Introduction

With the current popularity of Wi-Fi we expect that the account of its innovation journey will appeal to a broad audience: within business, academia and government, including strategists, policy makers and researchers in the fields of innovation, business management, standardisation and technology diffusion.

This book is divided into three parts. In Part 1 we capture the Wi-Fi journey from 1985 to 2008. We cover the early period, from invention, through innovation to mass-market success, characterised by broad diffusion and expanding applications. In so doing we recognise the shift in the application of Wi-Fi, from its original use as a wireless LAN within the enterprise to its current usage in the home and at 'hotspots' for internet access, whereby it has become instrumental in the hands of its users for the creation of Wi-Fi-based community networks in developed and developing countries.

In Part 2 we place the Wi-Fi journey in a broader context and pursue five different perspectives. First, we assess the role that Wi-Fi can play in providing universal access in remote areas that, hitherto, have been either underserved or not served at all. Second, we explore the Dutch connection, acknowledging the fact that most of the development of Wi-Fi (within NCR Corporation, AT&T, Lucent Technologies and Agere Systems) has taken place in the Netherlands, even though the products were originally developed for the US market and the activities were directed from US headquarters. Third, we explore the role of users in community-based innovation. In a fourth perspective we look at Wi-Fi in the context of radio spectrum management, recognising that Wi-Fi represents the first example of a global success story in the use of radio spectrum on a licence-exempt basis. Fifth, we explore possible future applications for Wi-Fi, bearing in mind that development efforts are ongoing, as reflected, for instance, in the issuance of new IEEE 802.11 standards on a regular basis. We conclude this part of the book with a reflection on our research findings, and from these derive implications for firm strategy formation and government policy making with respect to innovation and radio spectrum management.

Part 3 of the book consists of a series of annexes: a glossary, a timeline of major events in the development of Wi-Fi, an overview of the IEEE 802.11 standards and an impression of the Wi-Fi ecosystem.

Part 1 – Chapters 2 to 6 – collectively forms a longitudinal case study of the development of Wi-Fi. Each chapter thereby addresses a subsequent phase in the product life cycle of Wi-Fi. Each chapter is also topical, as they all deal with specific themes in the development of Wi-Fi, such as the creation of a wireless LAN standard, moving the business from early adopters to a mass market, the development of the 'hotspot' services business, and the emergence of community-based networks. Each chapter concludes with a summary and an interpretation of the case material in the context of related theory, provided by the editors. For these interpretations we use the theoretical perspectives on innovation as well as evolutionary and new institutional economics, which are introduced in Chapter 1. As common themes we use the innovation landscape metaphor, reflect on the role of the institutional environment and track the evolution of the industry.

This case study illustrates how the innovation process works in practice: with a close linkage to corporate strategy, and therefore to that extent planned, but with a high degree of emergence – that is, being shaped by individuals driving the course of events. The case study shows that innovation builds upon existing knowledge flows that combine, split and recombine. It also shows a change in the source of innovation, from the product manufacturers to the service providers and, finally, to the end users. Moreover, the case demonstrates that proactive radio spectrum regulation can foster innovation.

1 The case and the theoretical framework

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with contributions from Vic Hayes

1.1 Wi-Fi: an unexpected success story

In this book we explore and describe the genesis and development of Wi-Fi, which has become the preferred means for connecting to the Internet – without wires: at home, in the office, in hotels, restaurants and coffee shops, at airports and railway stations, at the university campus. Increasingly Wi-Fi provides access to the Internet for remote communities in developing countries, as in the Himalayas and in the Andes. Even in rural areas of developed countries, such as Denmark, where a community-based Wi-Fi initiative has emerged to provide wireless internet access, as the incumbent operator failed to extend the broadband infrastructure to less profitable areas in a sufficiently timely manner.

This is a remarkable result, considering that wireless local area networking was not even on the radar screen of the US Federal Communications Commission (FCC) in 1979 when it initiated the market assessment project that would lead to its landmark decision in 1985. In that year the FCC decided to open up three radio frequency bands designated for industrial, scientific and medical (ISM) applications for use by radio communication systems, on the condition that spread-spectrum techniques be used.

With hindsight, this outcome is a surprise. The Ethernet, which would become the standard for wired local area networks, had been demonstrated on an experimental basis in 1973, and in 1980 it was still the subject of a major standardisation battle within the Institute of Electrical and Electronic Engineers (IEEE). At that time business computing was *grosso modo* based on the use of mainframes. The increasing use of minicomputers had become the main market driver for the development of local area networks (LANs), first in universities and research centres, and then followed by corporations. It is worth recalling, moreover, that the personal computer (PC) had been invented only in 1974 and that the Apple II was launched in 1977, while the IBM PC was not introduced until 1981. The development of mobile computing equipment such as laptops and notebooks still lay in the future.

The current success of Wi-Fi is remarkable in many more ways. Previously, the most significant developments in radio frequency (RF) technology – radio

relay systems, radio and television broadcasting – had emerged under a licensed regime, whereby a government agency provided exclusive rights to the use of a specific part of the RF spectrum, thus giving the application protection from harmful interference by other radio frequency applications and users. The success of Wi-Fi was achieved under a licence-exempt regime, however, which meant that it had to contend with many other applications and users in the same RF band, including microwave ovens. As a result, the ISM bands were often referred to in the jargon of some professionals as the 'garbage bands'.

Following the assignment of the spectrum by the FCC, its principal use initially was indoor and corporate applications. The success of Wi-Fi resulted from at least two important changes in application, however. First, there was a shift in emphasis from corporate networking to private networking. In many homes Wi-Fi is the preferred solution over wired LAN alternatives for connecting computers to each other, to share printers and to connect to the Internet. Second, there was a move from the private to the public domain, as telecom operators now compete to provide internet access at 'hotspots' based on Wi-Fi. In this shift, Wi-Fi has moved from being a free service within corporations and homes to a fee-based service provided by hotspot operators. As a result, Wi-Fi has moved from indoor to outdoor applications and from stationary to nomadic use.

In the process Wi-Fi has progressed from a functionality that was added to a PC or laptop by way of an external plug-in to a functionality that is built into every laptop, based on an integrated chipset. Moreover, the example set by the FCC in the assignment of radio frequency bands for use by radio LANs has been followed by assignments by national regulatory agencies in the countries of Europe and Asia, including Japan, South Korea, India and China, thereby creating a global market for Wi-Fi products.[1] Meanwhile, the Wi-Fi logo introduced by the organisation that promotes the compatibility of products that adhere to the IEEE 802.11 standard, the Wi-Fi Alliance, has become synonymous with a globally recognised brand.

As indicated, it was not obvious at the outset that Wi-Fi would become a global success. The allocation of licence-exempt spectrum for radio communication by the FCC was not perceived favourably by all incumbents, And it resulted in an organisational reshuffle within the FCC. For the manufacturers it was not clear whether spread-spectrum technology, which had been developed in the military domain, could be produced at cost levels that would be commercially viable in the public domain. Nonetheless, the wireless alternative to wired infrastructure had a great deal of appeal. For NCR Corporation, the FCC's decision provided an opportunity to pursue solutions that would connect cash registers and point-of-sale terminals in a much more flexible manner at the customer's premises. It set in train a process that would involve a major change in corporate strategy, moving the corporation from industry follower

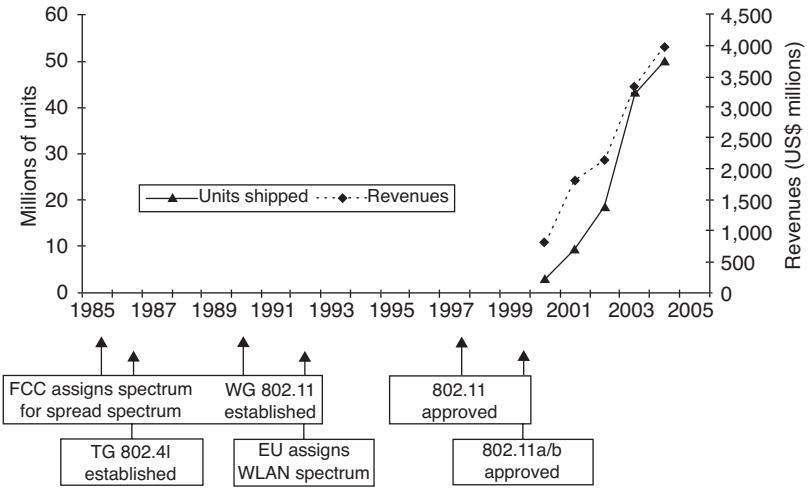

Figure 1.1 Wi-Fi product life cycle, 1985–2005
Source: This figure appears in 'Network modernization in the telecom sector', in *The Governance of Network Industries* (ed. Künneke, Groenewegen and Auger); copyright © 2009, Edward Elgar Publishing; reprinted by permission of the publisher.

to industry leader in this industry segment. It would require the tenacity of a small group of very dedicated engineers and marketers in pursuing an open standard, necessitating a commitment lasting for more than ten years, before global product success could be demonstrated. Figure 1.1 depicts the major milestones in the standardisation process next to the units of Wi-Fi shipped by the companies involved, and the corresponding revenues generated.[2]

The story of Wi-Fi is a good example of how the innovation process works in practice, and can be treated as a case history. It shows the linkage to corporate strategy, and it also shows the role of individuals in various parts of the organisation in driving the course of events. It shows the importance of teamwork, of personal commitment and of dedication. Moreover, it shows the importance of institutions in technology and product development. For example, the FCC plays a key role as a national regulatory agency in providing the governance of the radio spectrum; the IEEE provides the ICT industry with a platform to develop standards; and the ITU provides a platform for international coordination of the use of the RF spectrum.

The story illustrates that the development of Wi-Fi was not incidental – a one-off event; it shows clearly how knowledge that is accumulated and embodied in individuals migrates, combines and recombines as a result of people moving from one job or function to another and cooperating as part of a network of professionals. This has led to a continuous process of entrepreneurial

activity that can be traced back to the radio expertise of the Netherlands-based Philips Electronics Corporation and the LAN expertise of the United-States-based NCR Corporation coming together in the Engineering Centre in Utrecht, the Netherlands. The story also demonstrates that the locus of innovation is not necessarily the locus of manufacturing or the locus where most value is ultimately appropriated.

1.2 The theoretical framework

In this book, we explore and describe the development dynamics of Wi-Fi. Because we are interested in understanding the developments over a significant period of time, and because we are interested in the developments of one particular technology, we apply a longitudinal case study approach (Yin, 1989). As a meaningful starting point for our case we take the 1985 decision of the FCC on the civil use of spread-spectrum techniques. The period from 1985 to the present is divided in line with the phases that are typically distinguished in the diffusion of new technologies and the related adoption of new products: (1) introduction, which includes invention, innovation and trial production for the early adopters; (2) expansion, possibly leading to a mass market; (3) maturity; and (4) stagnation and decline (Kotler, 1997; Porter, 1980; Rogers, 2003). Based on the events that have unfolded to date, Wi-Fi can be considered to have progressed through phase (2) and, depending on what is regarded as being included under the heading of Wi-Fi, may have entered phase (3).

The exploration and analysis of the dynamic development process of Wi-Fi is necessarily of a historical nature and includes a variety of explanatory variables, such as the technology, laws and regulations, values and norms, the strategies of the various firms, and the like. In the process various actors played roles that sometimes helped and sometimes hindered the development of Wi-Fi in becoming a success. The behaviour of actors concerning an innovation process is influenced largely by the institutional structures in their environment, such as laws and regulations. On the other hand, actors do have a certain degree of autonomy in terms of realising their own objectives, exploring new ways and changing the structures around them. Moreover, actors interact not only with the structures in their environment but also with each other. In doing so they share ideas and they learn, but they also compete and try to control the behaviour of others. To explore and analyse the dynamics of Wi-Fi we need to know about the behaviour of the different actors involved. In Figure 1.2 we present the different layers in the structural environment of the actors, with the arrows indicating the interactions. This model is based on that of Williamson (1998), and has been adapted by Koppenjan and Groenewegen for the purpose of institutional analysis in the context of sociotechnical systems (Koppenjan and Groenewegen, 2005). We follow North in his definition of institutions as ‘humanly devised constraints that structure political, economic,

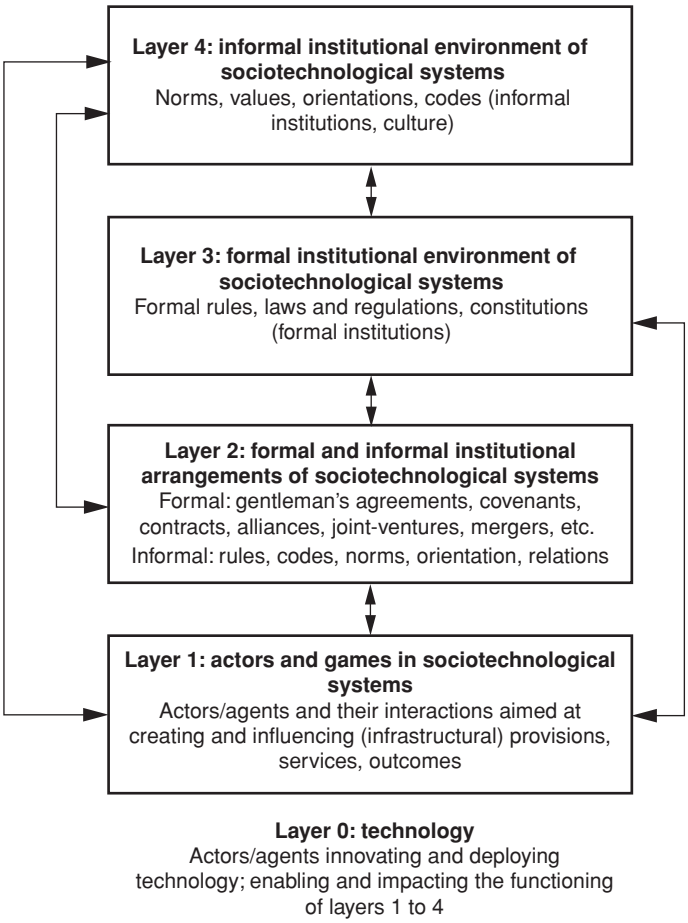

Figure 1.2 Five-layer model: levels of institutional analysis, technology enabled

and social interactions' and when he says that 'institutions consist of a set of moral, ethical, behavioural norms which define the contours and that constrain the way in which the rules and regulations are specified and enforcement is carried out' (North, 1990).

At the top of Figure 1.2, in layer 4, we find the so-called informal institutions, which influence the behaviour of actors. The culture in which the genesis of Wi-Fi was embedded has an impact on the motivation of actors and on their expectations of how the other private and public actors will behave. Ideas about universal service and the availability of technologies, such as Wi-Fi, to the

wider community belong to the domain of informal institutions. At layer 3 we show the so-called formal institutions, which influence and direct the behaviour of actors. Laws about competition, corporations and corporate governance, for instance, are examples of explicit institutions that have an impact on the behaviour of actors. Layer 3 is typically the domain of public actors, such as the national parliament, ministries and public agencies. Layer 2 consists of the so-called institutional arrangements, being the institutions that private actors make to coordinate transactions between themselves. A distinction is made between the institutions that private actors create purposefully, such as contracts and organisations, and the ones that evolve informally, such as norms. At layer 1 we find the actors, who through their behaviour create the institutional structures, while being at the same time constrained by them. The arrows indicate the interactive relationships between the different layers.

Technology has played an important role in the development of Wi-Fi: the process of innovation is the central theme of this study. We have expanded the model to reflect technology at layer 0, which forms the underpinning for all the other layers, thereby reflecting the all-encompassing nature of technology. Technology is considered as being developed by actors/agents in layer 1 and in its application it impacts layers 2 through 4, and in its turn technology is itself shaped through these interactions.

For our analysis, the institutional environment – i.e. layers 3 and 4 – is considered to be endogenous. This does not imply that the institutional environment is considered to be static, bearing in mind that the Wi-Fi case study covers a period of approximately twenty-five years. The innovation trigger at the basis of the development of Wi-Fi can be construed as a 'parameter shift' occurring at layer 3, triggering changes in the institutional arrangements, and the creation of new arrangements between the actors involved.

Because of the multiplicity of explanatory variables involved at different levels of the analysis, it is clear that our study is of a multidisciplinary nature. At layer 1 the disciplines of history, anthropology and sociology are relevant. Layer 2 is the domain of political science and law, as well as economics (property rights, for instance). For the analysis of the institutional arrangements at layer 3 we consider institutional economics to be particularly relevant, while for the analysis of the interactions between the layers we make use of the insights of evolutionary economics. As can be seen, understanding and analysing the development process of Wi-Fi is a multidisciplinary affair requiring the application of different research perspectives, methodologies, theories and concepts.

1.3 Innovation and the landscape lens

When we aim to explore the dynamics between the elements of Figure 1.2 over time and we wish to describe and analyse the innovation process itself in

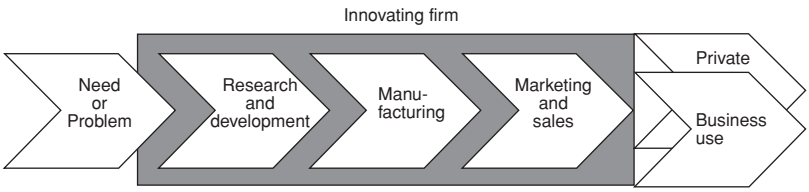

Figure 1.3 Sequential innovation process

particular, we are in need of a theoretical lens to provide us with the concepts to do so.

Innovation is a human phenomenon that occurs at all times and in all places. More recently, innovation has been recognised as the essential driver for continued economic growth and social development. In the words of Schumpeter: 'The fundamental impulse that sets and keeps the capitalist engine in motion comes from the consumer's goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates' (Schumpeter, 1942). For this reason, researchers have been interested in identifying why innovation occurs and under what conditions. In our case, we are interested in the reasons and the preconditions that facilitated the genesis and the development of Wi-Fi. Wi-Fi is an innovation rather than an invention. Invention is considered to precede innovation and is often ascribed to serendipity: the accidental discovery of new ideas. Innovation is considered as knowledge put into practice to solve a perceived need or problem. How the innovation is perceived depends on the knowledge base of the onlooker. Rogers (2003) defines innovation as 'an idea, practice, or object that is perceived as new to an individual or another unit of adoption'. Even if the innovation is not 'new-new' it may have considerable value to the individual or organisation involved. Of importance in our context is the innovation development process, which Rogers defines as 'all the decisions, activities, and their impacts that occur from recognition of a need or problem, through research, development, and commercialization of an innovation by users, to its consequences'. This definition suggests an underlying sequential process: a perceived need or problem triggers an action by an entrepreneur, who allocates research and development (R&D) resources, to create a solution for the need or problem perceived, which is subsequently commercialised. See Figure 1.3 for an illustration of the flow.

While this may be the dominant form of innovation in our industrialised economy, it is certainly not the only form. Based on his empirical research, von Hippel (1988) replaces this 'manufacturer as innovator' assumption by four functional categories of innovators: (1) the users, (2) the manufacturers, (3) the

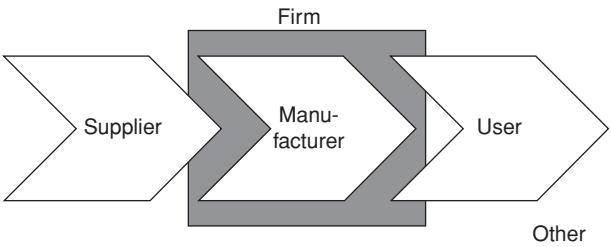

Figure 1.4 Sources of innovation

suppliers, and (4) 'others'. See Figure 1.4 for the relationship between these categories.

In the case studies supporting his research, von Hippel demonstrates that the innovators appear to be the actors that are best positioned to capture the temporary profits, or economic rents, from the innovative activities being undertaken. He observes, for instance, that, in the case of scientific instruments, the users are the main source of innovation; in engineering thermoplastics, the manufacturers are the source; in process equipment involving industrial gas, the gas suppliers are the innovators. In our Wi-Fi case we observe a shift in the locus of innovation, starting with the classical R&D model as it applies to the role of NCR in the innovation development process to the users involved in the creation of wireless neighbourhood area networks (NANs).

In our case we consider innovation, the innovation process and the resulting technological developments as the cumulative result of intentional behaviour on the part of actors. We thereby consider the innovation process to be an integral part of the overall organisational process of a firm, aimed at the production of goods and/or the delivery of services. As such, the innovation process is closely linked to the processes of manufacturing, sales and marketing, and it forms an important element in the strategy of the firm.

The firms that have business activities related to Wi-Fi can be considered to be part of an industry or industry segment. This industry is our next level of aggregation, which we use to capture the developments that all firms in the industry are facing, such as the rules of the competitive game, the process of standardisation and the laws and regulations regarding the use of radio frequency spectrum. The Wi-Fi industry is not a stand-alone industry, however, but an integral part of the broader ICT sector, with which it shares the (development of) the underlying information and communications technologies.

The perceived needs and problems that are addressed through the innovation process are, of course, determined by time and place. Our needs and problems reflect progress and the accumulation of knowledge. Hence, the available knowledge, technologies and tools that may be applied in the