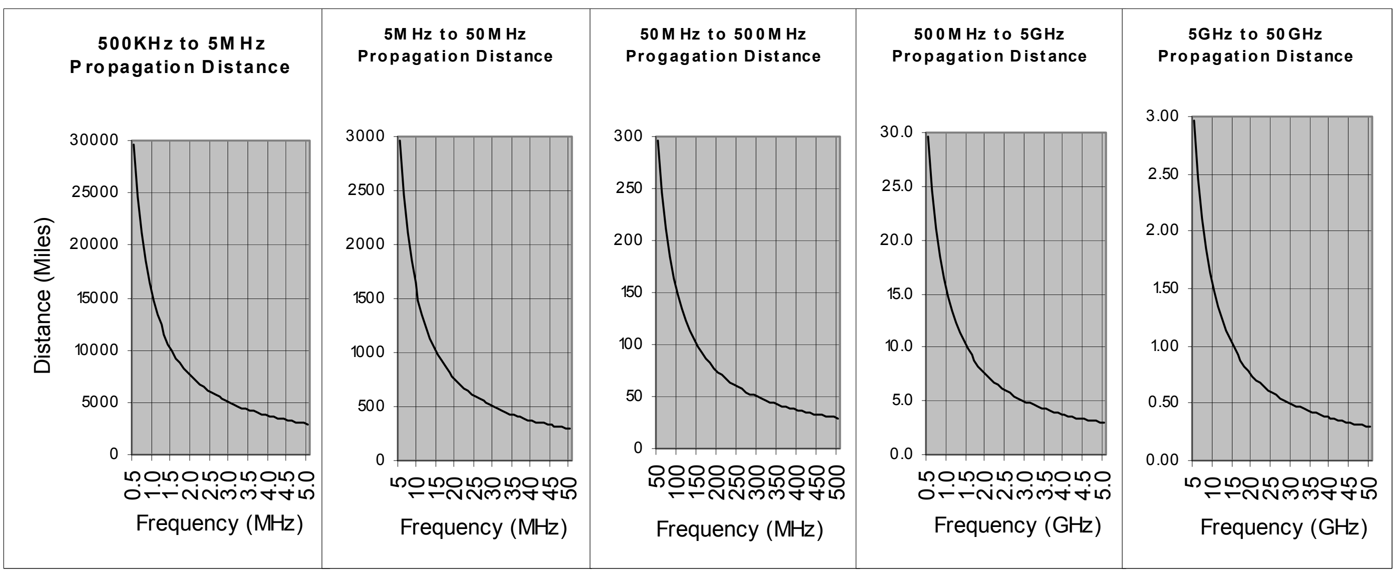
[1] Friis' free-space path loss equation (in dB) = 96.6 + 20 log(f) + 20 log(d), where *f* is frequency in GHz and *d* is path distance in miles.

attenuation, the transmission distances are best presented in five charts. In addition, base assumptions have been made in regard to transmit power (1 Watt/30 dBm), antenna gain (0 dB on both transmitter and receiver), receiver sensitivity (-90 dBm, which is a fairly typical commercial receiver sensitivity) and obstruction attenuation, (0 dB, i.e., no obstructions) in order to make the distance calculations uniform across frequencies. Certainly, in real applications these characteristics can vary quite significantly and have a notable effect on the propagation distance both positively and negatively. However, understanding these approximate propagation distances will go a long way toward fitting applications with the most appropriate frequencies. The key observation is, in general, an order of magnitude difference in propagation distance for every order of magnitude change in frequency. So while the general propagation distances for the 500 KHz to 5 MHz frequencies is in the 30,000 mile to 3,000 mile range, the 5 MHz to 50 MHz frequency range only propagates some 3,000 miles to 300 miles.

Figure 4: Propagation Charts

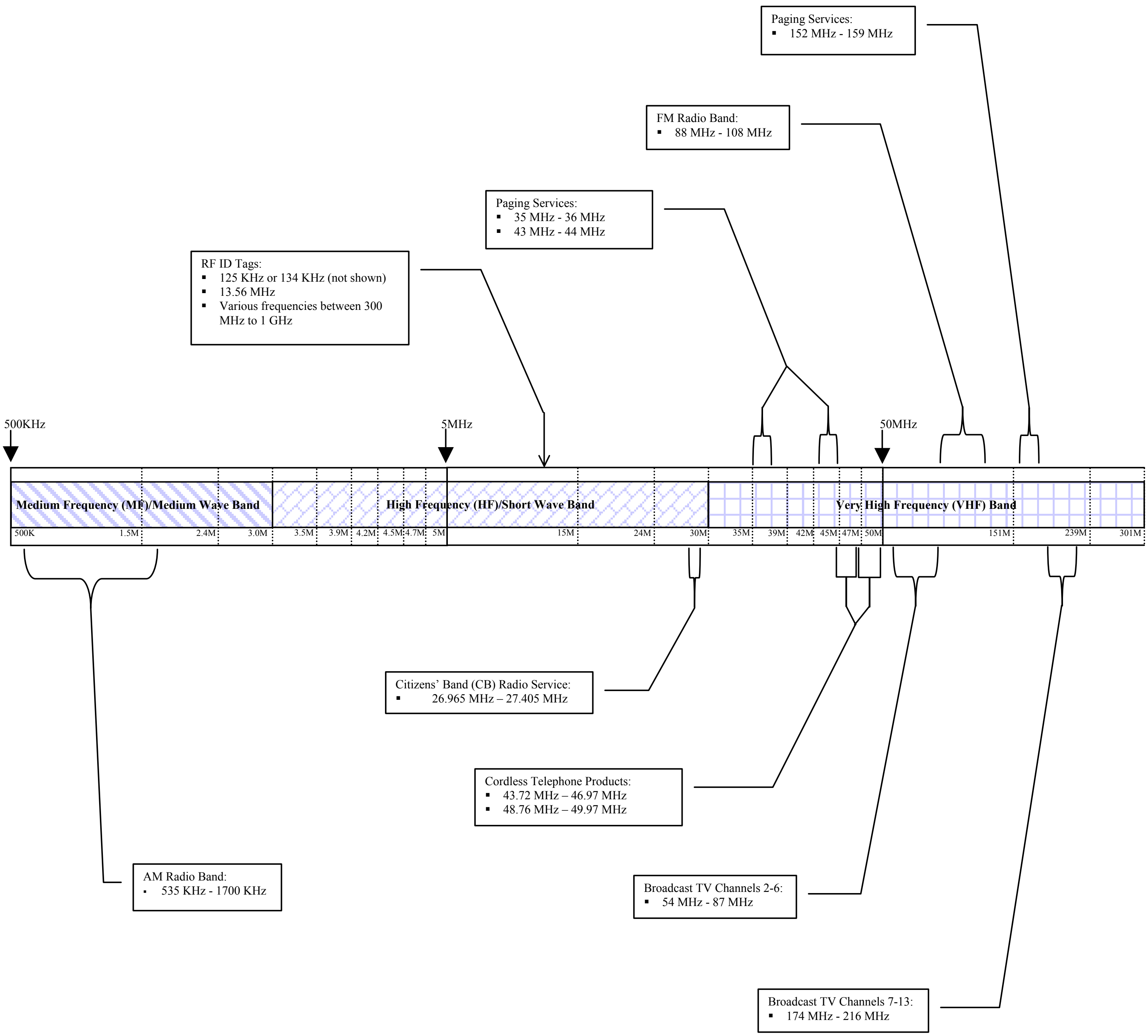
Assumptions:

- Transmit Signal Strength = 1 Watt/30 dBm
- Transmit and Receiver Antenna Gain = 0 dBm
- Receiver Sensitivity = -90 dBm
- Obstruction Signal Strength Attenuation = 0 dBm

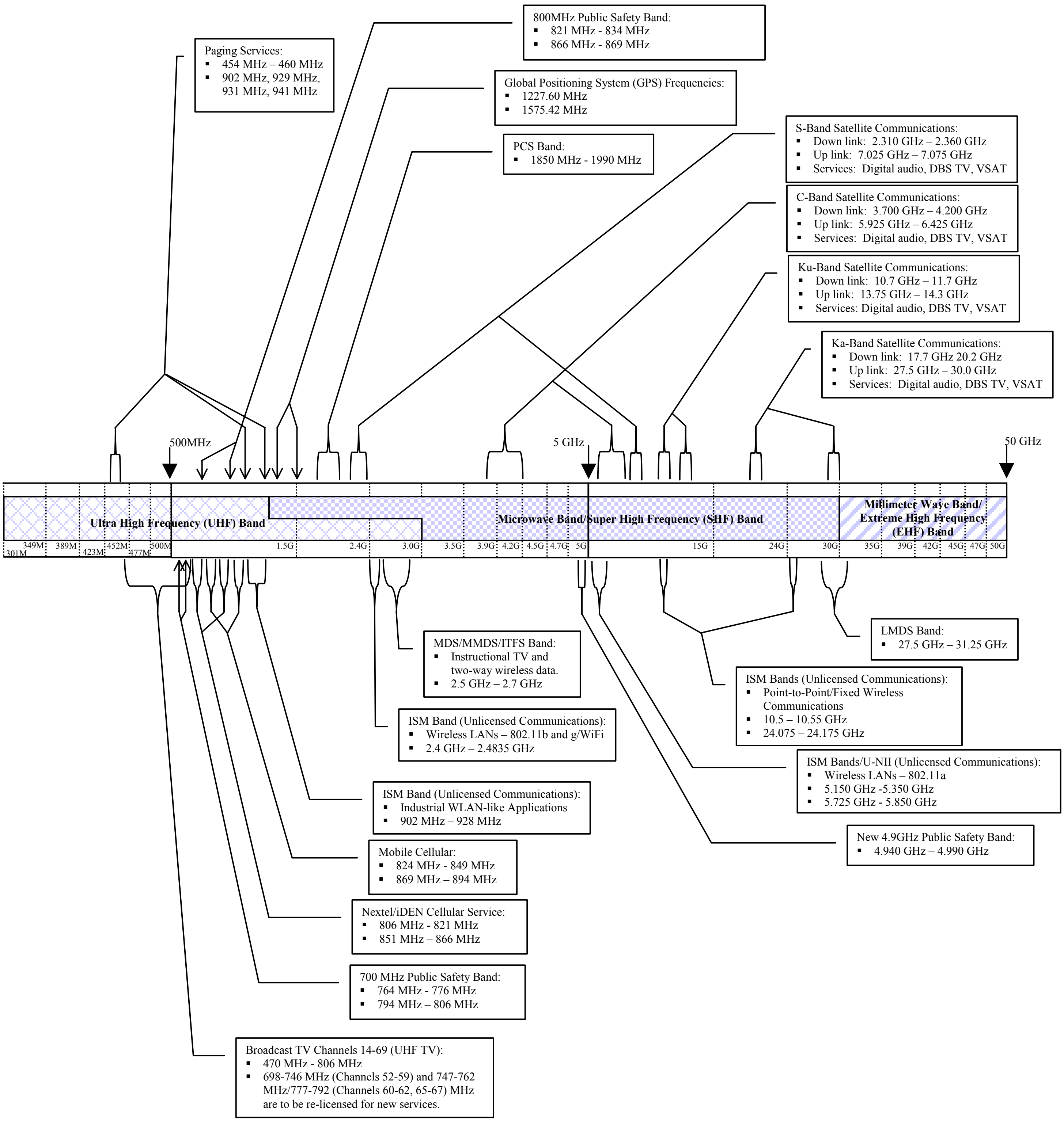


The continuum of electromagnetic frequencies in which wireless communications takes place is generally called the wireless spectrum. Figure 5 shows almost the entire wireless spectrum from 500 KHz to 50 GHz as well as the location of some common wireless communication applications. There are frequencies below 500 KHz and above 50 GHz that are useable for communications, but almost all wireless communications occur within this range. Electromagnetic signals are not exclusive to wireless communications and in fact can extend to much lower frequencies and much higher frequencies. Visible light, for example, also consists of electromagnetic waves, but is at much higher frequencies. In fact, infrared communications uses a form of light just outside the visible range and is an example of the use of light for wireless communications. Again to represent the 500KHz to 50GHz wireless frequency spectrum (representing a 100,000-times difference in frequency) the logarithmic scale is used on every order of magnitude. The application of the logarithmic scale has the effect of compressing the frequency bandwidth with higher frequencies. So, for any particular linear unit of measure in Figure 5, the amount of frequency bandwidth is greater with higher frequencies — i.e., moving to the right on Figure 5, where more of the common wireless communication applications exist. Also of note in Figure 5 are the names of frequency bands, which are included within the horizontal scale. These band names can be essential for interpreting some of the wireless industry's frequency terminology. The most important observation from Figure 5 is simply in where various applications are located in the wireless spectrum given the inherent frequency propagation characteristics represented in Figure 4. For an application to succeed, the frequency propagation characteristics much match the application requirements.

Figure 5: The U.S. Wireless



Communications Spectrum



Signal Strength

Coverage, as stated earlier, is fundamentally an issue about the management of wireless signal strength. The overview of the basic transmission configuration at the beginning of this chapter shows that there are multiple other points in the transmitter-receiver communications where signal strength can be affected. Namely, there are three other relevant aspects of signal strength that have a significant impact on link transmission distance and ultimately coverage, and basically add to or subtract from the propagation estimates of the previous section in Figure 4. These other aspects are transmit power, antenna gain and receiver sensitivity. Obstruction losses can also have a significant impact, but are really a result of environmental conditions. While they certainly need to be accounted for, they are largely beyond the control of product and application design fundamentals.

Signal strength is basically the amplitude of the wireless signal. How that amplitude is maintained through the transmission path determines if and how well communications can occur. The basic unit of signal strength is the Watt (W), similar to the light output ratings on light bulbs. However, signal strength is often measured in terms of the logarithmic scale decibels (dB), due to the logarithmic attenuation effects as a result of the dispersive propagation property explained earlier. But signal strength notations can have quantitative and relative meanings. When referring to an absolute signal strength level transmitted from a device, the "dB" notation is referenced to a known power reference (typically 1 milliwatt or 1 watt) and is indicated as dBm (dB of signal strength relative to 1 milliwatt) or dBW (dB of signal strength relative to 1 watt). When referring to a relative power gain, like the signal strength gain through an antenna or an amplifier, the "dB" notation is used without a reference — i.e., just "dB". This is an important distinction to make relative to the management of signal strength power though the various devices in the transmitter-receiver communications.

Here again, the objective is to establish an intuitive understanding for signal strength and how it affects different elements of the basic transmission link. Table 1: Power Conversions, is designed to establish that intuitive understanding by listing a wide range of power level, the corresponding alternative representations and the distance that a 1GHz signal would travel in an unobstructed (line-of-sight) transmission with no antenna gain to a receiver with a –90dBm sensitivity. Where the distance numbers in Figure 4 were calculated across frequencies (with all other variables fixed), the distance numbers in Table 1 are calculated across power levels (again, with all other variables, including frequency, fixed) in order to present specifically the implications of various power levels.

The most important observation from Table 1 is the relationship between power level and transmission distance. Here again, the logarithmic dispersive effect described in the previous section and embodied in Friis' free space equation, controls the distance changes at various power levels. For example, as can be noted in Table 1, a 1 mW (i.e., 0 dBm) transmit power signal propagates 0.468 miles. A 10-fold increase in transmit power to 10 mW (10 dBm) results in a distance propagation of 1.48 miles, or a distance increase of only 3.2 times. Similarly, a doubling of the transmit power (1 mW to 2 mW) only increases transmission distance by approximately 40 percent (0.468 miles to 0.661 miles). While the data in Table 1 is for a 1 GHz signal being received by a –90 dBm sensitivity receiver, the same effect also holds true for all other frequencies, albeit with different absolute transmission distances. ***Transmit power is thus proportional to signal propagation distance, but not on a 1:1 basis. A 10-times increase in transmit power results in a little more than a three-times increase in transmission distance.*** But ultimately from a technology and product perspective, generating that 10-times increase in transmit power still involves a variety of issues that are 10 times more complicated — i.e., requires 10 times the amount of electrical energy, which makes a device one-tenth as mobile on a battery powered basis, dissipates 10 times the amount of heat, etc. The net result is that increasing transmission distance and wireless coverage via increases in transmitter output power can often be more difficult and overall more complicated due to the disproportional relationship between transmit power and transmission distance.

Table 1: Power Conversions

Power (mWatts – mW)	Power (dBm) (=10*log$_{10}$ (milliwatts))	Power (dBW) (=10*log$_{10}$ (watts))	Line of Site Transmit Distance (miles) (@ 1GHz and -90dBm receiver sensitivity)
100,000	50	20	147.91
10,000	40	10	46.77
1,000	30	0	14.79
500	27	-3	10.46
300	25	-5	8.10
200	23	-7	6.61
100	20	-10	4.68
10	10	-20	1.48
5	7	-23	1.05
2	3	-27	0.661
1	0	-30	0.468
0.5	-3	-33	0.331
0.2	-7	-37	0.209
0.1	-10	-40	0.148
0.01	-20	-50	0.0468
0.005	-23	-53	0.0331
0.002	-27	-57	0.0209
0.001	-30	-60	0.0148
0.0001	-40	-70	0.00468
0.00001	-50	-80	0.00148
0.000001	-60	-90	0.00047
0.0000001	-70	-100	0.00015
0.00000001	-80	-110	0.000047
0.000000001	-90	-120	0.000015
0.0000000001	-100	-130	0.0000047
0.00000000001	-110	-140	0.0000015
0.000000000001	-120	-150	0.0000005

Antennas used in wireless systems also can have a significant impact on the signal strength, namely through the gain or amplification that can be realized in good antenna designs. Antennas as they are used in wireless systems are intended to transmit and receive the propagating electromagnetic signals. In the signal strength presentation thus far in this report and the transmission distant calculations in Figure 4, it was assumed that the signals propagated from a single point, much like how light propagates from a light bulb, and thus the antenna gain was assumed to be zero. But in reality, antennas can be designed to funnel the electromagnetic signal energy, much like how a reflective funnel around the bulb of a flashlight points light in a certain direction. When the electromagnetic energy is funneled via the appropriate antenna design, it results in signal amplification or signal gain as it goes through the antenna. Unlike a signal amplifier component, the signal amplification realized through the appropriate antenna design is actually passive amplification and does not require any actively powered components, which could be an additional drain on electrical power (usually a material concern for battery-powered mobile wireless applications).

Table 2: Gain Conversions

Signal Gain in "dB"	Distance Improvement (%)
50	31523%
40	9900%
30	3062%
27	2136%
25	1632%
23	1314%
20	900%
10	216%
7	124%
3	41%
0	0%

In addition, this passive gain is bidirectional in that that amplification works equally well transmitting or receiving. Table 2: Gain Conversions, is similar to Table 1 except that the power numbers in the left-hand column are relative power gain indications and the right-hand column now indicates the relative distance improvement for a given gain. For example, an antenna with 3 dB of antenna gain on just the transmitter would improve the transmission distance by 41 percent. However, if a similar antenna was used on the receiver, it would add 3 dB of gain there as well, and amount to 6 dB of gain through both antennas, resulting in approximately 100 percent distance improvement. ***So the appropriate use of antennas adds gain bidirectionally and improves both transmit and receive signals and can be a highly power-efficient way to improve overall wireless system signal strength.*** Ultimately, there are a variety of different antenna designs that can funnel signal energy into different patterns and provide different levels of gain. A "whip" or dipole antenna is one of the most common types and consists of a straight piece of wire of specific wavelength dimensions that produces a horizontally-oriented, doughnut-shaped radiation pattern and typically provides approximately 3 dB of gain. Parabola-shaped antennas, which produce a more focused beam, and other more complex designs are capable of producing higher levels of gain. But clearly antennas can be an important aspect of wireless applications.

The last significant aspect that influences the signal strength of a basic wireless link and the realizable transmission distance is the sensitivity of the receiver, which is simply the lowest absolute signal level at which the receiver will interpret the communications. The sensitivity of a receiver is a highly design-dependent aspect and can vary significantly from product to product. In general, the lower the minimum interpreted signal level, the further the link will communicate. However, depending on the general signal environment and in particular the background noise in the communications band, improvements in receiver sensitivity can yield diminishing returns in terms of transmission distance improvements. In addition, some applications simply may not need superior sensitivity or merit the extra development (in terms of design effort and additional costs) required to achieve excellent sensitivity.

Receiver sensitivities are typically referenced as absolute power levels, such as those indicated in Table 1, but typically fall at the lower-end (i.e., smaller signal level) range of the table. For example, as has been used in this report, -90 dBm is a fairly common commercial receiver sensitivity, though some products (like GPS receivers) might achieve sensitivities of -110 dBm or lower. Relative improvements in sensitivity can be viewed as simply additional signal gain in the communications, where Table 2 can be used to determine distance improvement. For example, a 10 dB improvement in sensitivity from -90 dBm to -100 dBm would potentially yield a 216 percent improvement in distance. Ultimately, however, continued improvements in sensitivity may not yield additional improvements in distance. Background frequency noise due to a variety of sources (shared band communications, sideband interference from neighboring frequency bands, etc.) may set a noise level “floor” below which the receiver cannot distinguish the intended signal from the noise. In addition, appropriate receiver sensitivity can depend on the application. For example, a short-range application may only require the receivers to achieve a -80 dBm sensitivity due to the limited link transmission distance and adequate output power from the transmitters. So ultimately, receiver sensitivity requirements can be quite application dependent. ***But fundamentally, receiver sensitivity is directly proportional to signal transmission distance and can thus have a significant impact on wireless coverage. Transmission distance improvements related to receiver sensitivity, however, are sometimes not possible or not required depending on the background noise level and the application requirements, respectively.***

Spectrum Regulation

Wireless communications is unique among all the various communication technologies in regard to the theoretically nonexclusive access to the medium. Unlike wired mediums, for example, where access to a physical cable is required, wireless communications can hypothetically be used by anyone with the a transmitter (and receiver) at any frequency — i.e., the electromagnetic “airwaves” are open to everyone. However, in order to facilitate rational and orderly wireless communications and avoid an electromagnetic free-for-all, most countries have instituted some form of regulation that sets rules for the use of frequencies. As a result, these regulations influence wireless communications at a fundamental and technological level, and among all the technological drivers for wireless applications, coverage is the one most influenced by these rules. However, from a higher-level application and business perspective, spectrum regulations and the evolution and changes of spectrum rules, as technology and communication needs change, have the potential to single-handedly create substantial business opportunities. So it is the combination of the impact to technological fundamentals and potential to create business opportunities that makes understanding spectrum regulation so important.

In the United States, the government body regulating communications is the Federal Communications Commission (FCC), which oversees every communication medium and industry in one form or another. The FCC is organized into six operating bureaus that are principally responsible for setting and enforcing regulations, and 10 other staff offices that provide support services to those Bureaus. The six operating bureaus are Consumer and Governmental Affairs, Enforcement, International, Media, Wireless Telecommunications and Wireline Competition.

The Wireless Telecommunications Bureau regulates the majority of the wireless industry, even though some aspects overlap into other bureaus such as International (satellite communications) and Media (broadcast radio and television, as well as some satellite and fixed wireless communications). The Wireless Bureau has a variety of goals that are reflected in its general activities, including fostering competition, maximizing efficient use of spectrum and facilitating innovation, new markets and new services. Overall, however, the Wireless Telecommunications Bureau is responsible for coordinating wireless communications in bands across the entire wireless spectrum through frequency allocations, usage licensing and defining high-level technological requirements as well as through product certifications of intentional transmitters (as opposed to other electronic products that may transmit electromagnetic signals unintentionally, and that also have to be FCC certified).

These Wireless Bureau activities materialize in the technological fundamentals and influence coverage, in particular, in a variety of ways. As discussed in the Frequency section on page 20, the absolute frequencies allocated for a wireless communications band can have a considerable impact on the fundamental coverage of that communication simply due to frequency-dependent propagation characteristics. Currently, most frequencies across the wireless spectrum and certainly the prime frequencies (relative to the propagation characteristics) across the spectrum are currently allocated to specific wireless communications, so the process of allocating frequencies for new services usually involves reallocating spectrum and/or changing rules in existing bands. The entire process of frequency allocation and rules setting is a combination of input from the FCC's internal engineering group as well as input from industry participants, through the FCC's rulemaking and public comment review process. The full set of enacted rules is documented in Title 47 of the Federal Code of Regulation, most of which is conveniently available electronically on the Internet through the FCC's web site, www.fcc.gov.

During the last few years, the FCC has been active in reexamining rules and frequency band allocations as market demands and technologies have changed, and as the federal government determined that this reallocation process could be a revenue generator via the auction process (effectively auctioning off new market opportunities). One of the first auctions was the 1994 to 1995 auction of the A&B block PCS mobile telecommunications frequencies, which netted more than $7 billion for the government and immediately created additional growth opportunities for the mobile telecommunications market. In contrast, the wireless LAN market, which has experienced significant growth lately, was actually initiated as a rule change in 1985 in the ISM bands as a result of the commercial development of spread spectrum technologies.

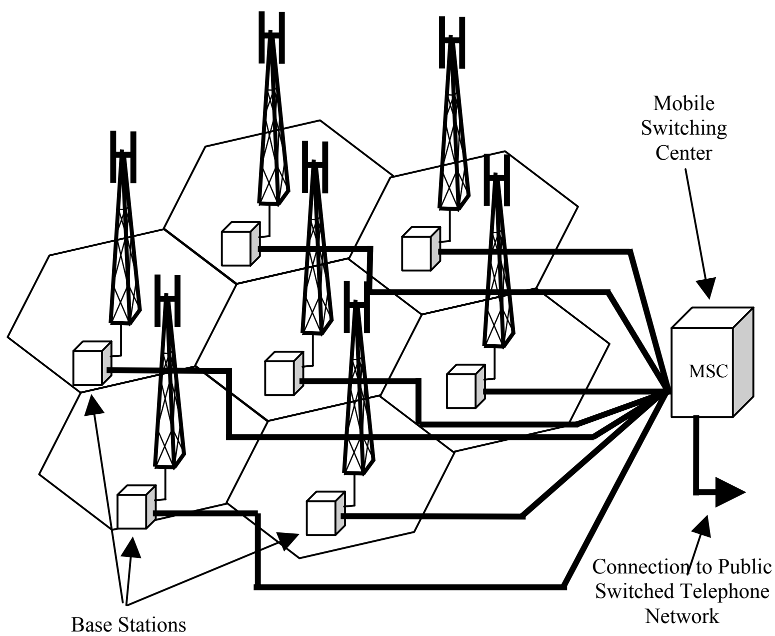
In general, the FCC rules deal mainly with high-level aspects of wireless communications within the specific bands, such as the maximum transmitted power levels, geographic licenses, etc. The transmit power level is one of the more important aspects that the FCC specifies and regulates relative to coverage. Typically the maximum transmitted power level is often articulated in the form of effective radiated power or ERP, which combines the transmit power level with gain specifications of the antenna to specify the absolute signal strength that can be transmitted. In addition, the FCC may license usage of frequencies on a geographic or site basis, which limits the licensee's exclusive use and coverage to that geographic area or single site. These types of usage licenses are common in industries such as radio and television broadcasting, mobile telecommunication and fixed wireless. Ultimately, however, not all frequencies are licensed on an exclusive basis, in that only the licensee determines how the frequencies are used. In fact, there are many bands that are licensed as shared bands or unlicensed bands that support many different types of applications and many users. These shared bands do not have a single licensee and users of products that transmit in these frequencies are not required to get a license. However, products communicating in unlicensed bands do need FCC approval before they can be sold. But the unlicensed nature of products using these shared bands can contribute significantly to the ease of deployment/ease of product sales. Typically, the coverage of these unlicensed bands is regulated via very low power output specifications, which inherently limits coverage, but improves geographic reuse of the shared frequencies. Cordless telephones, wireless remote control toys and wireless LANs are some of the most popular applications that use unlicensed wireless communications. An inherent problem with unlicensed communications, however, is that interference can occur if two independent users are in close proximity. The net results of this interference can range from completely prohibiting communications to simply a reduction in the link transmission distance and can thus be a considerable coverage, quality of communication and usability issue. ***Overall, the point to remember is that spectrum regulation (i.e., FCC rules) directly influences coverage through regulations on transmit power limits, geographic licensing, antenna configurations and the flexibility (or lack thereof) associated with licensed and unlicensed usage.***

Infrastructure Architectures

The technology drivers of coverage presented thus far have all applied principally to aspects of a basic wireless link consisting of a transmitter communicating to a receiver. Another way to improve coverage is by using some type of communication infrastructure. In wireless communications, the application of an infrastructure architecture usually involves the extension of communications to the point of wireless application (which could simply be a networked, remotely located wireless application or the extension of existing wireless communications beyond the maximum transmission distance) or the actual reuse of frequencies over a geographic area that also expands the coverage area beyond the coverage of a single transceiver. Fundamentally, the utilization of infrastructure architecture is something that needs to be incorporated into the overall system planning of a wireless application or service, because implementation and cost issues can have significant business consequence.

Ultimately, it is the application requirements that will drive the utilization of an infrastructure architecture. The simplest use of infrastructure for wireless communications is the basic extension of communications to the point of wireless application. The most straightforward form consists simply of a single wireless transceiver that is networked into a larger communications infrastructure either through some type of wired connection or through a wireless link communicating on a different frequency. A more complex variation of this concept can be used to extend an existing wireless link through what is commonly called a repeater device. A repeater picks up an existing signal either through a wireline connection or through a wireless receiver directionally focused on the transmitter and then repeats or retransmits the signal at an amplified level and at the same frequency over an expanded area. Each of these infrastructure techniques is typically applied on a situation-by-situation basis but also can be applied in conjunction with a more complex cellular-type architecture.

Figure 6: Cellular Infrastructure Architecture



The cellular infrastructure architecture represented in Figure 6 is the technique used in most mobile telecommunication systems. This architecture is used in situations where an application needs to provide coverage across an entire geographic area. The cellular architecture has the unique capability of enabling the reuse of frequencies across a geographic area by leveraging inherent limitations on wireless signal propagation. The basic idea is that the same set of frequencies can be reused in nearby cells because signal attenuation minimizes interference between these cells. Narrowband systems based on Analog, TDMA or GSM technologies typically spatially separate frequency reuse by one cell or more (i.e., don't reuse frequencies in immediately neighboring cells), where broadband based systems like CDMA can reuse the exact same frequencies in each cell, simply due to the spread spectrum coding technique utilized in CDMA. Either way, the net result is an increase in coverage due to the geographic reuse of these frequencies.

From an architectural perspective, the cellular design leverages a hierarchical communications structure to deliver expanded coverage communications. For example, a mobile user within a cell communicates to the base station controlling that cell. Communications from that base station then flows to a mobile switching center that controls a group of base stations. This mobile switching center then communicates directly with the public switched telephone network (PSTN) for voice communications or into the Internet for data communications, each of which in turn has its own hierarchical structures. This hierarchical communications structure for cellular systems is the key enabler in leveraging wide area coverage wireless communications into voice and data communication networks.

Mesh architecture is a newer architectural structure that is a variation of the cellular design being used in certain applications. Mesh networks fundamentally accomplish expanded coverage and frequency reuse similar to cellular systems, but are non-hierarchical in communications flow (or at a minimum non-hierarchical at the wireless levels of the architecture). In mesh networks, wireless devices — be it a user device or an infrastructure device — may become part of a single, spider-web like communications network, which means that each wireless device may act as a user interface or an infrastructure access/repeater interface. The net result is that any wireless device can communicate with any other wireless device, and in addition, route communications through the network. This type of functionality requires considerable intelligence capabilities to reside in every wireless device and thus also requires additional processing power in every device. Some mesh network architectures may use a basic hierarchical structure that, by lower-level routing, is less intelligent and transfers some routing capabilities to a higher level for complex routing functions. Mesh networks are particularly useful in applications where it is not possible to construct a coordinated hierarchical infrastructure. In fact, much of the early work in the development of mesh networks came from the military, where in-field armed forces were required to set up a wireless communication network using only mobile and semi-mobile/nomadic devices. This technology is now being applied to commercial wireless communications in WLAN and WAN situations.

In general, though, cellular infrastructure architectures can be applied to both fixed and mobile communication environments and can be applied to a variety of wireless communications applications and services, such as mobile telecommunication, wireless LANs, paging systems, etc. But the utilization of an infrastructure architecture delivers the fundamental benefits of frequency reuse, expanded coverage and, most importantly, further enables mobility — a golden rule fundamental that drives wireless applications. Certainly the cellular telecommunications industry is the best example of how an infrastructure's architecture can be used to expand coverage, improve mobility and deliver WAN services. However, the use of an infrastructure architecture can be a complicated business proposition because the implementation issues and extra costs involved may not be trivial and depend on other wireless technology aspects, most importantly frequency. The density and cost of an infrastructure depends on the basic transmission distance and is compounded in a two-dimensional sense. So, infrastructure costs rise by a factor of four if the basic transmission distance is cut in half. This implies a direct relationship between frequency and infrastructure cost in that the higher the frequency, the shorter the basic transmission distance and the higher the fundamental infrastructure density and cost. ***So, from a business and application perspective, the most important aspects to remember are that infrastructure architectures can be key to delivering wireless communication capabilities to the point of application, extending communications beyond the maximum signal propagation distance and enabling the geographic reuse of frequencies in expanding coverage area. Infrastructure density and costs, however, have an inverse relationship with signal propagation distance — i.e., the shorter the signal propagation distance, the more expensive the infrastructure to cover a given area.***

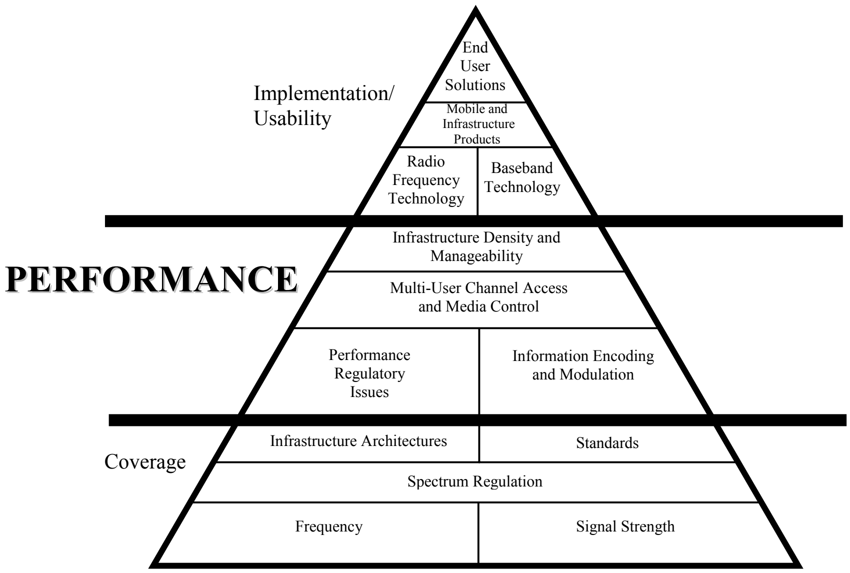
Standards

The final technological driver of coverage is the use of standards. Standards are key to expanding coverage by defining common approaches to the various aspects of wireless technology to enable infrastructure mobility and wireless interoperability in general. Standards are typically applied, and thus need to be addressed, on an application- and technology-specific basis. Across the entire wireless industry there are numerous standards organizations and industry consortiums that define the aspects of wireless communications for various industry sub-segments and application oriented markets. Standards can address nearly every aspect of a wireless communications application, from lower-level features such as the frequency and approach to information encoding and modulation (which basically defines how a wireless communication channel is established), as well as how the communication channel is accessed and shared among one or more users, to higher-level capabilities like control and interface protocols that manage users, mobility and communications in multi-vendor application configurations.

In fact depending on the application, standards can be important enough to almost single-handedly determine the market success or failure of a product, application or business. For example, the mobile cellular telecommunications market would never have achieved its worldwide popularity if it were not for the frequency bands that have been allocated (typically common on a nationwide basis) and the standard protocols that have been developed. Clearly, a mobile user would have a very difficult time moving from one cell to the next if the wireless technology were different between cells. In addition, roaming in a service area outside of the home location service would be impossible if it were not for the availability of a standard compatible infrastructure providing similar service. Similarly, the wireless LAN market has grown significantly since the initial IEEE802.11b standard was approved for that market in 1999. General interoperability between WLAN cards and access points, each potentially provided by different vendors, also would not be possible if it were not for the detailed specifications of the standard. ***So, standards can be the key factor in defining common approaches to wireless technology implementation and thus enable infrastructure mobility and wireless interoperability in general.***

Performance

Performance has long been a differentiating factor for successful products in a multitude of applications and markets. In fact, this characteristic is so fundamental that it is typically mentioned in everything from elementary marketing texts to advanced research on business strategy. Certainly, the old adage of "build a better mouse trap and the world will beat a path to your door" was coined around many aspects of product performance. The importance of performance also holds true in the communications industry because equipment and service providers are continually striving to meet the demands for higher data rates and more subscribers.



The wireless industry is similar because advances in technology are delivering performance improvements in a number of different ways. But performance can have different meanings for different products and applications, and some applications may not even require the highest level of performance. As a result, it is important to understand the elements of wireless performance that have the greatest impact on the success of applications and businesses, and how those elements are derived from the technological fundamentals. Through this understanding, intelligent trade-offs, decisions and analysis can be made to best fit the technological performance with the requirements of the application, and best position the application and corresponding business for success. ***These high-level wireless communications performance characteristics focus on quality, availability, throughput and user capacity, which are in turn derived from technological fundamentals such as regulatory issues, information encoding and modulation, channel access efficiency and control, as well as infrastructure density and manageability.***

Performance Regulatory Issues

At the most fundamental level, any wireless communication application is initially enabled through the identification of a frequency band and the operational rules for that band. As discussed in Spectrum Regulation on page 28, these are topics that fall within the domain of regulatory agencies governing wireless spectrum, which in the United States is the FCC. But it is particularly important to note that in the process of setting the frequency bands and rules, the FCC can largely determine some fundamental performance characteristics of the wireless products and services that use those bands. In particular, the actual bandwidth and usage rules can be determining factors of data throughput, multi-user capacity as well as the quality and availability of communications — all of which can have a fundamental impact on the success of an application.

Bandwidth is an often used and sometimes misused descriptor of throughput performance. It is not uncommon to hear bandwidth used in relation to a specific data throughput rate for a communication medium. However, for wireless communications, that usage can be misleading because bandwidth and data throughput, while related, are not exactly the same thing. Wireless bandwidth, as the word implies, is quite specifically the width of the frequency band used for communications, which is typically allocated by the FCC. That frequency width can refer to a channel, which could be a partial piece of a frequency band, or it can refer to the total band overall, with each potentially having a different meaning for performance characteristics such as data throughput and multi-user capacity. In addition, there are other aspects of wireless technology, such as modulation techniques, that can have a significant effect on data throughput, and thus cause further confusion with references between bandwidth and throughput. That said however, there is a relationship between bandwidth and potential throughput, in that the wider the frequency band (or channel) the higher the potential (maximum) throughput. Fundamentally, this relationship between bandwidth and throughput materializes in two different performance characteristics, namely data rate and multi-user capacity, depending on how the communication channel is partitioned. For example, if a give swath of frequency bandwidth is divided into 10 sub-bands (or channels) then each sub-band will only be able to carry one-tenth the maximum throughput of the total band, but the total band will now be able to support 10 simultaneous channels or users. This is the basic trade-off made in the architecture of most mobile cellular systems and also is, interestingly enough, the challenge wireless service providers face in scaling data rates to individual users for 3G services. ***But fundamentally, it is the frequency bandwidth set by the FCC or regulatory agency that determines the maximum potential data throughput and/or the multi-user capacity of a wireless communication band.***

Another important aspect of regulation that influences performance is band exclusivity and the licensed and unlicensed nature of usage. While these two categories of licensing and usage are not new, they have received more attention during the last few years as markets such as wireless LANs in the unlicensed 2.4GHz and 5GHz bands have experienced dramatic growth and are being designed into numerous applications far beyond what was initially envisioned. As a result, the FCC continues to attempt to facilitate that growth by examining licensed and unlicensed frequency bands and applications when the specification of a frequency band as licensed or unlicensed falls under its domain. Despite the popularity of unlicensed wireless applications, it is still important to understand the differences between these two types of bands particularly as it pertains to performance characteristics of quality and availability of communications. Licensed bands are those for which a single entity is given an exclusive right to determine how the frequency band is used. These licenses are usually given (or auctioned) on a geographic basis and are typically focused on certain applications or services (i.e., television broadcast, mobile cellular telecommunications, etc.). The exclusive right to use licensed bands puts complete control of communications in that band with the license holder and prohibits any other communications. This gives the license holder direct control of the quality and the availability (in a multi-user situation) of communications and also has historically carried the connotation of being a higher-quality frequency band. Unlicensed bands, as the name implies, do not have a single licensee and instead focus on the certification of products that meet the FCC transmission requirements of that band. Fundamentally, any vendor can obtain a product certified for use in an unlicensed band and sell that product directly to end users, who do not need any type of licensing approval to operate the product. This can facilitate better commercial sales of these unlicensed products. However, communications in unlicensed bands can be considerably less coordinated than licensed bands. The net result is that a user is more likely to experience communications interference (i.e., poor quality) due to another user communicating nearby, or complete blockage (i.e., complete communication channel unavailability) due to a stronger interferer. ***Fundamentally, regulations pertaining to the licensed and unlicensed usage of frequency bands can have a significant impact on the performance characteristics of quality and availability of communications. Applications thus need to address the suitability of these types of communications on an application-specification basis.***

Information Encoding and Modulation

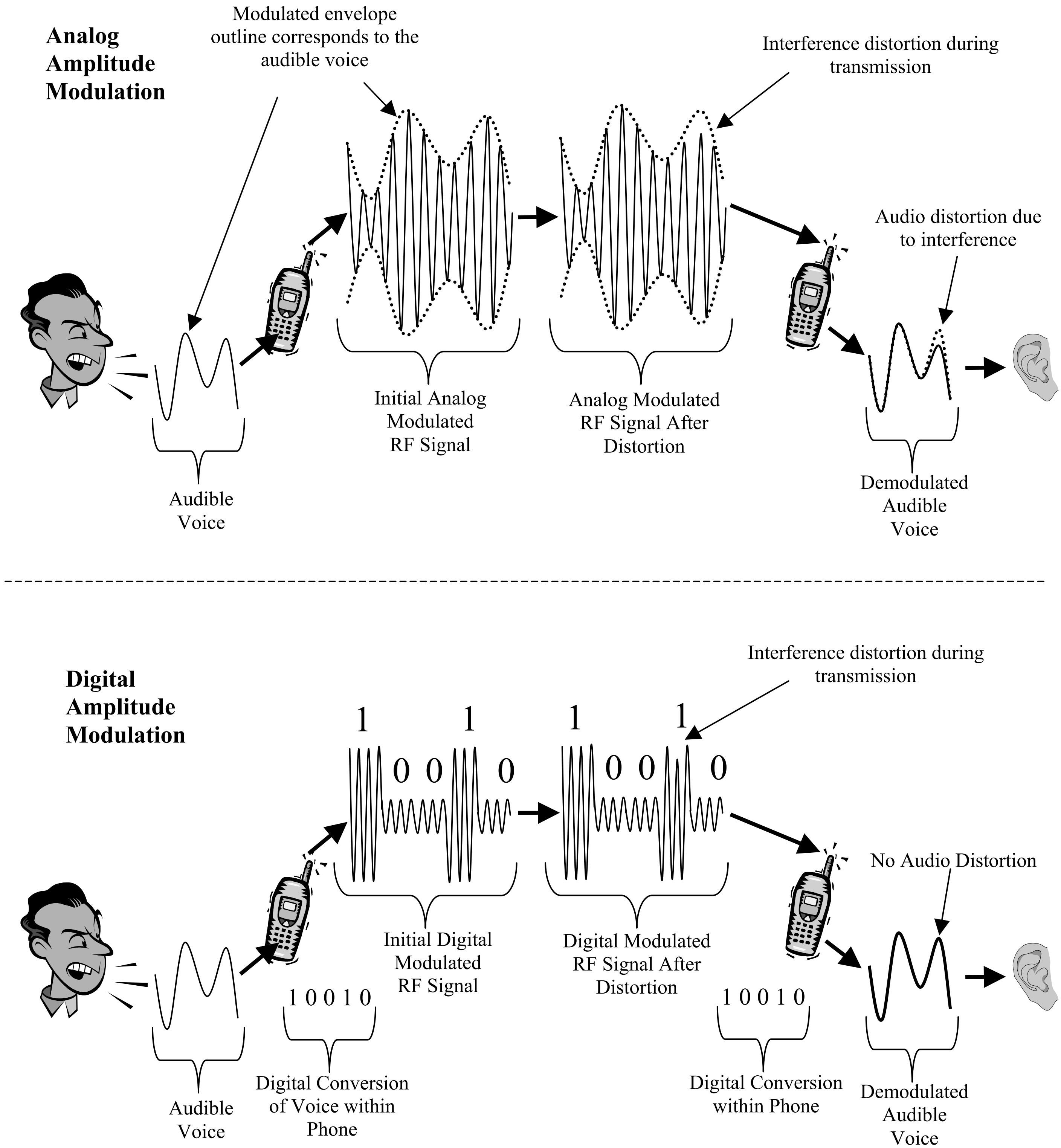
Information encoding and modulation deals with how the information to be transmitted is preprocessed and then superimposed onto a wireless carrier signal. From a fundamental perspective, these are the two principle functions of a transmitter in generating a wireless signal. The wireless receiver performs the exact inverse tasks — demodulation and decoding — according to the specific technique that has been used by the transmitter. This report will thus focus on these techniques principally from the transmitter perspective because that is the source of the encoding and modulation characteristics that influence performance. Each of these processes can have a significant impact, both positively and negatively, on the overall wireless communication performance, specifically in regard to the characteristics of throughput and quality of communications. While the detailed science behind each of these processes can be some of the more complex topics in wireless, there are straightforward ways to address these topics and rules of thumb that can be applied to link the details of encoding and modulation technology to the application and business issues that drive success in the market.

Encoding, the first step in preparing information to be transmitted wirelessly, encompasses all functions performed on the original raw content, which is also called the baseband information (as it is the information in its original form). A variety of encoding functions can be performed on the baseband information depending on the application and if the original content is analog (i.e., audible voice) or digital (numerical data) information. In fact, the entire encoding process can be quite minimal in the most basic implementations where, for example, an analog voice signal can be directly superimposed onto a wireless carrier. This report is focused on the more complex techniques that are applied to many wireless applications today, and that have the capability of influencing performance.

The most basic preprocessing function is simply the digital conversion of analog information. In general, the preprocessing and modulation of digital information can use a wider variety of techniques and has fundamental advantages that result in better performance than the transmission of analog information. As a result, many implementations will initially convert all original raw content to digital baseband data. Beyond that, some implementations may also add channel characterization information, which is basically a known segment of information (known both to the transmitter and receiver) that is included with every original transmission and is used by the receiver to factor out reception irregularities due to slight signal changes associated with the propagation of the signal (i.e., this also is referred to as channel equalization). The addition of this known information adds overhead to the data to be transmitted (and thus reduces throughput), but can significantly improve the quality of communications. An additional segment of overhead data that is often included is encoding for error detection and correction, which is basically a segment of data uniquely computed from a piece of the baseband information that can be used by the receiver to detect and possibly correct errors (over that segment of information) that may have occurred during signal propagation. Again, this can reduce overall throughput, but can improve quality by detection and/or correction of transmission errors. The baseband data to be transmitted can also be encrypted for security, which is largely a usability issue (not performance) but can actually reduce performance by requiring additional baseband processing and increase information to be transmitted. Finally, the baseband data can also be encoded to compress or reduce the amount of data to be transmitted. These compression functions typically take advantage of pattern segments of information within the original data and represent them in a reduced form, thus delivering a perceived improvement in throughput. ***Overall, the important issues are that encoding functions prior to RF signal modulation can improve the quality of wireless communications (usually by sacrificing throughput) as well as increase perceived throughput (via data compression), but typically not on a combined, mutually exclusive basis.***

While the digital conversion of information is important in the encoding process, it is even more essential in the modulation process because there are fundamental advantages of digital modulation techniques over analog modulation techniques, particularly in regard to the throughput performance and the performance of digital modulation techniques in the presence of noise (which exists in every realistic wireless propagation channel). Fundamentally, digital modulation techniques can perform better in the presence of noise and thus ultimately realize higher throughput for a given frequency bandwidth. The modulation of a wireless carrier signal boils down to altering the characteristics of a high-frequency wireless signal in such a way as to directly represent the information to be transmitted. Figure 7 shows a simple diagram using amplitude modulation to communicate information, specifically audible voice, and demonstrates why digital techniques perform better in the presence of noise. The diagram shows two representations of the same communication — one analog and one digital. The top representation shows the analog technique, where the amplitude of the high-frequency wireless carrier directly corresponds to the audible voice signal. As the signal propagates, interference is encountered, which alters the wireless signal — i.e., it knocks down a cycle of oscillation. When the wireless signal is then demodulated by the receiver, the interference distortion shows up directly on the demodulated audible signal and is heard as noise by the user. In the lower representation, the same sequence of events occurs, except that the audible voice is first digitized and amplitude modulated as “1”s and “0”s. This time, when the propagating signal encounters interference, it still changes the wireless signal, but does not change it enough to alter the “1” into a “0”, so when the signal is demodulated and the data is converted back to an analog audible signal, no noise is heard by the user. ***This noise immunity performance advantage is the fundamental reason why digital modulation performs better than analog modulation.***

Figure 7: Why Digital is Better than Analog



Ultimately, there are many different ways to modulate information onto a wireless carrier signal. The example in Figure 7 superimposed the information onto the wireless signal using slight changes in amplitude. Other techniques use changes in frequency and phase as well as simultaneous combinations of changes in two or more of these three characteristics, all potentially at different specific level. The net result is that there are a significant number of various modulation schemes. One will often hear a virtual alphabet soup of terminology used in relation to the acronyms representing these various modulation schemes, such as AM (amplitude modulation), FM (frequency modulation), PM (phase modulation), QAM (quadrature amplitude modulation), FSK (frequency shift keying), BPSK (binary phase shift keying), QPSK (quadrature phase shift keying), DQPSK (differential quadrature phase shift keying), GMSK (gausian minimum shift keying) and many others. Each scheme exploits slightly different techniques in altering the characteristics of the wireless signal to achieve different levels of performance, sometimes focused on different channel conditions and noise environments. However, the performance of all modulation schemes follows the same general rule in regard to the throughput results (per Hertz of frequency bandwidth) achieved in a realistic noise-present communication channel. Simply stated, the applicable relationship is that higher-complexity modulation schemes (i.e., those that simultaneously alter multiple wireless signal characteristics in complex techniques) can achieve higher data throughput rates per Hertz of frequency bandwidth, but will also require a higher signal-to-noise environment (i.e., stronger signal or a lower noise channel) for error-free transmission (higher complexity modulation schemes are generally more susceptible to errors).

The higher throughput performance that can be achieved via complex modulation schemes has been a popular research topic during the past few of years, and is principally driven by demands for higher data rates, a general shortage of good frequencies (i.e., those with appealing propagation characteristics), the need to support more subscribers and thus the overall demand for more spectrum. One way to take on the data rate and spectrum demand issues is to make better use of the available spectrum through more bandwidth efficient modulation techniques — i.e., transmit more bits per Hertz of frequency spectrum. But for every application encountering these types of issues, it is important to understand the trade-offs involved with more complex, bandwidth-efficient modulation techniques. From the applicable relationship stated in the previous paragraph, there is an implied trade-off between the throughput performance achieved with complex modulation schemes and the required signal-to-noise environment, which is a function of propagation distance from the transmitter. This means that the more bandwidth-efficient schemes could experience more transmission errors at certain distances under a given signal-to-noise environment or could experience a reduction in transmission distance because signal strength is reduced as the signal propagates further from the transmitter (please refer to the section entitled Signal Strength on page 25). Generally speaking, modulation techniques need to be addressed on an application specific basis. ***The rule of thumb to remember is that higher-complexity modulation schemes can improve performance by transmitting more data per given amount of frequency, but may also require a stronger signal environment and thus may reduce signal propagation distance.***

Multi-User Channel Access and Media Control

Multi-user wireless applications take performance a step further. A multi-user application is one where two or more users (wireless devices, subscribers, etc.) need to share the same frequency bandwidth and the same communication channel setup in that bandwidth. While still dependent on the throughput and quality of communication issues described previously, these applications ultimately require additional capabilities and leverage other technological drivers that determine multi-user performance — namely, channel access and media control, which drive better multi-user capacity and communication availability. If one envisions the frequency bandwidth and encoding/modulation setting up a communication channel, then access efficiency and media control can be viewed as determining how multiple users utilize that channel. These two technological drivers are closely related, but actually deal with different aspects of multi-user channel utilization. Channel access specifically pertains to the techniques by which users actually communicate using the shared channel; media control refers to the decision process to orderly determine if and when a user can communicate and what happens if there are collisions or errors due to multiple simultaneous communications. Access techniques have a significant impact on the overall system and subscriber capacity, and influence many other factors such as realizable communication throughput, frequency reuse, infrastructure deployment costs and time-to-market. Each of these factors, in turn, is important to the fundamental success of a wireless communication venture.

The simplest channel access protocol is basically no protocol at all, or what can generally be termed an ad hoc protocol. This technique does not use any rules that govern when a transceiver can transmit and when it should receive. When the transceiver has something to send, it simply goes on the air and transmits and then listens for a response. There is no guarantee that another device is not communicating at the same time or that the message actually is received by the intended receiver. Usually this technique will rely on a retry procedure if a “message-received” acknowledgement is not returned. Sometimes these retry procedures will incorporate a random “back-off” time: when an acknowledgement is not returned, the transmitting device will pause for a random amount of time and allow the assumed conflicting transmitter(s) to communicate. This type of protocol is generally used in very light traffic situations, for short bursts of infrequent communication. An example of an application of this type of protocol is used in wireless home security systems. These systems are usually very short range, and communicate infrequently when security sensors are being checked or when there is an alarm. In either case, it is unlikely that more than one wireless sensor will be communicating at a given time. Ad hoc communication channel access works well for this application. In general though, ad hoc access protocols are inefficient and do not make efficient use of the communication channel.

Fundamentally, channel access techniques are the mechanisms by which the communication channel resources are divided between the multiple users. More specifically, these techniques involve dividing the resources of frequency, time and coding capacity to create sub-channels within the main communication channel. Each sub-channel will obviously have only a portion of the total throughput capacity, but this division process enables multiple users to communicate simultaneously.

Dividing the frequency resources is basically an issue of dividing the total frequency bandwidth into smaller sections of frequency (i.e., separate channels) that individual users can tune into and access simultaneously. This is called Frequency Division Multiple Access (FDMA). This technique requires additional transmitter and receiver hardware capabilities to be able to tune into all the individual channels. In addition, it requires some type of higher-level channel allocation control protocol that will assign a channel to the transmitter and receiver pair that is requesting to communicate. This technique eliminates collisions between independent transceiver communications by locating individual communications on different frequencies. Each different frequency can be viewed as a separate communication channel completely dedicated to a transceiver's transmission. This type of access protocol can be more costly because each independent communication will require duplicate hardware and/or frequency agility to communicate on the different frequencies. In addition, depending on how many different channels are needed, more bandwidth may be required to support the communications. A variation of the basic FDMA technique that is generally much more frequency efficient and is experiencing more widespread use in newer, advanced system implementations is Orthogonal Frequency Division Multiplexing (OFDM), which allows the individual frequency channels to be closer together (in frequency) as a result of the coordination of the signal characteristics of adjacent channels that reduces adjacent channel interference.

Dividing the time resources, in the most basic implementation, involves sharing the throughput of the total frequency bandwidth on a time basis among the users and is thus called Time Division Multiple Access (TDMA). While the transmitters and receivers need only tune into a single communication channel, this technique requires some type of high-level scheduler that coordinates the multiple users, assigns timeslots and informs each user when to take control of the channel. A disadvantage is that channel efficiency can be low if transceivers with assigned time slots are not communicating. In this case, because these idle transceivers could potentially communicate, their time slots cannot be resigned to other devices, and that communication bandwidth would remains idle while other transceivers could be data rate limited. In general, this type of protocol requires strict overall coordination and synchronization between every device, so that each transceiver knows when to transmit and receive. This coordination can be difficult to implement and potential more costly than the simpler techniques; however, because of the communication time slots that are assigned or dedicated to each transceiver, the TDMA protocol tends to be quite user efficient and works well for voice telephony type traffic.

The third technique, dividing the coding resources, involves encrypting the digital baseband information to be transmitted with what is called a pseudo-random code. This code is a string of bits that are organized randomly over the length of the string, but used in a repeating fashion over all data to be communicated. This technique is called Code Division Multiple Access (CDMA). The idea here is that when information is encoded with a certain pseudo-random sequence, only a receiver using that same sequence can decode the information. If a receiver uses a different sequence, then the transmission is seen as random noise in its code differentiated communications channel. Multiple communications can thus use exactly the same frequency bandwidth and be differentiated via the pseudo-random code. Ultimately, however, each additional communication within the same frequency bandwidth adds noise to the channel, which is cumulative as more independent communication channels are added. This cumulative noise will eventually begin to cause errors in transmission and will thus limit the number of simultaneous communications that can be differentiated via CDMA. So while CDMA does not require coordination of frequency channels or time sequencing like TDMA, it does require the coordination of the pseudo-random codes between the respective transmitters and receivers, which typically requires precise timing and synchronization of the pseudo-random codes to achieve maximum code differentiated multi-user performance. In addition, CDMA systems typically use some type of precise transmit power control scheme, due to the cumulative addition of noise and the dependence of error-free communication on the transmit signal power level relative to the noise level (i.e., the signal-to-noise ratio). CDMA techniques do not use frequency or time to divide communications; rather, they use direct sequence spread spectrum encoding to distinguish between independent communications that coexist in exactly the same frequency bandwidth. The baseband information is combined with a digital pseudo-random codeword that spreads the modulated information over a wider bandwidth than would normally be used for the other modulation techniques. Though each independent channel will use a wider bandwidth, multiple communications can be overlaid in exactly the same frequency space. By overlaying multiple channels, CDMA can achieve high bandwidth efficiencies. This technique is quite difficult to implement, though, because all mobile transceivers must be very accurately synchronized. Any deviation in this synchronization will result in a decrease in potential capacity and potential inter-channel (inter-user) interference.

In actual implementations, depending on the application, these techniques can be used independently or together. For example, initial analog cellular telecommunications systems used FDMA only in their implementations. Second generation cellular systems aimed to increase subscriber capacity and leveraged multiple techniques to achieve better frequency efficiency and multi-user performance and thus better communications availability. For example, the TDMA cellular standards (IS-54 and IS-136) and the Global System for Mobile communications (GSM) standard use a combination of FDMA and TDMA, where there are independent frequency differentiated communication channels that each implement a TDMA technique to carry multiple calls on each frequency. The CDMA cellular standards use both FDMA and CDMA, where the total bandwidth is frequency divided into sub-channels in which a CDMA technique on each sub-channel is implemented to carry multiple calls.

Ultimately, it is the application requirement for multi-user capability that drives the use of these techniques. But there are, of course, limits to the multi-user performance. Fundamentally, these multiple access techniques do not increase overall throughput and in fact, generally decrease total throughput slightly when multi-access technique overhead is considered. As a result, the design details of these techniques need to balance the total available throughput with the multi-user throughput demands. But if the multi-user throughput demands exceed the total throughput capabilities, then each of these techniques will result in missed or delayed communications, or what is generally termed blocked communications. As will be presented in the following paragraphs, media access control technology can mitigate many of the problems with communications that conflict for the same communications resources. But fundamentally, a blocked communication occurs anytime a communication channel is requested but not granted due to all communication channels being in use at that moment. The number of blocked communications is often a metric recorded by the communication system (usually as a ratio relative to the total number of communication requests) and is used as an indicator of multi-access efficiency relative to the level of multi-user demand. ***But fundamentally, multi-user channel access techniques can enable the efficient utilization and sharing of wireless bandwidth among many users, and thus have a significant impact on multi-user capacity and communications availability performance.***

Media Access Control (MAC) is the other technological piece enabling multi-access systems, and can be conceptually viewed as the etiquette used by independent wireless users or devices to request and access a communication channel. Depending on the application, MAC processes may not be needed if the communication system can be designed so that there is a channel for every wireless user or device — i.e., fixed assigned frequencies, time-slots and/or coding resources. But in applications where the communication resources are shared and need to be allocated on a demand basis, then a control process technology is needed to relinquish access to communication channels and manage conflicts for communication resources when demand exceeds throughput capacity. In these applications, efficient MAC processes can have a significant impact on performance characteristics such as the availability of communications and the resulting user capacity supported by the application.

Fundamentally, any random access, multi-user communication application, wired or wireless, uses some sort of MAC process technology. Wireless applications, however, have some unique challenges over wired applications — for example, the mobility of users and the inability of each user to "hear" other users who are competing for communication resources. More specifically, the basic problem is that typically, there can be multiple users who are randomly, independently and sometimes simultaneously communicating on a wireless channel. In addition, any given user who may be communicating on a channel may not be within range to receive communications (i.e., detect a channel is in use) from another user also communicating or requesting to communicate on that channel. These situations can result in repeated communication collisions and inefficient overall throughput utilization unless MAC process technologies are applied to gracefully handle these situations.

In general, wireless MAC solutions focus on first detecting if there is any current communication in the channel (i.e., carrier sensing) and then on sending a short request to access the channel if no current communication is detected. This request transmission is collision prone with other users, which may be simultaneously requesting communications, and/or out of range of the first user. As a result, there is typically a back-off and retransmit protocol applied to this request transmission. Only when access is granted by the controlling base station or access point does the user transmit its communications and thus avoid collisions. This process is generally referred to as Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) and results in efficient throughput use, generally maximizing the number of users a wireless system can support as well as the bandwidth available to each user (under a given multi-user load). In addition, the process can be used to regulate the number of users supported on a system and thus deliver a minimum guaranteed level of throughput performance to each user, which can be a key Quality of Service (QoS) capability in delivering some delay-sensitive communication services (e.g., voice, video, etc.) This CSMA/CA MAC process is the basis of what is implemented in most wireless LAN control protocols. Other network implementation may add variations. For example, cellular networks use a special control channel for the collision prone access request transmission and then subsequently relinquish a different dedicated communication channel for the real communications. Ultimately the details of MAC implementations can be quite complicated. ***The important takeaway is that Media Access Control (MAC) functionality can have a significant impact on the collision management and bandwidth utilization of a multi-access system and thus improve performance in terms of availability of communications, the associated multi-user capacity and the quality of communication services.***

Infrastructure Density and Manageability

Finally, similar to the chapter on coverage, infrastructure issues add the last aspect to the analysis of performance. But from a performance perspective, these infrastructure issues principally focus on how multi-user capacity and the availability of communications are driven by the spatial density of an infrastructure architecture as well as by the manageability of infrastructure communication resources (i.e., communication channels) beyond the control delivered by the MAC technology. Each of these issues still applies to multi-user scenarios, where a fixed centralized base station or access point is communicating with many mobile users within a defined coverage range and fundamentally have the capability to dramatically improve the communication performance of multi-user wireless applications.

The general concept behind infrastructure density considers the spatial or geographic distribution of infrastructure equipment in conjunction with the corresponding reuse of frequencies as yet another communication resource that can be divided into a multi-access technique and leveraged to improve multi-user performance. Generally speaking, this is referred to as Space Division Multiple Access (SDMA) and spatially distributes communication resources by reusing frequencies across the spatially diverse user base. Ultimately, this leverages the basic coverage dynamics previously mentioned, such as the limited transmission range of wireless signals and the ability to control that range through transmit power, antenna gain, etc.

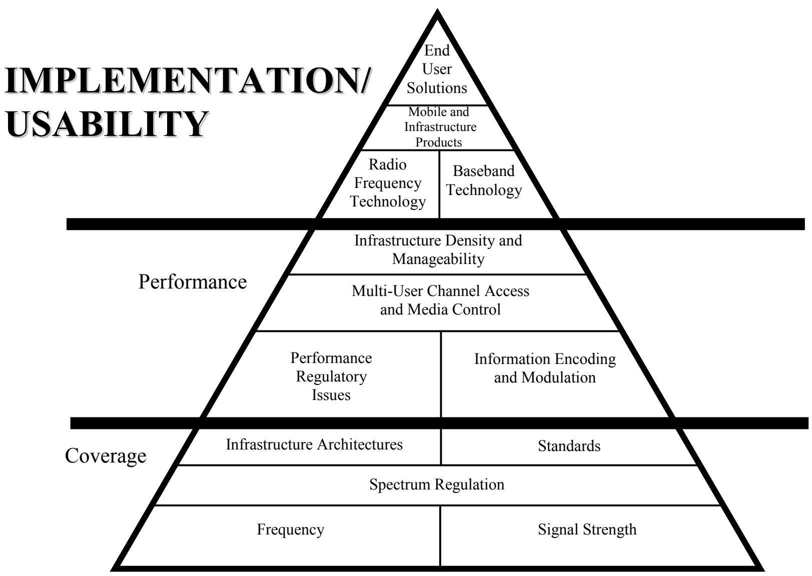
The principle thrust of SDMA involves an analysis of the user base across a given geographic area, and then designing an infrastructure architecture to support that user base plus some amount of general fluctuation due to the mobility of users. If the general number of mobile users grows in a given geographic area to exceed the basic multi-user capabilities, the coverage areas can be split into smaller regions, each with the same or similar capacity as the larger region, but using shorter transmission distances to cover the smaller area. This effectively increases the infrastructure density in continuing to supporting the increased user base. The net result of this is an increase in available bandwidth per geographic area, which can improve multi-user capacity, throughput data rate to each user, and the general availability of communications. The principle disadvantage is clearly an increase in infrastructure costs, which can grow at a rate of several times the cost of the initial infrastructure. In addition, real applications do not always have nice, predictable coverage areas and mobile users do not always fluctuate in predictable ways. These situations sometimes require nontraditional infrastructure solutions, such as coverage repeaters, that tap into existing capacity (via a wired or wireless interface) and retransmit it to an area needing coverage, as well as “smart” antenna solutions that can dynamically change the available bandwidth (and thus user capacity) across cell sectors and geographic areas, depending on user demand. ***The important issues to remember are that infrastructure architectures can spatially distribute communication resources and thus improve the available bandwidth per geographic area, resulting in better multi-user capacity, increased data rate per user and general availability of communications. These benefits have a cost trade-off, though, because higher density infrastructures require more equipment and can be more costly to deploy.***

The other infrastructure issue worth mentioning relative to performance is manageability. Ultimately, wireless infrastructure manageability can have different implied meanings depending on the application. For example, licensed band wireless communication services can typically implement fairly strict management procedures and can directly control most aspects of communications within the assigned band. Unlicensed networks, however, must operate in a much less controlled environment, where multiple independent users could be sharing the same frequency band, causing interference and implementing network infrastructures in a completely ad hoc fashion and thus must use more creative infrastructure management techniques. But what is clear is the entire topic of wireless infrastructure manageability is attracting more attention and will likely continue to be a focus in the future as wireless communications of all types (licensed and unlicensed) focus on standards-based approaches, implement more complicated infrastructure architectures, support more users, converge on more ubiquitous coverage and are enabled with more inter-network roaming and mobility.

The benefits of manageability can cover a wide variety of tasks that can be quite application specific, but in general they include such tasks as firmware/software revision control, remote infrastructure equipment configuration as well as security management and monitoring. These tasks, while not fundamentally improving performance, can clearly result in performance degradation if not executed. In addition, one of the more important infrastructure manageability capabilities is traffic and throughput monitoring. Most infrastructure management systems will have the capability to monitor many different aspects of communication traffic and throughput to individual users on not only a localized basis, but also across multiple infrastructure deployments and even across remotely located systems. Collecting this type of traffic information can be instrumental in detecting areas of high demand, communication channels experiencing interference as well as additions or changes to the network infrastructure. Often, the wireless infrastructure management system may have the capability to reassign communication channels and redirect throughput capacity to adjust for these situations and improve overall multi-user capacity and overall throughput performance. ***The net result is that infrastructure manageability can directly influence performance through diligent monitoring of maintenance and administrative tasks as well as through real-time traffic monitoring and throughput adjustments that result in better multi-user capacity and system throughput performance.***

Implementation/Usability

The final piece of the technological fundamentals puzzle falls into the general category of customer-facing issues that deal with implementation/usability, which is where all the technological fundamentals ultimately materialize into the application and business aspects that drive success. Implementation and usability are two closely related topics that influence similar success factors from a customer facing perspective. It is widely understood that product implementation is one of the most important factors in determining the success of a product, not to mention the corresponding success of a business, in most any industry. Yet for wireless applications in particular, what is less apparent are the direct links between the underlying technology and the product implementation and how those relate to the ultimate usability of the product or application. This is particularly important considering that the technological implementation, and thus many characteristics of the resulting product implementation/usability, is determined early in the product development process.



This chapter focuses on the topics of wireless product implementation and the corresponding application usability, and important links between the technological details and the application and business issues that drive success. ***In particular, the technological fundamentals behind implementation/usability can directly influence many key application and business issues such as product time-to-market, product costs, manufacturability and volume production, and competitive barriers to entry, as well as the more elusive usability-driven aspects such as product popularity (and thus product sales) and service minutes of use.*** Understanding the relationships between wireless technology and the implementation/usability fundamentals of these application and business aspects enables one to better position a product for success early in the implementation process.

Implementation/usability are very broad terms and can have different specific meanings for different applications and different companies in the value chain of the industry. As a result, the technological fundamentals for implementation/usability are categorized into three groups: the detailed design level, the product or box level and the systems, software and services level. This report is thus divided into four sections that build from the finer details of technology implementation to the systems, software and services that enable usability. The first two sections deal with the core of wireless functionality, covering the technological fundamentals behind the implementation/usability effects of the radio frequency (RF) and the baseband wireless functions (i.e., the components and circuitry involved in superimposing information onto a RF wireless signal and involved in encoding and prepping the information for transmission). The next section presents the high-level product implementation/usability fundamentals that make for successful products in the two general wireless product categories, mobile and infrastructure. Finally, the last section covers the high-level system, software and service fundamentals that further drive usability.

The circuitry that specifically implements the overall wireless functionality within a product can generally be dissected into two categories, the radio frequency (RF) functions and the baseband functions. These two functional groups exist in every wireless product in some general form, regardless of the specific application. As a result, the wireless portions of most any product exhibit similar implementation characteristics. Figure 8 shows a block diagram of a generic wireless transceiver and the division between the RF functions and the baseband functions. In actual implementations, these functions can be designed in a variety of different ways. Figure 8 shows one of the more common representations. Without getting distracted by technological details, the important take-away from Figure 8 is simply a general understanding of the functions of the wireless portion of a product, because these functional tasks go to the core issues behind implementation. For the transmit path, the baseband stage processes and encodes the information to be transmitted (usually voice or data information) and then modulates (superimposes) the information onto a digital representation of an analog signal. After a digital to analog conversion, the RF stage then up-converts that signal to the RF or carrier frequency, which is then amplified and transmitted through the antenna. The receive path does the reverse: the RF stage receives the high-frequency carrier signal from the antenna, amplifies it for processing and down-converts it to a frequency that can be processed digitally. The baseband stage then demodulates and decodes the originally transmitted information.

Radio Frequency Technology

The RF stage, in particular, is therefore responsible for all the functions that relate to the high frequency or carrier signal. This is important because the frequency of communications dictates certain operational requirements that influence the implementation and components used for RF designs, which in turn, influence the overall product implementation usability (i.e., the fundamental implementation principles of the RF stage are largely determined by the frequency of communication). As a result, there tends to be a wide variety of technologies applied to the solutions that specialize on specific applications and frequencies. So RF components can be even specialized by frequency, and a component that works at one frequency may not work at another, depending on the magnitude of the frequency difference. In fact, across the wireless spectrum, one will find a variety of components implemented in numerous technologies, resulting in different component availabilities and component prices, with assorted levels of integration that enabling different levels of manufacturability. ***But fortunately, these RF technology implementation characteristics, which are highly dependent on the frequency used for communications, generally follow somewhat predictable macro trends, according to frequency across the wireless spectrum. These trends can be used as the technological fundamentals to guide RF product implementation.***

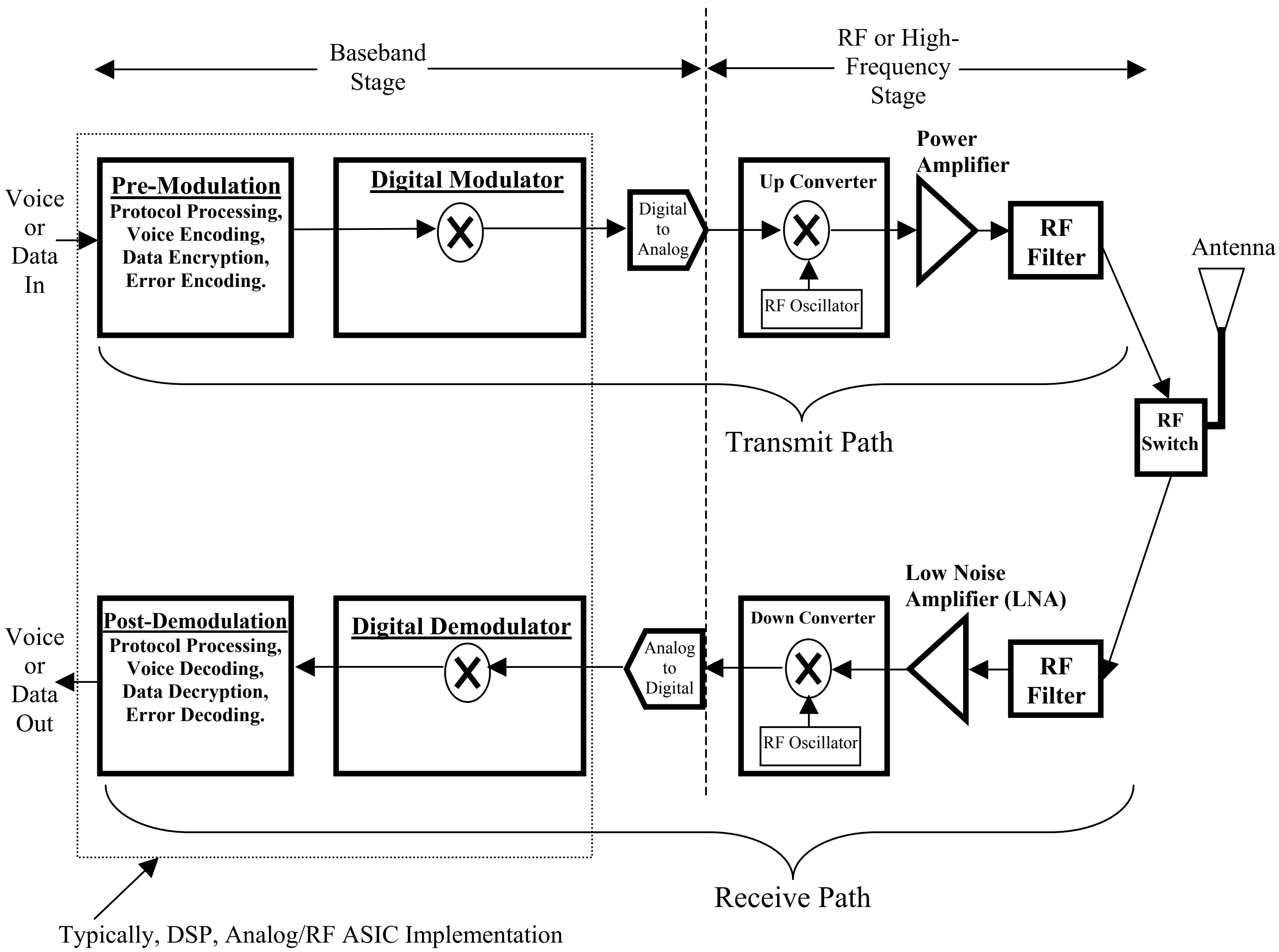
For example, the complexity and integration of wireless component technology generally have direct relationships with frequency, in that the higher the frequency, the more complex the technology and the lower the integration. This trend is principally due to the communication frequency and the capability with which RF integrated circuit technology generates signals that oscillate at RF frequencies. Components using pure silicon (Si) based technologies, which are capable of high levels of integration, are generally used in RF circuits in the lower frequency ranges (i.e., below approximately 800 MHz). Components made of newer variations of silicon, such as silicon germanium (SiGe), which are capable of moderate to high levels of integration, are being used more often in the middle spectrum frequencies (approximately 800MHz to 3GHz). Finally, components from the more complex materials such as Gallium Arsenide (GaAs), Indium Gallium Phosphide (InGaP), and others that exhibit fairly low levels of integration, are used for the higher frequencies above approximately 1 GHz.

It is generally difficult to put precise frequency limits on these various technologies because development progress continually improves operational performance and component application frequency ranges can overlap considerably. But the basic issue with RF component technology is the electron mobility, an elementary factor in frequency of operation, which depends on the fundamental characteristics of the material and the transistor design, but generally stays roughly the same for a given material. For example, the electron mobility of the average component designed with silicon is approximately 1,500 cm^2/V-s, whereas the electron mobility of designs using GaAs is approximately 8,000 cm^2/V-s, i.e., the higher electron mobility enables GaAs to produce higher frequency components. However, the basic problem is that implementing RF components in these higher electron mobility materials is more complex than the standard silicon IC processes and usually requires more sophisticated design and manufacturing capabilities, which can result in time-to-market delays. In addition, it is usually more difficult to achieve higher levels of circuit integration with these high electron mobility materials due to the additional heat that is dissipated, which becomes an increasingly difficult problem as frequency increases. Lower RF component integration, in turn, directly influences the integration at the circuit board and product levels, which can result in additional design complexities and delays. These complexities also can be turned around into competitive benefits, however, particularly for companies that can master the intricacies of RF technology and embody intellectual property in the designs at the RF IC or circuit board level. ***So fundamentally, RF technology implementation can often embody valuable intellectual property and thus be used as a barrier to competitors, but must also factor in the increasing complexity as frequency increases. This can require additional design and development resources and lead to time-to-market delays, as well as decreasing integration levels at higher frequencies, which can lead to lower integration and higher costs at the product design levels.***

However, the RF technology trends overall, including complexity and integration, are always somewhat of a moving target. Industry developments continue to advance RF integration technology that, in general, proceeds up the wireless frequency spectrum and enables wireless applications at continually higher frequencies. For example, silicon and silicon germanium technologies are continually being used at higher frequencies than previously thought feasible and gallium arsenide and the higher electron mobility materials are achieving better levels of integration at high frequencies through on-chip design improvements and multi-chip modules. In fact, even some of the filter and antenna technology is being integrated into multi-chip modules to provide a single chip solution to product OEMs.

This progression of advancement enabling applications further up the wireless spectrum has been the situation for some time. As a result, from a product implementation perspective, a few other trends emerge. The first is the general availability of wireless components for use in product implementations. Due to the historic progression of technology advancing up the wireless frequency spectrum, components generally become less readily available, particularly in volume quantities and commercial forms, the higher the frequency. In addition, since there is an inverse relationship between availability and price, RF components generally rise in price with higher frequency. Finally, due to all the preceding component trends (increasing complexity, decreasing integration, decreasing availability and increasing price), the manufacturability and volume production capability of wireless products implemented from those components generally decrease with increasing frequency. ***So overall, RF technology implementation can be complicated by less readily available and higher priced RF components as the frequency of communication used for applications increases. When coupled with the complexity and integration trends, this can also lead to more manufacturability issues, as well as higher cost and lower volume potential products.***

Figure 8: Generic Wireless Transceiver Block Diagram



Baseband Technology

The baseband stage of a wireless design generally performs all other signal processing functions outside of those performed at the high-frequency RF/carrier level. Figure 8 shows one of the more common baseband designs, with a single dedicated digital ASIC implementing all baseband functions. Historically, this has not always been the case because baseband functions have been implemented in other ways, including all-analog implementations. However, with advancements in digital signal processing during the last decade, more designs are using digital signal processors (DSPs) and/or custom ASICs to implement these functions. This approach has some clear advantages relative to the fundamentals of implementing wireless technology in terms of integration, programmability and the inclusion of more advanced functionality that can directly relate to aspects such as barriers to competition, product cost, manufacturability, volume potential, power efficiency and mobility usage. The appropriate baseband implementation can thus be a key factor in the overall product implementation as well as the ultimate product and service usability.

Figure 8 breaks down the baseband functionality into two generic blocks for each of the transmit and receive paths: one for pre- or post-modulation processing and one for digital modulation/demodulation. The pre- and post-modulation processing include all the reciprocal processing functions for tasks such as encoding/decoding (for data reduction) and encrypting/decrypting (for air link security), error encoding/decoding (for error transmission detection and correction) and protocol processing (which includes the higher level tasks such as communication channel request and acquisition protocols, channel access implementation, etc.). The digital modulator and demodulator perform the reciprocal functions of superimposing and removing the information from a digital representation of an analog signal. These functions interface to the RF stage through digital-to-analog (DAC) and analog-to-digital (ADC) converters.

With the exception of the DAC and ADC, almost all of these functions are typically executed on a single DSP or some combination of an embedded processor, for digital signal processing and custom ASIC designs. Occasionally, depending on the application and the volume shipments, the baseband stage is sometimes implemented as a fully custom ASIC, but the more general and flexible solutions are typically implemented with some type of processor. In fact, from a high-level perspective the digital signal processor of the baseband stage can be viewed as the central processor for the wireless device, much like how the CPU is viewed in a computer. Thus, dramatic improvements in DSP processing power, similar to what has been exhibited in the personal computer industry, result in significant improvements in functional performance for wireless devices as well. As DSPs get more powerful, for example, the baseband stage continually includes more functions that had historically been part of the RF stage. Some low- to mid-spectrum frequency applications are using the more powerful DSPs to implement the entire baseband and RF stages in a single IC. In addition, improvements in baseband processing power are allowing the inclusion of more advanced functions that result from the convergence of wireless communications with other technologies and devices. The baseband processing stage is clearly an enabling technology for implementing many aspects of wireless functionality.

The most significant implementation feature of the baseband stage, however, is integration, because it ultimately influences a multitude of application and business issues. Integration is, of course, the level to which all the baseband functions can be implemented on a single IC, either through a programmable DSP or a semi-custom/custom implementation. Since these implementations can leverage standard digital IC technology, baseband ICs can leverage the implementation economies of scale from the broader silicon IC marketplace. This allows an integrated baseband implementation to include very complex functionality in a fairly inexpensive implementation. So unlike the RF stage, where some functions may need to be implemented in discrete GaAs components, after the baseband stage design is implemented in an IC (either through DSP programming or semi-custom/custom logic design) it can realize significant cost reductions as volumes ramp.

This ability to include complex, advanced functionality also provides the opportunity for design differentiation and the capability to establish barriers to competition at the baseband IC product level. In addition, a highly integrated, single-chip baseband stage can improve the manufacturability and volume production potential of the wireless product. A highly integrated baseband solution also will result in a more power-efficient implementation, which directly results in improved battery life in a mobile wireless application, and ultimately in better mobility usage. The only downside to the integration focus of the baseband stage and the opportunity to integrate advanced functionality is the additional development that can be required in the programming or design process. This additional development can be significant and can add considerable time delays, increasing the product time-to-market. ***But the significant benefits of pursuing an integrated implementation for wireless baseband functionality usually outweigh the potential time-to-market development delays and can be used as potential barriers to competitors and ultimately result in many significant benefits including lower costs, better product manufacturability, higher volume potential, lower power consumption and better mobility usage.***

From a functionality perspective, the baseband IC also provides the opportunity to implement specific capabilities that can influence the application and business potential. A core enabler of this functionality implementation, as mentioned earlier, is the programmability of the baseband IC. Most newer baseband implementations allow some sort of programmability, which fundamentally allows the IC to address a much wider base of applications and can result in potentially larger sales volumes. In addition, this programmability allows baseband designers to customize the baseband functionality to the specific wireless application. This is becoming increasingly important as wireless communication is integrated into new applications and converges with other mobile computing and communication technologies. For example, as more wireless communication markets become based on standards, the baseband IC provides a technological means to implement those standard protocols, which can open a broader addressable customer base and drive volume demand.

In addition, some baseband ICs can provide the capability to integrate multiple standards into a single IC and enable communication roaming across multiple wireless technologies on a wider geographic area, thus dramatically improving geographic usability. As wireless converges with other computing and communication technologies, the baseband IC provides the platform through which to interface convergence capabilities. For example, newer mobile phones are implementing capabilities such as Personal Digital Assistant (PDA) functions (i.e., address book, calendar, etc.), Bluetooth communications, camera functionality and position location technologies, all of which typically use the baseband IC as their CPU and interface into the mobile cellular network. These capabilities are often being used as product differentiators to drive better sales for product OEMs and as a means to drive increased minutes of use for wireless service providers. Finally, as mentioned earlier, the baseband IC also is typically the platform used for implementing wireless security, which is largely a usability aspect of wireless communications that can notably influence (positively and negatively) product sales and service usage. ***So from a baseband functionality perspective, programmability, technological convergence and customization can all be key implementation factors that can be used as product and service differentiators and drive better sales volume, expanded geographic usability, enhanced overall product appeal and better usability, resulting in higher service minutes of use.***

Mobile and Infrastructure Products

In the value chain of the wireless industry, the product level category builds on the technological fundamentals provided by the component-level technology to implement the circuit board/module and box-level finished products. As a result, these products reflect similar wireless dynamics in terms of their technological fundamentals and the impact to key application and business issues. In addition, the wireless product-level category can be dissected into the two major sub categories of mobile products and infrastructure products that have unique implementation/usability characteristics that are important to understand relative to positioning products in these wireless markets. In general, implementation of these products is focused on not just the wireless functionality but also on the functionality for the complete product, which may include a variety of other functions such as a wireline network connection, a user/customer interface, additional processing and software capabilities, and a plethora of other technologies resulting from the convergence of wireless with other technologies, services and functions. Implementing these products thus requires a combination of detailed component-level design expertise and higher system-level knowledge. Ultimately, the product level category is one step closer to the end application and thus also focuses on more usability aspects.

Of the two wireless product categories, mobile products most directly leverage the benefits enabled by RF and baseband components in pursuit of the mobility aspect of the wireless golden rule. Integration is the most important technological fundamental of mobile products because integration at the component level directly ripples up into integration at the circuit board and product level, enabling a number of benefits. Integration at the component level generally reduces component count and improves manufacturability at the circuit board and product levels. This in turn improves the volume potential and the ability to reduce product costs as sales volumes increase. In addition, integration results in smaller circuit board and overall product implementations and directly leads to attractive form factors for mobile products. Integration at the component level also typically results in better overall power efficiency at the product level, which drives longer battery life. Small size and long battery life are key factors in better mobile product usability and are core contributors to success regardless of the focus market.

Sometimes, however, high levels of integration are difficult to attain. As mentioned in the previous section, the additional development costs required to achieve high levels of integration can sometime be quite high and ultimately are difficult to justify for newly introduced products manufactured at relatively low volumes. There is sometime an iterative cycle between the product level and component level, where increasing sales volumes at the product level will drive integration development efforts at the component. This, in turn, drives better dynamics at the product level. However, achieving success in the mobile products market can be more complicated than simply producing a small, long battery life mobile device, particularly if it is a consumer-oriented product. The combination of the sometimes-fickle consumer with the convergence of wireless communications and a variety of technologies, services and functions, makes it quite difficult to design successful wireless products.

The cellular handset market is the best example, where functions such as MP3 players, cameras, Internet access, messaging, color screens and mobile video games, etc., are all integrated into the handset along with the core voice communications capabilities. Some of these functions are included as differentiators to drive additional product sales and some are included to drive additional services and service minutes of use. Certainly there is no exact formula for success, but there are two high-level concepts on which to focus — mobility and individualization. Mobility is a golden rule driver of wireless overall, and individualization is a phenomenon that arises from an individual's usage of consumer wireless products. The more a product can combine these factors, the more likely it is to succeed. ***Overall, successful mobile products leverage integration into better manufacturability, attractive form factors and improved battery life. They also focus on mobility and individualization in convergence with other technologies, services and functions for consumer oriented products.***

The infrastructure product category, as used for the purposes this report, includes everything that is not mobile. This includes a wide variety of products but can be generally dissected into two sub-categories mirroring the golden rule. One category is driven by mobile applications, and one category is driven by advantageous deployment economics. Mobility driven infrastructure can be generally defined as wireless communications equipment that enables mobility but is not mobile itself. This typically implies a situation where the infrastructure equipment is acting as an extension of an existing network (typically a wireline network), enabling mobility to potentially many simultaneous users. As a result, mobile infrastructure equipment typically has special performance requirements to handle simultaneous users and signal dynamics associated with mobility. Mobile infrastructure equipment has thus historically been more focused on performance and functionality than cost, product size and integration. While this is still true, that focus is changing somewhat as the market matures.

Two central themes remain constant as the market changes: delivering coverage and enabling flexibility. Coverage is clearly the main function of mobile infrastructure equipment because without adequate coverage, mobile communications breaks down. In markets such as cellular telecommunications, inadequate coverage can have a meaningful effect on the overall usability of the service, and influence customers' minutes of use and the ability to attract new subscribers. However, as the cellular infrastructure equipment market has matured and become more competitive, the equipment focus has changed to be more price sensitive and conscious of economical ways to deploy coverage, as network operators struggle with getting a reasonable return on infrastructure investments while keeping up with competition by delivering next-generation services. This influences the infrastructure product market by increasing emphasis on implementation costs, which has resulted in a variety of infrastructure products designed for improving and deploying coverage more economically (i.e., micro base stations, repeaters, tower top amplifiers, etc.).

Ultimately, coverage means more than simply blanketing a geographic area with adequate signal. It also means the ability to handle multi-protocol communications and the embedded network intelligence to handle intra-network roaming, which also are key flexibility characteristics, as different over-the-air protocols proliferate (i.e., GSM, TDMA, CDMA and even potentially roaming capabilities to WLAN networks) and inter-network roaming becomes even more important. Roaming and multi-protocol capabilities ultimately result in the ability to address a larger customer base, enable increased customer minutes-of-use and overall wireless communication usability. Mobile infrastructure product flexibility also extends to other capabilities as well, such as enabling both voice and date traffic as well as position location capabilities, messaging services, etc. ***Successful mobile infrastructure product implementations thus focus on delivering wireless coverage economically and/or on enabling flexibility through network intelligence, and the ability to incorporate additional product and service enhancements — all of which lead to better mobile usability and drive service minutes of use.***

Wireless infrastructure products that are driven by advantageous deployment economics generally include everything that is not driven by mobility. These include products such as point-to-point and point-to-multipoint microwave radio systems, and generally any other fixed wireless communications products. Nevertheless, these systems all have common technological fundamentals that drive their implementation. These systems are typically more application focused than those driven by mobility, and thus typically do not include some of the flexibility and advanced capabilities such as roaming network intelligence, multi-protocol communication capabilities and the ability to integrate advanced services. However, these fixed wireless systems must still be flexible enough to carry multiple types of traffic (i.e., voice and data) and be feature-rich enough to compete against wireline alternatives, because that fundamentally is the single most important competitive dynamic. For example, these fixed wireless systems must either enable communications where wires cannot go, or deliver communications faster, cheaper or easier than wireline alternatives. In general, fixed wireless systems will be more expensive than wireline alternatives simply due to the cost of RF and baseband wireless technology. As a result, these fixed wireless infrastructure products must focus more on implementation cost, particularly when competing head-to-head with wireline alternatives. So from a product implementation perspective, the ability to implement a cost competitive product can single-handedly determine the market adoption and sales volume of these fixed wireless products.

In addition, these products are not completely independent from the mobile products category because some mobile products do find applications in the fixed wireless market. This occurs when a product that is driven by mobility to relatively high volumes, leverages those economies of scale into a low cost implementation that can, in turn, compete in the fixed wireless market driven by advantageous deployment economics. These are products initially designed for mobility that end up with the ability to compete better at the advantageous deployment economics level as well. This has occurred with cellular infrastructure products, which have been used in fixed wireless local loop applications, and with wireless LAN products that were initially used in mobile applications but are now finding uses in fixed communications as well. ***Fundamentally, wireless infrastructure products that compete based on advantageous deployment economics must leverage the ability to go where wires cannot, or must deliver communications cheaper, faster or easier than wireline alternatives and thus focus intently on product costs, which can single-handedly determine product sales volumes.***

End-User Solutions

On top of the wireless communications capability provided by the core wireless technology and product implementations, is the market for end-user solutions. In general, these solutions use a wide variety of technologies (of both wireless and completely non-wireless nature) and pursue diverse applications and markets. Despite the diversity, these solutions are all driven, in one way or another, by the wireless golden rule and wireless technological fundamentals, and more importantly, are principle enablers of wireless usability. As a result, it is useful to characterize these products and understand the fundamentals that drive successful solutions. However, this product group can be one of the most elusive and difficult to characterize because implementations can be quite varied, and can use and/or integrate very diverse technologies that can be implemented in unique combinations of hardware, software and services. In addition, these solutions are most directly linked to the customer's usability, and are thus subject to continually changing demands and interests. But fundamentally, these end-user solutions are key enablers of wireless usability across a wide variety of applications and are ultimately responsible for driving numerous key business fundamentals, including initiating new markets and new revenue sources as well as driving additional wireless usage, network popularity and subscriber growth.

By definition, wireless end-user solutions are enabled by some type of wireless network service or wireless communication capability. Typically, the deployment of that service or capability is driven by a fairly specific application that forms the primary end-user solution and fundamentally consists of integrated systems of the previous product categories — i.e., the technology and products (mobile and infrastructure) that enable wireless communications and deliver on mobility or advantageous deployment economics. In addition, that communication service and primary solution can often be used as a platform from which secondary end-user solutions can be deployed and drive new sources of revenue. This combination of primary and secondary solutions on wireless networks is becoming increasingly important with the evolution of wireless communications and the commoditization of many primary solutions and services.

Cellular networks are the best example of communication services on which much of the market for secondary end-user solutions is focused. Cellular networks and services were, of course, initially deployed with the intent of delivering mobile voice communications, but are now being upgraded to deliver data communications and are thus enabling more secondary end-user solutions such as messaging, wireless Internet access, location based services, etc. Wireless LAN services look to be positioning for a similar evolution — i.e., they were initially deployed as wireless data extensions to LAN networks, but are now beginning to emerge as a publicly available network extension to the Internet and as a market for secondary solutions such as voice, video, location capabilities, etc. ***Fundamentally from a wireless network service provider perspective, successful end-user services are determined by customer usage, which is***

still largely driven by the primary end-user solution/service offering (i.e., the principle service driving network deployment), but are increasingly augmented with the delivery of secondary end-user solutions that focus on further enabling that usability, and in turn, on generating additional revenue.

The secondary end-user solutions are considerably more difficult to characterize, because there are a wide variety of technologies used in implementations that pursue very diverse markets. For the purposes of this report, a high-level summary of the competitors and their solutions focuses on four categories: hardware network intelligence, software applications, content functions and integrated solutions. Hardware network intelligence basically consists of additional hardware elements in either the infrastructure or mobile product forms. These elements add additional processing capabilities like switching and routing capabilities specifically geared for IP traffic, position location determination and delivery capabilities (either infrastructure or mobile device oriented), intra-network roaming intelligence, network management capabilities and others. Software applications encompass software-only solutions that leverage standardized processing platforms in either infrastructure functionality or mobile device applications. This could include a wide variety of smart handset/PDA applications like email, messaging, mobile Internet browsers, map software, etc., as well as infrastructure-oriented solutions like content management systems, mobile protocol processing engines and other infrastructure-based software solutions. Content functions basically include both original mobile-oriented content and content aggregation, which are mobile-oriented games, news and entertainment as well as solutions that aggregate that content for distribution over mobile networks. Finally, integrated solutions basically combine functionality delivered by the other solution categories into more of an application specific solution. These solutions can be quite varied, but could include a solution that integrates position location capabilities with mapping software to provide route tracking/management capabilities to a delivery application. While the technologies and applications can be quite varied, all of these solutions are in one way or another driven by wireless fundamentals.

From a secondary end-user solutions perspective, a number of common characteristics emerge. The first is distributed intelligence. Considering the additional infrastructure equipment and the proliferation of smart handsets and wireless enabled PDA, coupled with new software applications, the amount of distributed intelligence throughout many wireless networks is increasing. This distributed intelligence is enabling new secondary end-user solutions such as mobile video distribution, multi-media messaging and others that would not otherwise be possible.

The second significant common characteristic is in the use of standardized platforms. The market for software-only solutions in both handset and infrastructure products is only possible through the utilization of standard platforms such as the Symbian OS, Mobile Windows from Microsoft, PalmOS from PalmSource, Brew from Qualcomm and others. Similar to software for the PC industry, the use of standard platforms will likely result in a more vigorous third-party market for wireless software, yielding a variety of new secondary end-user solutions. However, in the mobile product/handset marketplace, there are more choices as to the standard platform compared to the quasi-monopoly situation in the PC industry.

The final interesting characteristic about wireless end-user solutions pertains to the individualization inherent in these applications. In many wireless applications, and in particular with mobile solutions, the information and intelligence being communicated and exchanged tends to be very focused on the individual or specific application. This results in some solutions having the capability of being highly customized to a user's needs and interests, and in market applications that tend to initially be very vertically market focused before potentially growing into more horizontally oriented applications. Ultimately, all of these characteristics are key enablers of the usability of secondary end-user solutions. ***Fundamentally, successful secondary end-user solutions leverage the capabilities of the underlying technologies and products into an end-application and usability-focused product or service that leverages distributed intelligence, standardized platforms and the individualization capabilities of wirelessness to drive new market applications and revenue sources as well as increased service usage, improved service popularity and subscriber base growth.***

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Moeller Ventures is a wireless market research, consulting and strategic advisory firm that focuses on bridging the classical gap between the details of technology and the issues of business and finance that drive success by leveraging core industry research into market reports, customized due diligence, strategic partnering and other executive-level consulting. This focus incorporates extensive expertise and a proven track record in dealing with technology, competitors, market trends, regulatory issues and financial analysis, and leveraging extensive relationships across technology suppliers, OEMs/system integrators and end customers, as well as venture capitalists and institutional investors. The net results reflect a real-world understanding of the details of growth businesses and markets as well as the integrated issues of technology, business and finance and how those issues can be leveraged to create value and maximize success for client organizations.

Moeller Ventures was established by Jim Moeller in March 2002. The company leverages his experience as an analyst in the investment banking business with RBC Capital Markets (formerly Dain Rauscher Wessels and Wessels, Arnold & Henderson) as well as his 10-year experience in the technology industry, where he worked with companies such as ADC Telecommunications, a wireless technology startup company named Uniplex, the ETA Systems division of Control Data Corporation and IBM. In addition, Mr. Moeller has served as a consultant and freelance analyst, designing technology for projects such as CATV video conferencing and embedded wireless applications as well as writing technology market reports for an independent research firm.

While at RBC Capital Markets and Dain Rauscher Wessels from 1997 through 2001, Mr. Moeller was the lead wireless technology analyst and studied a large number of public and private companies. During this time, he developed relationships with key industry executives. Mr. Moeller initiated coverage of the wireless semiconductor and broadband wireless sectors with insightful reports that resulted in DRW winning underwriting positions on numerous initial public offerings and secondary offerings in those segments. The lead-managed IPO of Aironet (a broadband wireless LAN company) by DRW continues, to this day, to be the firm's most successful wireless transaction, going public in July of 1999 for a valuation of $150 million and subsequently being purchased by Cisco in a sole-managed M&A transaction by DRW that closed in March of 2000 for $1.4 billion. In addition, in 1996 Mr. Moeller was a freelance technology market analyst who wrote reports for Datapro (acquired by the Gartner Group) on topics such as cellular and PCS wireless technology, wireless data communications and mobile computing.

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