Fast Times at 2.4GHz:

The Open Standards War Between Wi-Fi and Bluetooth

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Introduction

(Open) Standards Wars

In "The Art of Standards Wars," Robert Shapiro gives a brief overview of several major standards wars in business history. The oldest one he mentions is the battle over standard railroad gauge between the Northern and Southern United States. The development of railroads in the United States was done with little coordination, so that by 1860, there were seven different railroad gauges in the United States. The gauge with the largest installed base, a little over 50%, was 4'8 1/2" wide, while the second most popular gauge was 5' wide. The 4'8 1/2" gauge was predominant in the North, while the 5' gauge was predominant in the South. (Shapiro, 1999)

Railroad gauge is an excellent low-tech example of what will be referred to in this paper as an *open standard*. For a standard to be open, it must satisfy the following conditions:

1) Availability: The standard must be available to anyone who wants to implement it. In the case of railroad gauge, the standard was literally lying on the ground in front of people. Anyone who wanted to find out what it was could simply measure it.

2) Maximize End-User Choice: This refers to an end-user's ability to choose whom they would like to provide them with an implementation of the standard. In the case of railroad gauge, any steel working company was eligible to implement the standard for any customer.

3) No Royalty: No one has to pay any fee to implement the standard, though there may be a fee to certify that a particular implementation meets the standard. There was no fee to implement a railroad gauge, although one might have to pay a fee in order to get someone to certify that your railroad did indeed meet that standard.

A list of these and other attributes of open standards are provided by Perens (2003).

In 1860, with seven different railroad gauges available, it seems strange to refer to a "standard." And yet there were tremendous economic benefits, primarily from increased efficiency, to having a single railroad gauge standard for the entire country. In addition, there were significant economic benefits for each region of the country to not switch from their preferred gauge to the one used in the other region, in terms of the costs involved with making the switch. Therefore, a standards war developed, and it lasted until 1886.

Most of the standards wars that Shapiro discusses deal with two different technologies, each of which had a single major company on each side. Good examples of this situation abound, and include GE versus Westinghouse for electricity, CBS and RCA for color television, and Microsoft versus Netscape for web browsers. We will refer to this situation as a "closed" standards war, to contrast it to the open kind.

Open standards wars tend to occur when a new technology needs a standard, and that technology has two key attributes. The first is a network effect. Railroads are an excellent example of this, since railroad track joined together forms a very large network, and the value of that network increases as the amount of track attached to it increases at a nonlinear rate. This phenomenon is generally referred to as Metcalfe's Law, named for the inventor of Ethernet networking technology, Robert Metcalfe. As we can see, the importance of the law bearing his name well predated Mr. Metcalfe.

The second key factor is a widespread assumption by many players that the technology in question is going to be a huge opportunity, and that each player is relatively free to implement the technology as he sees fit. The path by which this information becomes available to everyone is not particularly important. In the case of railroads, American parties could see the important and far reaching effects of railroads in Britain, and could assume that a similar phenomenon would occur in the United States. In addition, there were no institutional restrictions that prevented a company from building their own railroad. Note that each of the closed standards wars mentioned above fails at least one half of this second requirement. Patent rights and the restricted licensing of radio spectrum prevented many players from entering the electricity or color television standards wars, even though it was widely evident that they would be important. In the case of the browser wars, anyone was free to implement a browser, but it was not widely evident to most players (including Microsoft) that browsers would be a huge market.

In the current economic environment, where the rapid growth of new network-based technologies such as mobile phones and the Internet is still very fresh in the collective memory, many players are on the lookout for new network opportunities. Therefore, many new open standards are being formulated and implemented, most notably new standards for web services and for wireless networking, two technologies whose success very much depends on having a standard way of communicating information between very different parties.

With an open standard inevitably comes a standards war. In the case of wireless networking, this standards war was between Wi-Fi, backed primarily by American network equipment makers, and Bluetooth, backed primarily by European mobile phone manufacturers. But to say that either of these two groups was the primary backer of a technology would ignore the many major companies, and many influential startups, that became involved in the standards war between these two technologies. In this paper, we examine the history of each technology, and use the framework of disruptive technologies to explain why there was a standards war between these two technologies at all. The evidence from this section is then used to recast the relative importance of the key assets Shapiro listed for a standards war around what has emerged as the central theme of a battle for an open standard: speed.

The Path of Innovation

The history of the development of Wi-Fi and Bluetooth are more similar than different. Both were designed to be disruptive technologies, with large corporations (and a few small startups) as the driving force behind their initial development. These companies realized that in order for the technology to take off on a large scale, standardization efforts would be required. But the path that each company chose for developing and standardizing the technology differed in a significant way, and this difference is largely responsible for the current position of each technology in the marketplace.

The Story of Wi-Fi

Wi-Fi, the trade name for the IEEE's 802.11b standard, is the result of a long series of research and product development all in the general area of Wireless Local Area Networks (LANs). Although the IEEE's first wireless LAN standard was released in 1997, the 802.11 working group was founded in 1990. During the seven-year period between the formation of the working group and the first official release of a standard, several companies that were active in the standardization effort created products that were based on draft versions of the standard and offered them in the marketplace. Key early players included AT&T (which later spun off the wireless LAN technology as part of Lucent Technologies, which later spun out Agere), a startup called Aironet (which was acquired in 1999 by Cisco Systems), and a company called Windata that was one of the earliest developers of wireless LANs. (Pahlavan, 2001) These companies found early adopters for their technology in the form of universities such as Carnegie Mellon and MIT, who preferred wireless connectivity to rewiring hundred of old buildings, and hospitals, who could keep doctors and nurses connected as they roamed through the building. (Gurley, 2001a)

The nature of the technology rollout meant that standardization was important, but not an absolute necessity. A university or hospital could choose to standardize on a single company's wireless LAN technology, using its access points and connection devices. By the time the first 802.11 standard was released in 1997, the technology was fairly well established in the early adopter population. The initial standard specifies for data transfer rates of up to 1Mbps in the unlicensed 2.4Ghz frequency range of the spectrum.

However, the growth of the Internet over the years means that there are more potential applications, and a much wider audience, for wireless LAN technology, so the IEEE and its members immediately set about creating two branches off of the original standard. 802.11a is a version of wireless LANs that can transmit data at up to 54Mbps in the 5Ghz frequency range, an unlicensed section of the spectrum. (Conover, 2001) 802.11b is a version of wireless LANs that can only transmit data at a maximum of 11Mbps, but in the unlicensed 2.4Ghz frequency range of the spectrum, the same one as the original standard. The 802.11b version of the standard also had certain technical advantages related to the total area that could be covered, and in its ability to carry a signal through walls more consistently than the 802.11a version. It was the 802.11b standard that the majority of the early wireless industry, including Agere, Aironet (later Cisco), and Apple rallied around, and who gave it the marketing name "Wi-Fi," for "wireless fidelity." (Flickenger, 2000)

Starting in 2000, Wi-Fi followed a rapid growth trajectory, based on wide-scale deployment in business environments, followed by an expansion into homes. Interestingly, in the home networking market, it wasn't one of the major developers of the technology that became the market leader. That honor went to a small company called Linksys, which had built and sold cheap, easy-to-use routers for the home and small business market, and moved into producing wireless routers and cards soon after the 802.11b standard was finalized. In 2001, the company controlled 57% of the market for low-end routers, and 28.3% of the market for wireless routers, ahead of Agere at 19.3%. (Wong, 2001) Cisco Systems acquired Linksys in 2003. (Spooner, 2003a)

Today, a primary force behind the growth of Wi-Fi is Intel, who began a 300 million dollar marketing campaign based around its Centrino laptop technology, which includes an integrated Wi-Fi chip. Intel is also working to put Wi-Fi technology into its desktops. The company is planning to add a Wi-Fi chip and software based access point into its next chipset for desktop computers. This would mean that consumers would no longer need to purchase a Wi-Fi access point, but could instead simply use their desktops to connect other devices to the Internet wirelessly. (Spooner, 2003b)

The Story of Bluetooth

Bluetooth begins with Jaap Haartsen, a researcher for Swedish cell phone maker Ericsson. In 1994, his team began developing a radio-based system for connecting a cell phone to a headset wirelessly. They soon realized that the technology they developed could be used for far more than simply connecting a cell phone to a headset, and the company began to explore the potential of the technology further. They also discovered that several other companies were attempting to solve the same short-range connectivity problems that they were working on. In 1998, Ericsson, IBM, Intel, Nokia, and Toshiba formed the Bluetooth Special Interest Group (SIG) in order to create a standard for a low power, short-range connectivity technology based on Haartsen's work. (Time.com, 2001) From the start, the hope was that Bluetooth would become the de facto method for connecting a device, whether a cell phone, handheld, or laptop, to the Internet. The expectation at that time was that devices supporting Bluetooth technology would be available the next year. (Luening, 1998)

In general, the story of Bluetooth has been one of abundant optimism combined with little substance to back it up. Instead of releasing products a year after the SIG was formed, they released the first completed version of the initial technical specification. (Miles, 1999) There was also a concern at the time that the initial Bluetooth chips would be too large and too expensive in order to be practical for the handheld devices and cell phones they were initially designed for. In spite of these concerns, optimism in the Bluetooth community was still high: over 721 companies were in the Bluetooth SIG by this point, and Cahners In-Stat predicted that there would be 670 million Bluetooth-enabled devices by 2005. (Miles, 1999)

By the end of 2000, early Bluetooth devices were being released as add-ons for laptops that would enable them to connect to Bluetooth access points, in a connection model very similar to the one for Wi-Fi. The prices for Bluetooth cards were about the same as those for Wi-Fi cards. At this point, Cahners In-Stat was predicting that there would be 1.4 billion Bluetooth-enabled devices in 2005. (Fried, 2000)

In April of 2001, Microsoft made waves by announcing that it would not include support for Bluetooth in its new operating system, Windows XP. Microsoft had become a key member of the Bluetooth SIG, and this move was widely considered to take some of the wind out of Bluetooth's sails. The reason Microsoft gave was that the current state of Bluetooth hardware and software was not yet "production quality." (Shim, 2001) The problem was that there were relatively few Bluetooth-enabled devices available, and that those that were available were difficult to use.

Less than six months later, an Intel executive became the first core member of the Bluetooth SIG to publicly state that the technology had lost its chance to become the wireless networking standard, and that that role would be filled by 802.11b based technology. (Kanellos, 2001) Intel has since moved into Wi-Fi based technologies, leaving the Bluetooth market almost entirely.

Since that time, things have picked up for Bluetooth somewhat. Microsoft has decided to include support for Bluetooth in a service pack for Windows XP. (Spooner, 2001) The automobile industry has picked up Bluetooth in force, with both BMW and Chrysler including Bluetooth technology in future car designs. (Cant, 2003) The Bluetooth SIG pointed out that the number of Bluetooth chips shipped every week recently passed the 1 million mark. (Broersma, 2003) The expectations for the technology have clearly changed, however. Cahners' revised predictions for the technology have been reduced from 1.4 billion to several hundred million Bluetooth devices on the market by 2005. (Spooner, 2001)

Different Paths

In comparing the development paths each technology took, one of the most interesting things (aside from the very different results) was the different early decision made in each case with regards to standardizing the technology. With Wi-Fi, the release of commercial products preceded the formal release of a standard, whereas with Bluetooth, the standard was released long before any products were. To what extent did these different development paths help (or hurt) each technology?

The lifecycle of wireless LAN technologies, culminating with Wi-Fi, closely follows a pattern described by Christensen and Raynor in "The Innovator's Solution." In the early stages of the commercialization of a new technology, its performance is not "good enough" by the standards of early users. Therefore, these early users are more willing to pay top dollar for implementations of the technology that approach their performance needs. This leads early developers of the technology, in this case, Lucent/Agere and Aironet, to create highly integrated, proprietary systems that allowed them to push the boundaries of wireless LANs- how fast they could transmit data and how wide of an area they could cover. The integration, in this particular case, occurred between the access points and the access cards, and the software that ran on top of both of them. Users were able to buy a completely integrated solution from one company that was guaranteed to work together. When the technology was standardized, low-cost manufacturers, such as Linksys, were able to enter the market and rapidly take share from the early, expensive, proprietary players with technology that was more affordable and provided "good enough" performance for a wider market. As the Wi-Fi market moves forward, we are seeing a situation where Intel, the manufacturer of a highly integrated subsystem of handhelds and PCs, is moving to integrate all of the Wi-Fi technology into its subsystem. Before long, Intel will become the only player in the market to be making real money off of Wi-Fi.

Bluetooth's development thus far does not fit the pattern laid out by Christensen and Raynor. It certainly could have. Many companies had developed technologies early on that were quite similar to one another, and to what was eventually released as Bluetooth.

Wi-Fi, Bluetooth, and Disruptive Innovation

Wi-Fi and Bluetooth were designed to serve different purposes, and as Wi-Fi has grown in popularity, proponents of Bluetooth have actively pointed out that Wi-Fi and Bluetooth do not compete directly. (Fleishman, 2002; Gurley, 2001b) Despite this, everyone acknowledges that there is an overlap between Wi-Fi and Bluetooth in the area of wireless networking, in that both technologies can be used to connect a device directly to another device, or to a wired network (such as the Internet) through a base station. Wi-Fi was better suited for acting as a wireless networking technology, and it won the battle to do so. However, according to Bluetooth's defenders, this does not take anything away from Bluetooth.

In this section, we argue that Bluetooth's growth in the marketplace overall was seriously damaged by Wi-Fi becoming the standard for wireless networking. The core reason for this was that both technologies were created to be disruptive, in the sense first outlined by Clayton Christensen in "The Innovator's Dilemma" and later by Christensen and Raynor in "The Innovator's Solution." (Christensen, 1997; Christensen and Raynor, 2003) In order to understand the importance of this fact further, we must first look at the technologies that Wi-Fi and Bluetooth were attempting to disrupt.

No More Wire Cables. Ever.

Wi-Fi and Bluetooth were both designed as more flexible replacements for traditional wired technologies. Wi-Fi was designed as a complement to Ethernet and a replacement for it in certain environments where mobility and flexibility were at a premium. In fact, the first name for the industry group that supported Wi-Fi was the Wireless Ethernet Compatibility Alliance. (intel.com, 2003) Bluetooth, on the other hand, was designed to replace the cables that connect various mobile devices to each other, in particular, the cable between a headset and a cell phone. In order to understand why each technology developed the way it did, we must understand the attributes of the competing technologies each was attempting to disrupt.

Robert Metcalfe developed Ethernet while he was working at Xerox PARC. He later went on to found 3Com in order to commercialize the technology. Ethernet went on to become the industry standard LAN networking technology. It is characterized by high transfer speeds (the latest Ethernet specification sets the upper limit of the transfer rate at 10GB/sec), and protocols that allow multiple users to share the same connection. It is a low-level specification that does not specify what high level protocols can be used with it. (Karlgaard, 2003; 802.3 standard, 2002)

Ethernet and Wi-Fi have another link between them: the official standards for both technologies are set by the same committee of the IEEE: 802. Ethernet is developed and standardized by working group 802.3, while Wi-Fi was developed and standardized by 802.11. Wi-Fi was developed much in the mold of Ethernet, with a focus on high transfer rates and multi-user access.

Bluetooth, on the other hand, was designed to be a cable replacement technology. The primary candidate for a standard cable technology at the time Bluetooth was in development was the Universal Serial Bus (USB). Intel initially developed USB, in conjunction with Compaq, Digital, IBM, Microsoft, NEC, and Northern Telecom. (Govan, 2003) At the time of Bluetooth's development, USB featured low data transfer speeds, at least relative to Ethernet. USB had a low-speed mode that maxed out at 1.5 Mbps, and later a high-speed mode (USB 1.1) that transferred data at up to 12 Mbps. USB only works over short distances, about 3 meters for the low-speed mode, and 5 meters for the high-speed. (USB FAQ, 2003) It is also designed to be universal, so that any sort of device- PC, speakers, cell phone, PDA, etc.- can use USB to transfer data.

Like the connection between Ethernet and Wi-Fi, there is a similar connection between the companies that developed USB and the ones that developed Bluetooth- both IBM and Intel were key players in the development of both specifications. Bluetooth was designed to be a wireless analogue of USB, and shares many of its features: low transfer speeds over short distances and a desire for universality.

Both Wi-Fi and Bluetooth were specifically designed to disrupt legacy technologies- Ethernet in the case of Wi-Fi, and cables in the case of Bluetooth. In "The Innovator's Solution", the authors discuss two primary strategies for disruptive technologies to follow in displacing an established counterpart, the low-end disruption and the new market disruption. (Christensen and Raynor, 2003) In the next section, we discuss the characteristics of each disruption, and analyze how the Wi-Fi versus Ethernet and Bluetooth versus cables disruptions fit into these categories.

Swing Low or Look New

Low-end disruptions generally occur when there is an overserved population of customers at the low-end of the mainstream market, who would be happy to pay for a cheaper version of the product that was good enough for their needs. There are many examples of low-end disruptions in business over the past 100 years, but the auto industry offers a particularly good example. Toyota and Nissan executed a low-end disruption of the American auto industry starting the 1960s by selling cars that served the low-end of the market adequately and were cheaper than American cars. Over time, as the Japanese automakers have gone mainstream and up-market, Korean car manufacturers such as Hyundai and Kia have pursued the same low-end strategy against them. The most critical aspect of the low-end disruption strategy is a business model that is able to make attractive profits at lower prices. For example, discount retailers are able to charge less for goods than department stores because they are more efficient at turning over their inventories, so even though the discounters have lower gross margins, their greater efficiency means that their total profits are about the same as the full service department stores. (Christensen and Raynor, 2003)

New market disruptions are generally driven by the creation of a new technology that has lower performance attributes by traditional metrics, but has other features, such as simplicity or convenience, that certain customers find attractive. A good example of this type of disruption is Canon's development of desktop photocopiers. At first, these photocopiers could not compete with Xerox's industrial copiers in terms of speed or quality of the copies. However, since the Canon copiers were much smaller and easier to use than the Xerox machines, people could do their own copies near their desks, instead of having to take their material to the company copy center. The Canon desktop copiers created a new market for people who desired this simplicity and convenience and were not as concerned with the clarity of their copies, and in time, as the Canon copiers improved, they were able to displace the big machines in the company copy centers entirely. The PC industry is another excellent example of a new market disruption. The business model for new market disruptions usually requires profitability at a lower price than that of the traditional technology, while also requiring that this profitability be made at initially small production volumes. Profitability allows the developers of the new technology to improve it so that it can bring more and more customers over to the new value chain it creates. (Christensen and Raynor, 2003)

A disruptive business model is not required to fit strictly within the confines of either of these two approaches; most disruptive businesses have been some combination of the two. For example, Southwest Airlines initially targeted a new market of people who were taking buses or trains rather than flying, but in doing so, they also pulled in low-end customers of the traditional airlines. Similarly, Charles Schwab grew by targeting both people who had never invested before, and low-end customers of the full-service brokers. In the next two sections, we analyze where the strategies followed by Wi-Fi and Bluetooth fall along the spectrum of disruptive business models.

Wi-Fi as Disruptive Innovation

Wi-Fi does not do as well as wired Ethernet along the traditional performance metric: data throughput. But its performance (11Mbps at the high-end, 5 Mbps on average) is good enough for most end-users of a network. In addition, it adds tremendous flexibility and convenience. Users are not required to be sitting close to an Ethernet port in able to stay connected to the network. Companies do not need to predict how many users in a conference room will need a network connection. Employees can gather information and stay connected during impromptu meetings in the hallway or cafeteria, where it would be extremely expensive and inconvenient to have Ethernet ports.

Wiring every inch of a building or house with CAT5 cabling is extremely expensive, placing it out of reach for almost everyone. Thus Wi-Fi could enter the market with a price point that, while not cheap, was still significantly less than the price of the alternative. This brought in both new customers, who had not considered networking before because of the cost, as well as low-end customers of traditional Ethernet solutions who did not require the high throughput. These new customers, in turn, brought in new suppliers, who were able to drive down the price of Wi-Fi even further, creating a positive feedback loop lowering the price/performance ratio of the technology. This makes Wi-Fi a classic example of a hybrid disruptive innovation.

Bluetooth as Disruptive Innovation

Bluetooth, when compared to USB cables, has a similar performance profile as Wi-Fi does when it is compared to Ethernet. Bluetooth has a lower data throughput than USB does (Bluetooth maxes out at 1Mbps, and generally runs at 500Kbps, USB 1.1 gets 12Mbps). (Bluetooth Specification 1.0, 1999; USB FAQ, 2003) However, Bluetooth's performance is adequate for most users and devices, and it creates additional flexibility and mobility by not restricting users with cables, as USB does. It adds convenience by allowing connections between devices to be instantaneous and always on.

Unfortunately, the one area where Bluetooth could not compete with cables, at least at first, was price. The initial Bluetooth technology was expensive to develop, and the low number of initial users meant that Bluetooth could not get the economies of scale needed to lower prices right away. Thus when Bluetooth cards started arriving on the market in 2001, the price tag was between one hundred and two hundred dollars. (Freeman, 2001) As mentioned above, one of the requirements for a disruptive technology, whether low-end or new market, is a lower (or at least comparable) price than the traditional technology it is attempting to displace.

Here we have one of the key factors in the slow growth of Bluetooth: *it could not compete with cables on price right away*. According to the framework laid out by Christensen and Raynor, this greatly lowered the probability of it succeeding as a disruptive innovation.

Bluetooth versus Wi-Fi

Bluetooth proponents have actively pointed out that Bluetooth does not compete directly with Wi-Fi, and that Wi-Fi's rapid growth takes nothing away from Bluetooth. While it is quite clear that each technology was developed with different goals in mind, it also seems clear that the rapid growth of Wi-Fi had a strongly negative impact on Bluetooth. One reason for this is presented above: the existence of Wi-Fi took away one avenue of disruptive growth for Bluetooth. Bluetooth could have served as a way of connecting wirelessly to a network, although more for the home than the office, due to its user and bandwidth limitations. In that environment, Bluetooth would have been competing against Ethernet, not cables. Its performance would not have been as good as either Wi-Fi's or Ethernet's, but it still would have been good enough for many users. The same price advantages that existed for Wi-Fi early on would have existed for Bluetooth, which would have spurred the same growth (and accompanying rapid fall in price) for Bluetooth technology as it did for Wi-Fi. The low price and prevalence of Bluetooth that this situation would have spurred would have given Bluetooth the low cost advantage it needed to be a massive disruptive innovation to both Ethernet and cables.

How to Win a Standards War Without Really Trying

In 'The Art of Standards Wars,' Shapiro discussed three kinds of standards wars: evolutionary vs. evolutionary, revolutionary vs. revolutionary, and evolutionary vs. revolutionary. An evolutionary standard is one that maintains backwards compatibility with the earlier standard, while a revolutionary one breaks backwards compatibility in order to improve the standard in a desirable manner. In the standards battle between Wi-Fi and Bluetooth, there was not an earlier wireless networking standard to maintain backwards compatibility with, so by Shapiro's classification, this was a revolutionary vs. revolutionary war. However, a closer examination reveals that the distinction between "evolution" and "revolution" is more involved than simply whether or not a technology is new. The extent to which a new technology fits in with the current technology infrastructure, and builds upon themes in other standard technologies, also play a role in determining the extent to which a new technology is a true revolution. In this section, we examine certain technical aspects of the Wi-Fi and Bluetooth standards, in order to understand how their basic design related to the design of other standard networking technologies.

Getting the Scope of The Technology Right

Christensen and Raynor discuss the evolution of technology markets in terms of two primary periods: a "not good enough" period, where customers are not satisfied by the functionality of a technology and demand ever greater performance, and a "good enough" period, where most customers find the performance of a technology adequate, and focus instead on other attributes of a product, such as convenience and price. (Christensen and Raynor, 2003) During the "not good enough" period, highly integrated companies are better able to provide the performance customers require, and are able to thrive by charging a high price for their proprietary solutions. During the "good enough" period, modular systems integrators are more flexible and can charge lower prices, and drive out the proprietary systems integrators of the "not good enough" phase. The profits formerly went to the proprietary system integrators now pass through the modular integrators- right to the highly integrated manufacturers of the subsystems assembled by the modular integrators. (Christensen and Raynor, 2003)

Examining the networking industry in terms of this framework, it is quite clear that the majority of the customers are satisfied with the performance of the currently available networking products, and that standardized, modular interfaces between different layers of the network are the rule. In fact, networks are one of the most highly standardized pieces of the technology infrastructure. The world's most influential standards organization, ISO, developed the Open System Interconnect (OSI) as a *de jure* standard for developing and deploying network protocols and network applications for the entire world. (USAIL, 2003) The growth of the Internet has created a *de facto* standard as well, the TCP/IP network model. The TCP/IP network model is a proper subset of the ISO OSI network model. Each standard describes a network in terms of modular layers. For the ISO OSI, the layers (from lowest to highest) are physical, data link, network, transport, session, presentation, and application. TCP/IP explicitly refers to four modular layers, the lowest of which is the link layer, the network layer, the transport layer, and the application layer. (USAIL, 2003)

The Wi-Fi Protocol Architecture

Wi-Fi, as developed by the IEEE 802.11 working group, was designed to fit in explicitly within both the OSI and the TCP/IP network models. It defines a MAC sublayer of the data link layer and three possible physical layer implementations. It relies on higher-level protocols, such as IP and TCP, for routing and session management. (802.11 standard, 1997)

The Bluetooth Protocol Architecture

In contrast to Wi-Fi, Bluetooth defines its own stack of layers. At the highest level, there are actually three possible top layers- the Cable Replacement layer, the Telephony layer, or the "Adopted" layer, which includes the high level parts of other protocols, such as the OSI protocol from the network level up to the application level. These three levels reflect the main high-level functions of Bluetooth. They rest on top of the Logical Link Control and Adaptation layer (L2CAP), which performs translation services for each of these protocols into a common format to be passed on to the lower levels of the stack. The next level down is the Link Control level, which performs roughly the same functions as the data link layer in the OSI model. Finally, there is the

Baseband layer, which controls the Bluetooth Radio in both its synchronous and asynchronous data transfer modes. The Baseband also has a backdoor for an audio connection, so that audio information can skip the other layers of the stack entirely. (Bluetooth Specification 1.0, 1999)

Comparing the Architectures

Wi-Fi was designed as a modular component of the industry standard network infrastructure, as defined by OSI and the TCP/IP network models. Bluetooth, on the other hand, was designed to be a complex system that would support both analog and digital information along separate data paths, as well as multiple, incompatible data standards- not just for transferring data over networks, but over cables and telephones as well.

It seems quite clear that Wi-Fi is best understood as a new, modular component of an overall LAN infrastructure. The majority of the infrastructure that Wi-Fi made use of was already widely deployed in TCP/IP networks for connecting to LANs and the Internet. To deploy Wi-Fi as a wireless LAN, an administrator was only required to swap out the bottom two layers of the OSI network stack. This familiarity played a key role in Wi-Fi's initial growth.

By comparison, Bluetooth was an entirely new architecture. While it resembled the OSI stack at the physical and data link layers, its support for multiple incompatible protocols required the implementation of the L2CAP layer to act as a translator. The ability to pass directly to the physical Baseband layer through the audio path was also different than the standard networking model. All in all, deploying Bluetooth as a wireless LAN would require an administrator to learn and support an entirely new, far more complicated, network stack. This, in addition with the performance limitations of Bluetooth, made it less likely that users would be willing to deploy a Bluetooth based network.

The Seven Assets in an Open Standards War

Shapiro identified seven key assets that help in waging a standards war, which we discuss here in terms of their relevance to Wi-Fi and Bluetooth in particular, and to open standards wars in general.

Control Over an Installed Base of Users

In terms of wireless networking technology, there was already an installed base for technologies similar to Wi-Fi in universities and hospitals, based on implementations of preliminary versions of the Wi-Fi standard by various network manufacturers. Bluetooth, on the other hand, had no installed base. Even though Ericsson and Nokia had millions of mobile phone users, none of those users had Bluetooth technology in their phones, or even a preliminary version of Bluetooth. Advantage: Wi-Fi.

Intellectual Property Rights

Intellectual property rights are largely irrelevant in the case of an open standards war. The nature of such a battle is that it is going on between standards that are available to anyone and are free of royalties. The IEEE is therefore an ideal body for creating such a standard, since the IEEE has a clause in its bylaws that prevents it from using patents in a standard, unless they have received written assurance from the patent holder that they will not attempt to enforce the patent rights. Therefore, the issue of intellectual property rights is not highly relevant to an open standards war, unless there is a significant third party who can claim some IP rights over a part of the standard. The war is then transformed into one between an open standard and a closed standard, which is a different case entirely.

Ability to Innovate

Both the companies backing Wi-Fi and those backing Bluetooth are able innovators. In fact, many of the same companies backed each technology. It is therefore hard to assign an innovation advantage to either party. There is, however, an interesting artifact that emerged largely after the standards war was over. There were many startups in the initial stages of Bluetooth that sought to sell Bluetooth-based wireless access points, bringing Bluetooth into the wireless networking realm occupied by Wi-Fi. (red-m.com) Now that Wi-Fi dominates wireless networking, companies such as Intel are moving to create low-power, low-cost Wi-Fi chips that can be used in small devices, like mobile phones and handhelds. (Spooner, 2003b)

In an open standards war, each competing technology is open to all players in the market. Innovation is not so much a tool for winning an open standards war, but rather it is a reward for winning a standards war. When players can choose which technology they are going to innovate around, they will choose to innovate around the one that looks like it will win. Therefore, companies involved in an open standards war should not focus as much on innovation as they should on getting good implementations of the standard to market quickly.

The standards war between Wi-Fi and Bluetooth provides an excellent example of how innovation can be downplayed during an open standards war. An important part of both the Wi-Fi and Bluetooth protocols is the ability to encrypt transmissions between devices, so that packets could not be intercepted. Wi-Fi's security protocol, WEP, has long been known to be less secure than the security protocol that was developed for Bluetooth. (Xydis, 2002) The Bluetooth developers spent a year developing the Bluetooth specification, including that security protocol, while the Wi-Fi developers spent a year developing products with the undeniably inferior WEP security. But in the end, the security issues were not enough of a concern for users to wait for Bluetooth products to be developed, and so the readily available Wi-Fi products rapidly filled the wireless networking niche Bluetooth needed to succeed.

First-Mover Advantage

Undeniably, the advantage has to go to Wi-Fi; products based on the original 802.11 specification were available before the Bluetooth SIG was even founded. One could even argue that Wi-Fi's significant first-mover advantage was primarily responsible for its success over Bluetooth.

Manufacturing Capabilities

While it seems at first glance that the technologies were pretty even with regard to manufacturing capability, the advantage here was actually quite significant, and it belonged to Wi-Fi. The reason is not because the network equipment makers that backed

Wi-Fi were better manufacturers than the mobile phone companies, but because the network equipment makers had been manufacturing technology similar to Wi-Fi for many years, and because the constraints on Wi-Fi, in terms of cost, size and power consumption, were not nearly as restrictive as they were for Bluetooth. This made creating Bluetooth chips that much more difficult for manufacturers, which added to the delay in releasing Bluetooth-enabled devices on to the market. Advantage: Wi-Fi.

Strength in Complements

In the case of wireless networking, the situation was not “strength in complements” as much as it was “weakness from lack of complements.” Bluetooth technology emerged during a telecommunications boom, when many parties were excited about the potential of third generation (3G) wireless technologies, that would allow broadband data transfer rates to mobile devices such as cell phones. A big potential role for Bluetooth was as a common data link between a mobile phone and a laptop or handheld, where the mobile phone would use 3G to act as a modem for the other device. Unfortunately for Bluetooth, the telecommunications bubble burst, and 3G technology has not taken off in Europe and the United States to nearly the degree that it was expected to by this point.

Another example of a technology whose development could have helped Bluetooth was PDAs, personal digital assistants. PDA users have different needs than laptop users, in particular, they have greater power constraints. One of Bluetooth’s advantages over Wi-Fi is its low power consumption. Since PDAs also have much less storage available than laptops, they are not usually used to transmit large files, so Bluetooth’s lower throughput would not have as much of an impact. If the primary customers for wireless network connections had initially been PDA users, instead of laptop users, it might have very well been the case that Wi-Fi’s power needs would have meant that they would have waited for Bluetooth. Instead, Wi-Fi is now developing a standard for a lower power, lower throughput version of its technology, moving in to fill a niche in the market that could have been served by Bluetooth.

The advantage in this area has to go to Wi-Fi, not for any complements it had, but for the expected complements to Bluetooth that didn’t materialize.

Brand Name and Reputation

The advantage here goes to Bluetooth, since it was the very large number of prominent companies that supported the standard that was responsible for much of the early hype about it. On the whole, one has to wonder about the relative importance of brands in an open standards war. After all, Linksys, a relative unknown, became a dominant player in home and small business Wi-Fi networking rather quickly. Advantage: Bluetooth.

Penetration Pricing

Shapiro mentions penetration pricing as a tactic, not an asset, but we include it here because it can be used in a standards war by an opponent that may lack several of the key assets, but recognizes the importance of controlling the standard and is willing to pay an actual cost (in terms of low prices that may lead to losses) in order to gain market share. In the case of Bluetooth and Wi-Fi, one of the main goals of the Bluetooth SIG was to create a very low price technology. As was discussed above, the fact that they could not get the price of the technology low enough to compete with cables was a serious problem for their adoption path. So the question could be asked, why did they simply not accept a loss on the technology at first in order to drive adoption?

In the case of a closed standards war, between a few parties, this strategy might indeed be quite reasonable. But it doesn't apply in an open standards war due to the existence of a many-player version of the Prisoner's Dilemma. Because it is an open standard, there is no way for the company that is selling the technology at a loss to be sure that it will reap the benefits of controlling the standard. It is highly possible that a competitor could come in and dominate the standard after the company invested so much money in seeing it succeed. Thus no player has an incentive to do penetration pricing, and the tactic is irrelevant in an open standards war. (Shapiro, 1999)

Summary

The previous two sections illustrate the fundamental importance of speed in an open standards war. It's not speed in any single area; it is speed across multiple factors that, when combined with network effects, adds up to an overwhelming advantage. From a technology point of view, the fact that Wi-Fi was more evolutionary than Bluetooth meant that developers and customers could understand it and begin working with it faster. The installed base of users, even though it was relatively small, added to the population of developers and users who were already familiar with Wi-Fi and did not need to climb a learning curve. The fact that they beat Bluetooth to market with real products was a big head start in the race. And finally, the fact that it was much easier to manufacture Wi-Fi devices allowed them to pile it on after their initial head start.

The fact that Wi-Fi dominated these factors masked some of the possible interactions between the assets that could have given greater insight into their relative importance. In particular, it would be interesting to see how well an installed base of users for one technology compared with a significant manufacturing advantage for the other. At what point would the ability of one side to create new technology cheaply and rapidly weigh against an installed base of users?

The other key assets that Shapiro mentions are largely subordinate in an open standards war. Intellectual property rights are irrelevant. Innovation tends to follow the winner of an open standards war, not drive a particular standard ahead, and requiring too much innovation can even significantly delay the release of products that support a standard. Brand names and the importance of complements are interesting in as far as they can slow down the adoption of the opposing standard, but they are not sufficient on their own to dominate the other factors.

Conclusion: Closed Thinking in an Open Standards War

Given the incredible importance of speed in an open standards war, why didn't the Bluetooth SIG move faster? A closer examination of the history of Ericsson and Nokia, two of the key companies in developing the Bluetooth standard, provides some clues. At first glance, it seems strange that Nokia would be interested in participating in the development of a Bluetooth standard, since Ericsson had a lead in developing

Bluetooth technology and is one of Nokia's direct competitors. However, much of the success of these two companies is owed to the fact that they were able to cooperate on the development of mobile communications standards, first for Scandinavian countries, and then for the rest of Europe. Scandinavia (comprised of Denmark, Norway, Sweden, and Finland) was unique in that it had its first standard for mobile communications, NMT, as early as 1981. (Bach, 2000) This common standard allowed mobile phone makers in these countries to exploit economies of scale in developing and deploying their technology. By 1985, Nokia and Ericsson combined accounted for one fifth of the entire world cell phone market, and today are both global companies, all as a result of having a widely applicable cellular standard before anyone else did. (Bach, 2000) Standardization, especially where network effects played a prominent role, was simply how these companies did business.

But developing a mobile telecommunications standard is much different from creating one for a local wireless networking technology, and the difference is that spectrum licensing limits the number of players involved in implementing the telecommunications standard. This effectively makes a telecommunications standard, even if it is available to anyone, a closed standard, since there is a significant barrier to actually implementing it. The standardization processes that mobile device makers such as Ericsson and Nokia had participated in and disproportionately benefited from were far different from the open standardization tactics that were required in the wireless networking war. These companies were simply not prepared to adjust to the new circumstances, and the technology suffered for it.

All of this is not to say that Bluetooth has been a complete failure. As was discussed in the Bluetooth overview, the costs of the components are falling, and Bluetooth is seeing success in certain niche markets, such as the auto industry. There is also significant work to ensure that Bluetooth is compatible and functional in a Wi-Fi driven world. Shapiro discusses these phenomena in his paper, in which the losing standard can still gain some success in certain niches, or by adapting to be compatible with the dominant standard. It is quite possible that the next several years will see the emergence of devices that support both Wi-Fi and Bluetooth seamlessly.

But is it likely? Only time will tell. The classic example of an open standards war, the railroad gauge battle between North and South, may offer some clues. Although the South spent many years adapting to the different gauges- by lifting cars between tracks with different gauges, or simply laying down new rail- they eventually capitulated. Over two days in 1886, all of the rail in the South was switched over from the 5' to the 4'8 1/2" standard. The economic costs of keeping the different standard was simply too great. A similar fate may await Bluetooth.

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