1 Introduction

Over the past ten years there has been a revolution in the development and acceptance of mobile products. In that period, cellular telephony and consumer electronics have moved from the realm of science fiction to everyday reality. Much of that revolution is unremarkable – we use wireless, in its broadest sense, for TV remote controls, car keyfobs, travel tickets and credit card transactions every day. At the same time, we have increased the number of mobile devices that we carry around with us. However, in many cases the design and function of these and other static products are still constrained by the wired connections that they use to transfer and share data.

Short-range wireless links have the ability to transform the way that these devices share data, whether that is high-speed streaming, or an occasional indication of a change of temperature. To aid this transition, an enormous amount of work has gone into designing wireless standards and the associated chips and software to support them. Despite this, the task of changing from a cable to wireless is still seen as a daunting prospect by many designers; wireless retains its reputation of being close to black magic. The aim of this book is to demystify wireless and remove some of the misconceptions that continue to surround it, as well as to investigate and explain the new mythologies that these wireless standards have generated.

1.1 The growth of standards

In the last 15 years, a number of short-range wireless standards have emerged. Two reasons in particular lie behind this. First is the desire to remove cables from products, driven by the continued growth in portable products. Second, the availability of globally accessible license-free spectrum, along with cost-effective silicon, particularly in the 2.4 GHz and 5.1 GHz bands, has provided an economy of scale that has made the integration of wireless much more affordable.

Not all of these standards have survived – some have disappeared, whilst others have prospered. HomeRF and HiperLAN are largely forgotten. In contrast, Bluetooth and Wi-Fi are present in over a billion devices. With their success, the industry has come to recognise the benefits to be gained from standards, amongst which are the security of supply resulting from multiple silicon suppliers, improved interoperability and robust performance. All of these emerge from competition and a critical mass of engineers refining and evolving the standards.

Behind Bluetooth and Wi-Fi in terms of volume, but targeting specific industrial and automation applications, is an emerging set of standards based on the 802.15.4 radio specification, including ZigBee, 6LoWPAN and WirelessHART. Another newcomer, which offers a new radio optimised for ultra-low power and a future generation of Internet connected devices, is Bluetooth low energy. In addition to these, a wide range of proprietary radios use the same unlicensed bands.

Despite the impressive volumes of chips being shipped, relatively few different applications have come to market. Instead, we have seen implementations dominated by a few 'killer' applications. In the case of Bluetooth, these have been gaming controllers and voice headsets; for Wi-Fi it has been wireless network connectivity. Other standards are still struggling to find their place in the wireless ecosystem.

Two factors affect this: the first is the 'route to volume', which gives a financial advantage to standards that can get a 'free ride' in a mass-volume product. The second is the relative complexity involved in turning any of the standards into an interoperable application.

The free ride is an advantage that has allowed Bluetooth and Wi-Fi to slide down the price curve to the point where they have become cheap enough to enable new applications. To understand this phenomenon, we need to look at the economics of designing and manufacturing silicon chips.

Funding semiconductor start-ups is always a gamble, especially when the companies are aiming to support industry standards. Because several companies will target the same standard, it is a basic fact of life that a significant proportion will fail to gain any share in the market. That is an inevitable consequence of the cost structure for wireless chip designers; the expense of designing a chip means that they need to sell millions to survive. The general consensus is that the cost of designing a complex wireless chipset ranges from around $3 million to $10 million. The higher end of that range typically includes application processors and embedded protocol stacks. That cost can rise even higher if there are multiple radios in the chip. From the other side, manufacturers using these devices need the cost of the chips to be below the $5 price point. In the case of Bluetooth, where over one billion chips are sold each year, the cost is now under $2 per chip. For the highest volume users in the mobile phone industry it is approaching $1.

With these price points and a potential profit of less than a dollar per chip, companies need to sell a minimum of 10 to 20 million chips to cover their development costs. Those that do will make money and gain a significant market share. Those that don't will run out of cash.

For a standard to be able to justify calling itself a standard there need to be at least three manufacturers who are making interoperable products. Without that, there is no guarantee of a real, ongoing, ecosystem. To sustain it requires an annual marketplace of 50 to 100 million chips.

Attaining that volume is difficult. So far, DECT is the only short-range radio standard that has got there by itself. But it managed that by starting off as an expensive, corporate product, with plenty of margin. For others, that's where the 'free ride' comes in. Both Bluetooth and Wi-Fi were built into products – handsets and laptops, respectively – before any general usage occurred. That meant that the volume of chip sales was present to fund the silicon companies and the standards community. It drove the price of chips down so that companies could design and manufacture affordable headsets and access points, which eventually became taken up by consumers, driving a virtuous circle. For these two technologies the chip costs are now sufficiently low that there is a burgeoning market in new product applications. However, without that free ride, they would probably still be relatively low-volume products, if they existed at all. It is an important lesson for standards developers, as well as a cautionary one for designers embracing new standards, who need to be sure that the standard and chips they include in their products will continue to exist for the lifetime of their design.

1.2 Markets

There are some exciting new areas of growth for products using wireless standards. I will cover the market in more detail in the final chapter of this book, but to give an indication of the range of different applications, it is worth pointing out their diversity, both in terms of current areas and those that are poised to emerge in the next few years. Today, many wireless chips in products like laptops and mobile phones are never used. New markets are poised to change that, as wireless will become a fundamental element of these products' functionality.

The first three covered below – games, voice and Internet access, account for over 90% of today's wireless applications. The ones that follow have the potential to join them as major new markets.

1.2.1 Games controllers

The success of the Nintendo Wii and its imitators has provided the largest single use of a wireless standard – in this case Bluetooth. It is a good example of how users accept wireless as an integral part of a product. It's also a good illustration of wireless being a fundamental part of a product's function. Unlike a phone or a laptop, where it is just one of many features, a games controller will not work without it.

1.2.2 Voice

Voice, as exemplified by the wireless headset, is the next largest application for wireless, accounting for the majority of stand-alone Bluetooth chips that have been sold. Riding on the back of an estimated two billion Bluetooth-enabled mobile phones, it is likely to retain that position for a number of years. However, it is believed that only around one-third of the headsets that are sold are used after the first few days.

1.2.3 Internet access

Following close behind is Wi-Fi, which connects laptops and mobile devices to the Internet through access points. Over the coming years we'll see that connectivity extend to other products wanting to report their status to a remote website or monitoring service, making use of the growing infrastructure of public and personal access points. Although usage is increasing, it is estimated that over half of PC-based Wi-Fi chips and over three-quarters of those in mobile phones are never turned on.

Despite the fact that Wi-Fi gives the ability to connect directly to the Web, almost all of its use is by people for email and web browsing. When we look at web connections that do not involve people, the low-power standards of ZigBee and Bluetooth low energy will come to the fore to connect a new generation of battery-powered products to the web, using intermediate devices as gateways.

1.2.4 Internet connected devices

Internet connected devices are key to the growth of a number of emerging markets. The following section provides an overview of these. Chapter 12 explores them in more detail.

1.2.4.1 Health and fitness

Wireless is expected to revolutionise healthcare by linking personal consumer devices to medical services or personal web applications. The area is known variously as telehealth, eHealth and mHealth, the latter generally referring to products that link to, or are connected through, a mobile phone.

The driving force behind this market is the need to reduce costs as the demographics of an aging population puts ever greater pressure on the cost of delivery of healthcare. It also attempts to address personal health management by providing constructive feedback for the third of the population with long-term chronic diseases.

The market is a wide one, spanning sports, fitness and wellness. It also covers the provision of assisted-living devices for the elderly and infirm, which help them to maintain their independence and live at home. As each installation may employ several dozen different simple sensors it opens up a potential market for billions of wireless devices.

1.2.4.2 Smart energy

Smart energy is the remote control of appliances that consume power. Governments around the world are developing strategies to reduce energy consumption and one approach being pursued aggressively is that of controlling how energy is used. Smart-energy initiatives attempt to try to modify user behaviour, either to use less energy, or to spread its use, so that less power generation infrastructure is required.

A key cornerstone of this approach is the supply of smart-energy meters, which inform users of their actual consumption. The next step is for the utility supplier to control appliances around the home to reduce or spread energy usage. Gas and water meters are unlikely to be powered, and wall-mounted and free-standing products, such as thermostats and displays, may need to run on batteries or scavenged power; hence the interest of the ultra-low power wireless standards, including ZigBee and Bluetooth low energy, which are being promoted to address these market needs.

1.2.4.3 Industrial automation

Although a smaller market, there are many high-value applications for wireless within industrial automation and factories, where the cost of wiring sensors is significant. Wireless technology opens up the possibility of installing a greater number of monitoring sensors, particularly on rotating or mobile machinery, or where cabling is expensive or impractical to install.

Much of the cost benefit of wireless in industrial automation is to receive better feedback on the state of machinery, allowing pre-emptive maintenance to reduce downtime and the associated cost.

1.2.4.4 Home automation

Home automation has been slow to take off, but is starting to grow with the availability of wireless products, which are easier to install. The current market is predominantly for alarms, both burglar and safety (smoke and carbon monoxide). Although most of these products use proprietary wireless standards, which are vendor-specific, ZigBee and Bluetooth low energy are developing profiles to address these and bring interoperability to this market. A number of other emerging wireless standards are appearing that specifically address these markets, foremost among which are Z-Wave and the EnOcean Alliance.

1.2.4.5 Consumer accessories

Today, home automation in the form of the TV remote control is one of the most successful wireless applications, albeit infrared. The appearance of wireless in a growing number of products used within the home, plus a desire to extend wireless connectivity to applications on smart mobile phones, is resulting in vendors moving from infrared to standards-based wireless links.

1.3 What is a standard?

It may seem an obvious question, but before moving on, it is worth trying to put a definition around a standard, or at least a wireless standard. Over time, the word's meaning has evolved or been changed, with an increasing number of specifications claiming to be a standard. The following definition is my own view of what a standard is, and helped determine what I have included and excluded from this book.

From a philosophical starting point, the purpose of a standard is to allow devices that adopt it to work together, or share elements of their design. I would argue that a basic requirement is that one must have the ability to implement it using elements of technology from a variety of different manufacturers. In other words, if it is only supported by one supplier of chips and protocol stacks, then it is not a standard. Even if the specification is published in the public domain, if that one manufacturer disappears, then the standard effectively dies. That currently excludes 'standards' like Z-Wave and ANT. They may attract alternative sources of supply in the future, but today they are a single supplier standard, which carries a risk for the product designer. As I've already pointed out, to maintain its viability, a standard needs to ship around 100 million chips per year. Without that, purely financial factors threaten its long-term survival.

The next criterion I apply is that the standard has, or references, a protocol stack that extends up through enough layers to provide the ability to design interoperable applications. If it does not, then it is essentially a building block upon which a standard can be built. So 802.15.4 falls at this hurdle, although it provides the foundation for ZigBee, WirelessHART and 6LoWPAN, while 802.11 scrapes through, at least in its alphabet soup incarnations, through its use of TCP/IP. But it was really the work of the Wi-Fi Alliance that changed its position from being purely a radio and baseband to the status of a proper, interoperable standard. If a standard does not provide this level of definition, then it runs the risk that installation and usability can become poorly defined, making it difficult for users to understand.

My third criterion examines how well the body responsible for the standard ensures that products will work together. That needs

Table 1.1 *State of the wireless standards*

Standard	Application profiles	Multiple suppliers	Qualification program	Enforcement program
Bluetooth	Yes	Yes	Yes	Yes
802.11	n/a	Yes	No	No
Wi-Fi	Yes	Yes	Yes	Yes
802.15.4	n/a	Yes	No	No
ZigBee	Yes	Yes	Yes	Not active
Bluetooth low energy	Yes	Yes	Yes	Yes
WirelessHART	n/a	Yes	No	No
6LoWPAN	n/a	Yes	No	No
Z-Wave	Yes	No	Yes	No
ANT	Yes	No	No[a]	No
Wireless M-Bus	No	Yes	No	No

[a] The ANT qualification is a self-certification.

a qualification scheme, which devices have to pass before they are allowed to market. Without one, designers have too great an opportunity to tinker with the detail of the standard, resulting in products that do not work together. This is where the number of standards really starts to fall.

Finally, I'd add one last requirement, which is that the standard has an enforcement program to allow it to remove non-compliant products from the market. Without this, the qualification process has no real teeth. And the enforcement program must be used. So far, only Bluetooth and Wi-Fi can claim this, although ZigBee has a program in place. Table 1.1 is a snapshot of where the different standards and pretenders are at the moment.

The higher a standard scores in the table, the better the chance that you will find an interoperable ecosystem of products. When a standard can say yes to all four of those points, it can claim to have moved successfully from being a proprietary standard with good PR to being a true standard.

1.4 Choosing a wireless standard

Despite the number of different standards available, and the number of chips being shipped, there are still relatively few different applications that have achieved any volume. A major reason for this lack of diversity has been the comparative difficulty of adapting the standards to support interoperable applications. That is not something that particularly interests silicon suppliers. To reach high volumes, it is generally in the interest of silicon, stack and application providers to concentrate on a few highly focused applications and hope that others will extend the market application areas.

The fact is that most silicon companies have limited resources to support a wide range of different applications. They make their money by selling tens of millions of chips to a few very large customers. To further this cause, they develop reference designs for popular products, such as headsets, access points and PC adaptors. As most products on the market are based on these, there is surprisingly little practical knowledge around in using the standards for other purposes.

Without a comparative understanding of the standards and how to interface with the chips, it is quite difficult both to choose the most appropriate wireless standard and then to design it into an application. Getting to grips with wireless is not easy; designers need to know how to choose a standard, which is an important skill in its own right, how to make connections using it and how to interface it to their data protocols.

In practice, designers can change very little, if anything, within a wireless standard. If they could, it would no longer be a standard. However, most books on wireless concentrate on the fine detail of the one particular standard they choose to address. That can be very interesting, but for most designers it is irrelevant. It is important to know enough to make an informed decision, but as far as a