by Wolter Lemstra

Wi-Fi: a remarkable innovation journey

What are the policy lessons from an industry success story?

In this contribution we discuss the genesis and development of Wi-Fi as a combined result of (1) a change in the US communications radio spectrum policy in the 1980s, (2) the industry leadership provided by NCR, its corporate successors and collaborators, to create a global standard and to deliver compatible products under the Wi-Fi label, and (3) the influence of the users that moved the application of Wireless-LANs from the enterprise to the home, from indoor to outdoor use, from a communications product to a communications service, and from operators to end-users as the provider of that service. In concluding, we assess the implications of this case for the formation of government policy.

Wi-Fi preferred access to the internet

To-day, Wi-Fi is the preferred means for connecting to the Internet – without wires: at home, in the office, in hotels, at airports, at the university campus. Increasingly Wi-Fi, which is synonymous with Wireless Local Area Networks (WLANs) based on the IEEE 802.11 standard, provides access to the Internet for remote communities in developing countries. Even in rural areas of developed countries community-based Wi-Fi initiatives have emerged to provide broadband wireless Internet access, as incumbent operators failed to extend the wired infrastructure to less profitable areas in a timely manner. Moreover, local governments in major cities have recognized the added-value in providing Municipal Wi Fi.

Telecom contrasts

These Wi-Fi developments are in stark contrast with the traditional developments in the telecommunication sector which were focused on voice communication, whereby the development of new products took place in large specialized firms, such as Alcatel, Ericsson, and Nokia, in close collaboration with the telecom operators, e.g., BT, DT, or FT, who exploit these product for a profit as part of their service offering.

Wi-Fi has its roots in the field of local area networking in support of data communication between computers. This is the market segment of private networking for business users, i.e. at the edge of the 'public' network. This segment is characterized by private entrepreneurship in an unregulated market environment, whereby the end-users invest in their own networking facilities.

The use of radio spectrum provides for another contrast. As spectrum capacity is considered a scarce resource, the use of radio waves is highly regulated. Hence, governments apply a tight licensing regime to regulate the use of frequency bands among a variety of users and applications, with the objective to prevent interference.

WiFi originated in the field of unregulated data communications...

These objectives and principles can be recognized in the governmental licensing policy in the area of cellular or mobile telecommunication, which regulated in the early 1980's the use of analogue systems, in the early 1990's narrow-band digital systems, and more recently the use of third generation wide-band systems. Wi-Fi, on the other hand, operates in unlicensed frequency bands. The original assignment was in bands set aside for industrial, scientific and medical applications, the so-called ISM-bands. In these bands Wi-Fi competes with many other applications, including microwave ovens.

Wi-Fi originated in the field of the unregulated data communication environment, being targeted at the enterprise market. With the advent of the Internet it has become the leading platform for home networking. Subsequently, it has moved 'outdoor' providing Internet access at 'hotspots', thereby providing alternative access to the 'public'
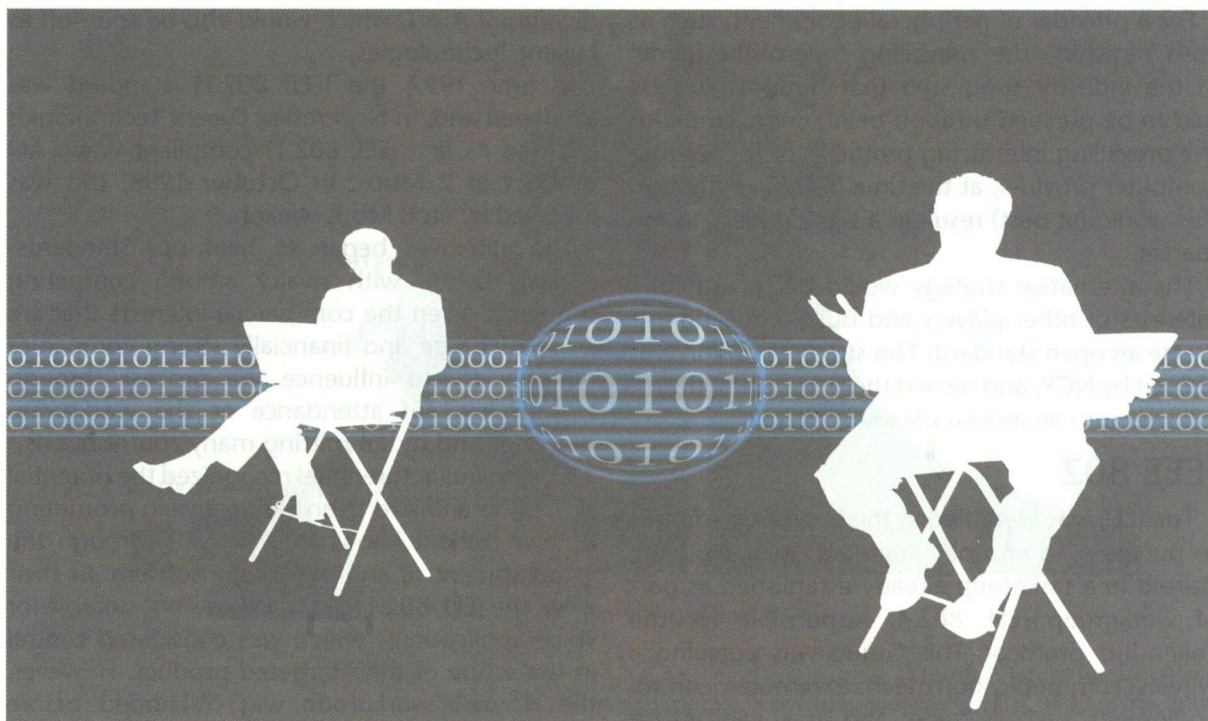
telecom infrastructure. In the context of citizens initiatives, it has become a tool for neighbourhood area networking, partly in competition with the 'public' telecom infrastructure. Through mesh-networking and in nomadic mode, it provides other access and networking alternatives to the existing 'public' telecommunication infrastructure. Through the application of VoIP (voice-over-IP) it now also provides capabilities in the voice-telephony domain.

The genesis of Wi-Fi

Traditionally peripheral equipment was connected to computers using a dedicated wired infrastructure, to be replaced by a Local Area Network (LAN) in the 1980s. As a consequence the so-called 'moves & changes' were both costly and time consuming. In traditional building, the wish to preserve the architecture of fine wooden paneling and marble floors did not combine very well with the increasing need for wired infrastructure. Moreover, it was lacking flexibility, for example, required in connecting additional cash registers during Summer Sale and the Christmas Season. It was a concern well known to the suppliers, including NCR, the leading provider of cash registers in the 1980's.

Strict regulation of the radio spectrum did not allow alternative solutions based on wireless techniques to be applied until 1985 when the US Federal Communications Commission (FCC), opened up the 915 MHz, the 2.4 and 5.8 GHz bands designated for Industrial, Scientific and Medical (ISM) applications for the use by radio systems, under the condition that spread spectrum techniques would be used to limit interference and to be able to operate in a relatively hostile environment.

Leading up to, and following this landmark event, firms were starting to develop Wireless-LAN products for the US market, these included companies such as NCR, Proxim, Telesystem, and Symbol Technologies. The required LAN expertise within NCR resided with a small group of engineers located in Utrecht, the Netherlands. The necessary radio frequency (RF) expertise was acquired 'in person', through the hiring of experts from Philips Electronics and by providing RF training to the engineers in residence. The R&D project assigned by NCR Headquarters in Dayton, Ohio, to the Utrecht Team would lead to the release in December 1990 of the first product –a PC adaptor with external antenna– operating in the 915 MHz band, providing a single communication channel at 2 Mbps.

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For a provider of peripheral equipment, such as cash registers, the prevailing 'rule-of-the-game' in the industry suggested that business success had to be pursued through being compliant with the prevailing interfacing protocols of the leading computer provider, at the time IBM, even though this would (at best) result in a second place in the market.

The alternative strategy would be to align the interests of other players and build a coalition to create an open standard. This strategic option was chosen by NCR, and moved them from an industry follower into an industry leadership role.

IEEE 802

The IEEE was identified as the appropriate forum to pursue such an open standard. In 1985, work started in a taskgroup already established as part of workgroup IEEE 802.4, responsible for the Token-Bus protocol. This Group was pursuing a wireless communication means to remotely control equipment, such as cranes and small vehicles for the manufacturing industry.

However, NCR found this taskgroup to be inactive and decided it needed to take the lead to obtain results. After an intensive study, Bruce Tuch, leading the R&D efforts, observed: "Making the IEEE 802.4 protocol fit with the wireless medium was like trying to use a boat to get across a swamp instead of a hovercraft." An attempt to start a project for extending the IEEE 802.3 Ethernet protocol with a wireless modem failed due to the lack of interest of the workgroup members.

This opened the way for the establishment of a new workgroup IEEE 802.11 in 1990. This workgroup was co-established and chaired by Vic Hayes of NCR. By October 1991, the requirements for a Wireless-LAN standard were defined and agreed upon; the work on the specification of the physical layer (PHY) and the media access control (MAC) layer could be started. In 1993, the year that AT&T acquired NCR, the foundations for the PHY and MAC were agreed upon.

One year later, in November 1994, the design of the protocols had sufficiently progressed to start the highest level of approval, the Sponsor Ballot, in July 1996. Also in 1996, NCR would be spun-off through the AT&T tri-vestiture, and become an independent company again. However, the WLAN activities would remain with the equipment division of AT&T, which would also be spun-off as Lucent Technologies.

In June 1997, the IEEE 802.11 standard was approved and, in November, Lucent Technologies released its first IEEE 802.11-compliant WaveLAN product at 2 Mbps. In October 1998, this was followed by an 8 Mbps version.

The initiatives began to heat up. Standards-making is rife with rivalry among competing suppliers, given the commercial interests that are at stake. Large and financially strong companies typically try to influence the process through a high level of attendance at the workgroup meetings and by submitting many contributions.

Chip manufacturer Intel recognized the potential of WLANs and had been very active in promoting its own variant known as HomeRF, through the establishment of an industry consortium. In their view, the IEEE 802.11 standard was not suitable for voice applications, which was considered central in the scope of their targeted product. However, the HomeRF-workgroup was disbanded before completing their task. This may be ascribed to the success of the IEEE 802.11 extension to 11 Mbps data transfer rate and the availability of devices at competitive prices, which arguably undermined the business plan of HomeRF.

In another standardization forum, the European Telecommunication Standardization Institute (ETSI), the European telecom equipment industry and telecom service providers took the initiative to try and establish an European standard for WLANs under the name of HIPERLAN in 1991.

The standard was approved in 1996 and HIPERLAN type 2 in 2000. Although major industry members had been developing prototypes, in the end no product was brought to the market. The scope of the HIPERLAN standard was considered too wide, leading to complex devices and high costs, which at the time of the release would be too high to compete effectively with products based on the IEEE 802.11 standard.

Crossing the chasm

While the availability of an open and broadly supported standard in the industry is a necessary condition for business success, it is not sufficient. Following the release of an IEEE 802.11 compliant product in the fall of 1997, Lucent Technologies was selling its privately-branded ORiNOCO products, and through Micro-Electronics – its

Main Street

Tornado

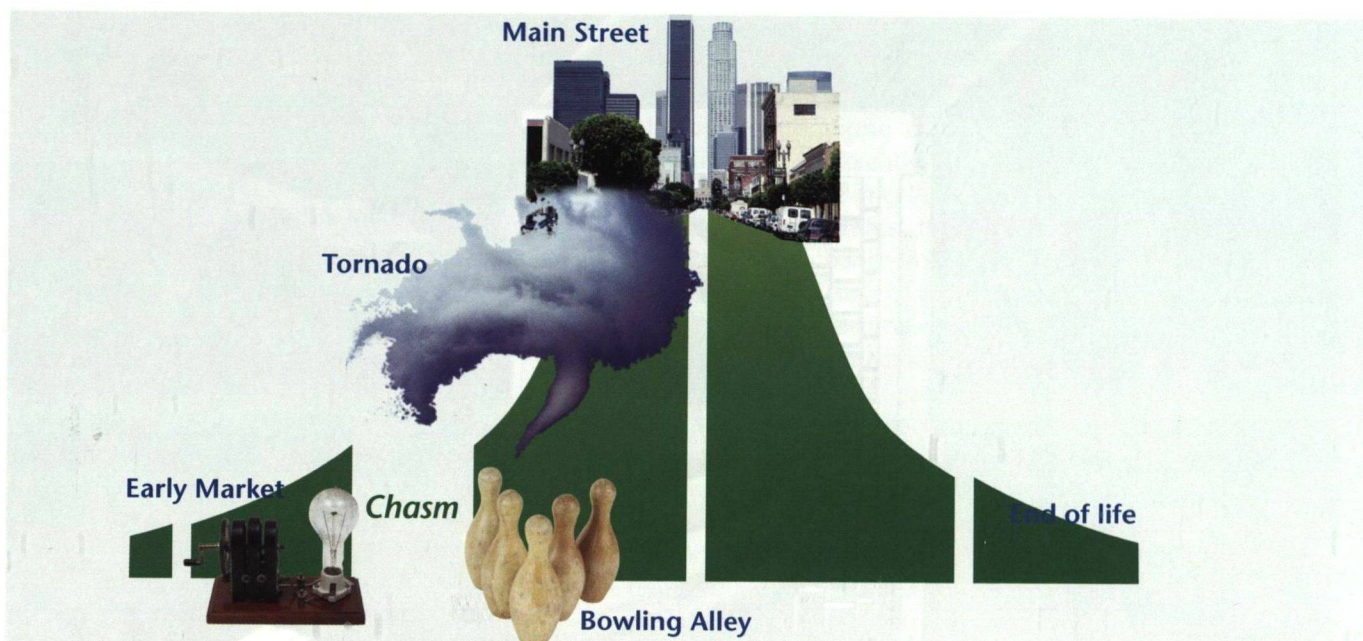**Early Market**   *Chasm*

Bowling Alley

End of life

Figure 1. Crossing the chasm
Source. Wi-Fi, a remarkable innovation journey, Dr. Ir. W. Lemstra 2008

semiconductor and opto-electronic components division – it was selling WaveLAN network cards to IBM, Dell, Toshiba and other computer manufacturers. However, the volumes remained relatively small.

The fortune of WaveLAN (and, for that matter WLANs) would take a turn for the better following an unexpected call from Apple Headquarters, simply stating: "Steve Jobs wants to have a meeting with Rich McGinn about wireless LANs." Apparently Steve Jobs, who had returned to Apple as 'interim CEO' to reinvigorate the company, had decided that Wireless-LAN had to be the key differentiating feature for the iBook which was scheduled for launch in 1999.

The meeting in the Apple Boardroom was an interesting one, with Steve Jobs concluding the meeting with: "We need the radio card for USD 50, and I want to sell at USD 99." Then, reportedly, Steve apologized for leaving, stood up, said "Hi!" and departed. Lucent Technologies accepted the challenge and delivered a WLAN product with a speed of 11 Mbps, which for the first time could compete effectively with the available wired solutions. This agreement became for Lucent Technologies the 'head pin' in the metaphor of 'The Bowling Alley', introduced by Geoffrey Moore to describe the difficulties of moving the business

from serving the early adopters to serving the mass market (See Figure 1) .

In another strategic move the industry partners established in 1999 the Wireless Ethernet Compatibility Alliance (WECA) to promote 802.11 compliant products under the Wi-Fi label. In 2002 WECA changed its name into the Wi-Fi Alliance, recognizing the power of its Wi-Fi label. By early 2006, the organization, with its 250 members, had certified more than 2500 products. Another boost came in October 2001 when Microsoft released its Windows XP operating system which includes support for IEEE 802.11 based communication and was the result of close collaboration between experts of Lucent Technologies and Microsoft.

The process of standards-making is rife with rivalry among competing suppliers...

In 2003, Intel launched the Centrino chip with a USD 300 million advertising campaign. This campaign would ultimately transfer the success of the 'Intel Inside' campaign to the mobile – wireless segment through 'Centrino Inside' which provides in-built Wi-Fi functionality. This step remains a major landmark in the product life cycle of Wi-Fi. It implies that Wi-Fi is no longer a functionality that is added-on afterwards, but that Wi-Fi had

Telecom innovation strategy
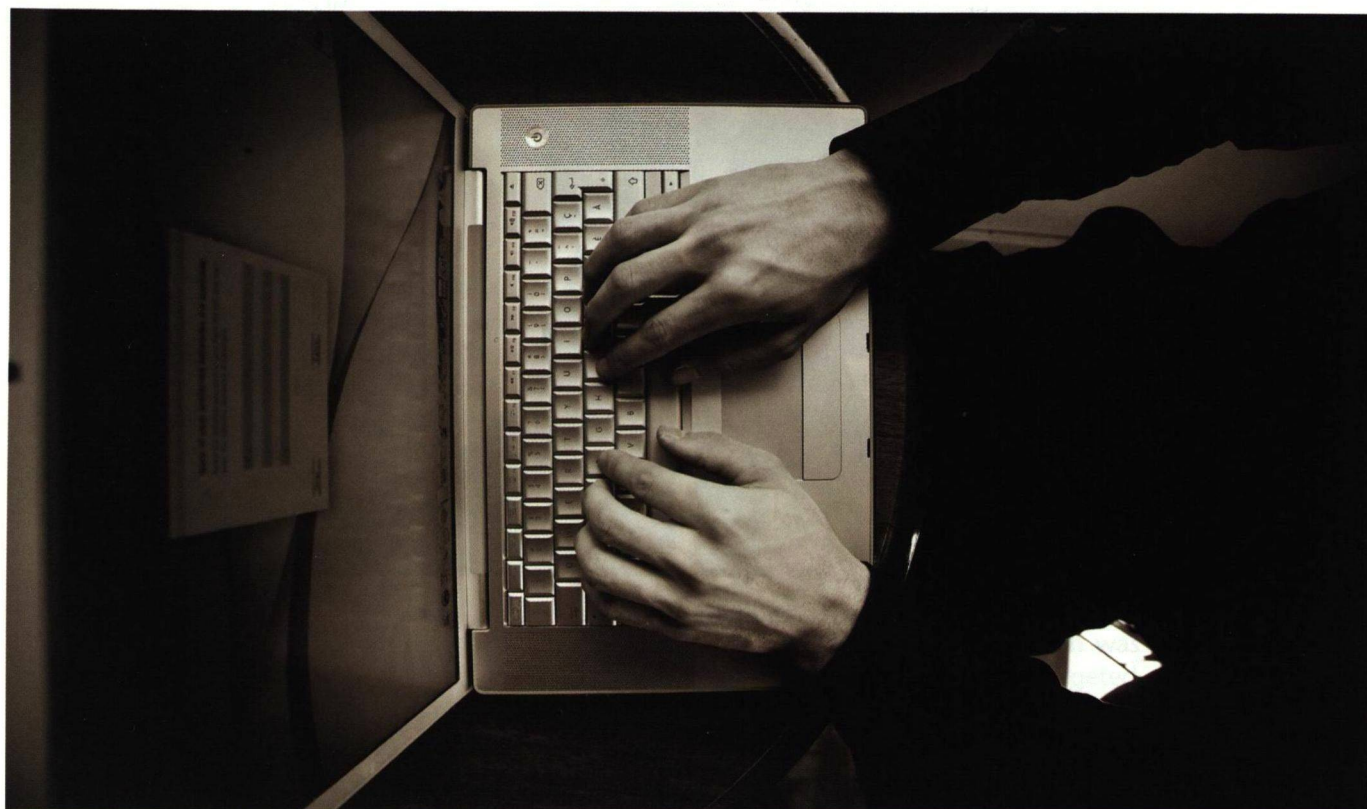
become a standard, built-in feature of modern laptop computers.

From private to public domain networking

The idea of using Wi-Fi for public access to the internet is attributed to Stewart who conceived 'Wayport' in 1993 while working on the MAC layer at AMD. Hotspots frequented by business travelers, such as airport and hotel lounges, were the first locations to be targeted by Wi-Fi operators.

Public domain Wi-Fi became much more popular after Starbucks made an agreement with MobileStar to equip all its outlets with Wi-Fi in 2001. As a plethora of Wireless Internet Service Providers (WISPs) started to extend the footprint of Wi-Fi, this did not necessarily increase the convenience for the user, as each provider has unique log-in procedures and billing arrangements. This has resulted in the emergence of so-called roaming providers who link a diversity of Wi-Fi network providers, while providing to the user with a single interface.

WISPs typically exploit Wi-Fi technology to provide internet access services for-a-profit, or in the case where the location owner exploits the 'hotspot', the objective is to stimulate the revenues of the core business. Next to these commercially oriented organisations, groups of volunteers have emerged that are providing Internet access for free or at very low cost.

The shared Internet Access (and often also direct communications among community members) is provided based on Wi-Fi Access Points being interconnected forming a Wireless Neighbourhood Area Network (WNAN). These communities of volunteers are mostly motivated by their enthusiasm to explore the possibilities of new technologies and their wish to demonstrate their technological savvy. These groups are in many ways similar to the early members of the 'Homebrew Computer Club' that emerged in Silicon Valley when the first do-it-yourself computer kits came on the market in the mid 1970s.

A typical example of a Wi-Fi community in the Netherlands is 'Wireless Leiden', a group of volunteers that started in the year 2001 and has built a network that includes 60 nodes and is covering most of the Leiden city and it is linked to neighbouring towns to cover an area of about 500 km². Similar community initiatives have sprung up in virtually every country.

The more recent development relate to metroWireless. In a comparative study of these initiatives, Van Audenhove et al. conclude that local government motives

to engage in wireless network deployment are policies to close the 'digital divide', aimed at city renewal, stimulating innovation and tourism, and improving the 'economic fabric' of the city.

In comparison, the European initiatives are more oriented towards "hotspots" and "hotzones" and not necessarily aim at full city coverage, an attitude that may be influenced by uncertainty on the critical position of the European Commission regarding these initiatives with respect to distortion of competition.

Implications for radio spectrum policy

For government policy, the Wi-Fi case is important as it reflects the first large scale deployment of radio communication on an unlicensed basis. The worldwide adoption of Wi-Fi demonstrates that RF spectrum can be used effectively using a license-exempt regime. As the initial RF assignment has been based on the use of the existing bands designated for the use of Industrial, Scientific and Medical applications, the use can be considered to be highly efficient as no new spectrum had to be allocated.

The common understanding that open access regimes lead to a 'tragedy of the commons' is shown not to be applicable to this case. Although access is not restricted and no protection is offered under this unlicensed regime, the limitations set to the power levels used appear to be effective in creating a localized use that resembles the characteristics of a private property regime.

The adoption and use appears not to be restrained by the lack of protection. Albeit, the regime does not provide any indicators that signal congestion or deterioration of service is leading users to abandon the use of Wi-Fi. Hence, there may be an undisclosed but very localized 'tragedy of the commons'. Hence, monitoring of the use by regulatory agencies is still required.

> *Do open access regimes necessarily lead to a 'tragedy of the commons' ?*

The lack of "exclusivity" also associated with open access regimes has shown to be less of an issue in this case. Multiple product vendors and later service providers have shown to be willing to invest in the development of products and services to exploit the unlicensed part of the RF spectrum.

One could argue that this is the result of the return on investment largely being based on the sale of the Wi-Fi equipment, and not in the exploitation of a service requiring complementary and deep investment in the creation of a network infrastructure, as is the case in cellular communications.

The case illustrates that innovation can be triggered by a change in policy, and by lowering the barriers to the use of radio frequency spectrum as an input to the production function. The case also shows the innovation potential of a license-exempt RF spectrum regime.

It also shows the constancy of purpose required to ultimately reap the economic and social benefits: the invention of spread spectrum technology dates back to 1942, the idea to allow the civil use of the technology originated with Mike Marcus in 1980, new regulation was issued by the FCC in 1985. It took NCR and the industry until 2000 to kick-start the large scale deployment of Wi-Fi.

Acknowledgement

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