Theorizing Convergence: Co-Evolution of Information Infrastructures

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Abstract. This paper engages in a study of the conditions for convergence between information infrastructures. Inspired by the visions of convergence as one of the essential building blocks to achieve the goals of the Information Society and eEurope as well as the observation that no model has been proposed to address how and why convergence develops, we aim at providing a theoretical framework for studying such phenomena. To analyze the interrelatedness of the parallel evolution of information infrastructures, we introduce a concept of co-evolution and apply it to a study of the ongoing development of the two wireless communication platforms Universal Mobile Telephone System (UMTS) and Wireless Local Area Network (WLAN) in Norway. We emphasize the importance of an adequate understanding of the infrastructures involved, including the installed bases and their intra- and inter-linkages, to anticipate possible trajectories of co-evolution. Focusing on the network dimension of the communication platforms, we show how the various technologies, politics, interests and user preferences linked to the installed bases of each of the platforms may strongly influence the direction and speed of their co-evolution.

Keywords Co-evolution, convergence, information infrastructure, installed base, UMTS, WLAN.

1 Introduction

Due to the ongoing digitalization of all types of data, multimedia and telecommunication networks, convergence has become an increasingly important issue, not least in the political arena. The common understanding of convergence is illustrated by Andrew Odlyzko: "… in which computing, telecommunications, and broadcasting all merge into a single stream of discrete bits carried on the same ubiquitous network" (Odlyzko 2001, p. 1). Even if we do not fully subscribe to this vision, in particular because we see the process of merging as uncertain and contingent, it is clear that there will be substantial implications of the technological developments in the ICT sector in the years to come.

The commission of the European Union (EU) as well as the Norwegian authorities currently recognize convergence as a cornerstone in: "… the strategy to make the European Union the most competitive and dynamic knowledge-based economy with improved employment and social cohesion by 2010, as well as enabling the implementation of the Information Society for all" (COM 2002a). EU and European national strategies and action plans have therefore been focused on how to stimulate convergence, in particular as it is seen to be vital for the further development of the European economy. Through their description of the key challenges of realizing convergence, however, it seems like they view convergence as something achievable through political initiatives and stimulation such as deregulation, standardization and harmonization nationally and across Europe. At the same time they put limited emphasis on the characteristics of the involved technologies and their specific implementations.

We argue that the prevailing political visions are based on a far too simplistic understanding of the development of ICTs. They apparently express a flavour of determinism by understanding convergence as a given or predetermined process, and not as only one possible result of a range of highly political and uncertain processes. Our point of departure is rather the opposite, claiming that there are politics and diverging forces involved in the development and implementation of ICTs in general and in particular in the evolution of communication platforms. We rather see convergence as a possible outcome of a *co-evolution*[1] by which we understand the parallel and simultaneous evolution of distinct, still interrelated ICT platforms. In this process, the platforms mutually influence each other in ways which can not be fully anticipated. In our empirical study, we investigate the co-evolution of the two communication platforms UMTS and WLAN as they evolve through a complex interplay of processes. The further direction of this co-evolution can be anything on a continuum from full integration to divergence. A possible close integration of the platforms may also take many forms, in particular since their evolution is driven by different actors with a variety of interests, agendas and preferences.

As a theoretical tool for studying the nature of the evolution of communication platforms, we apply information infrastructure (II) theory. Infrastructure are characterized as *large, shared, open, standardized* and *heterogeneous* networks of socio-technical actors (McGarty 1992; Star and Ruhleder 1996). In particular we understand infrastructures as *evolving* (Hanseth and Monteiro 1998) and accordingly having an essentially historical character, implying that changes are related to what already exists (David 1985). We thus put emphasis on the significance as well as the constituents and structure of their *installed bases*. Inspired by a *relational perspective* (Star and Ruhleder 1996) of the evolution of infrastructures, we further distinguish between the *demand-side* of installed base, which is composed of the user preferences, practices and investments, and the *supply-side*, which is composed of the ICT providers' investments and preferences related to design, implementation and diffusion. Further, the installed bases are interlinked with and influenced by other infrastructures in their evolution. We argue that our co-evolution process framework will provide analytical support to understand these interrelationships.

The anticipated convergence between the communication platforms WLAN and UMTS has been much debated in the trade press as well as the telecommunication- and computer-science literature (e.g., Jaseemuddin 2003; Lehr and McKnight 2003). While UMTS represents the next generation mobile telephony, building on a vertically integrated set of protocols, WLAN extends the reach of local area networks based on open Internet standards. In this paper, we demonstrate how our theoretical framework supports a deeper understanding of the factors that will influence their future co-evolution. By comparing UMTS and WLAN as ICT platforms we show how the analysis of co-evolution benefits from capturing the dynamics of these platforms, both on the demand and supply side, as well as the interaction between the two.

When introducing the concept of co-evolution, we do not argue against convergence as such. We rather argue that the trajectories of communication platforms (as for example UMTS and WLAN) are strongly influenced by both converging and diverging forces, and that a possible final integration will follow patterns that are not easily anticipated. This directs us towards two central questions; firstly, what enables co-evolution to turn into convergence, and what may be the obstacles associated with this, and secondly, to what extent do the various communication platforms have to change or break with their installed base to enable convergence?

This paper has primarily two objectives. First, we aim to develop a theoretical process framework to help understand the evolution and co-evolution of information infrastructures. Second, we further demonstrate how this theoretical framework supports an analysis of the anticipated co-evolution of UMTS and WLAN.

1.1 Empirical Research Approach

Our study belongs to the interpretative IS research tradition (Meyers and Avison 2002; Walsham 1993). Our research objective is to gain more insight into the dynamics of information infrastructure developments by taking into account the constituencies of UMTS and WLAN as well as their context. Our research has had a hermeneutic character in that we have iterated between studying parts and the whole (Klein and Myers 1999). On the one hand, we have focused on the rather detailed technical matters of the two platforms, on the other, the corresponding overall political and institutional framework and market conditions in which the platforms have been planned, designed and implemented.

The empirical data presented is based on case studies. According to Yin, a case study "investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (Yin 2003, p. 13). The two communication platforms were selected primarily for two reasons. Firstly, as stated above, because their convergence had been anticipated and discussed. Secondly, the choice was also motivated by their similarities as well as their differences. While both platforms can be understood as providing wireless access to mobile users for slightly different purposes and in a complementary manner, they can also be seen as competing and engaged in a battle of systems (Hughes 1983). Thus, these two platforms appeared to us as particularly suited for a study of convergence.

We have followed the development and implementation processes of the UMTS and WLAN[2] in Norway from 2002 to 2004. Even though it can be argued that their development trajectories have been different in other countries, we believe that the basic international character of both platforms prevents significant national peculiarities, at least in Europe The same standards have been adopted across Europe; the user terminals (mobile phones, PDA's, PCs etc.) have only limited national adaptations; and the communication networks rely on smooth international interoperability. We have focused on a limited part of the infrastructures and their context, and their effect on the process of co-evolution, leaving out other factors that may influence their future evolution. This is at the same time the very nature of IIs; as they reach out in a variety of directions it is not possible to have the overview since there is no overview to have (Neumann and Star 1996).

The data collected are primarily qualitative; however supplemented by facts about key actors, technical characteristics, standards along with the political vision and action plans, the status regarding the implementation and the common use of these platforms. The data is filtered through our understanding of the existing institutional context, prevailing policies and the strategies of the involved actors. The data collection across various sources was chosen because it is particularly useful in theory generation since it provides multiple perspectives on the case under investigation (Eisenhardt 1989). The data have been collected using various methods, as shown in table 1.

Goal/ motivation	*Method*	*Data source*
Overview of overall policy and institutional framework	Document studies	On European level: - European commissions website and archive (http://europa.eu.int), in particular its policies related to the Information Society (http://europa.eu.int/information_society) - The website of the Council of the European Union (http://ue.eu.int) as well as the EU's 6th research programme (FP6) (http://www.cordis.lu/ist/) On Norwegian level: - Primarily the government and the ministries, in particular the website of the Ministry of Transport and Communications (http://odin.dep.no/sd), and Post and Telecommunication Authority (http://www.npt.no/)
Insights in design and standardization strategies and approaches as well as technical characteristics of the platforms	Document studies	- Trade press in general UMTS: - Primarily the UMTS Forum (http://www.umts-forum.org), 3GPP (http://www.3gpp.org) and UMTS world (http://www.umtsworld.com/) WLAN: - Primarily IEEE (http://grouper.ieee.org/groups/802/11), the Wireless LAN Association (http://www.wlana.org) and Wi-Fi planet (http://www.wi-fiplanet.com)

Table 1. Primary data sources

Broad overview of the two platforms	Unstructured interviews	- One interview with a senior researcher from a telecommunication network operator - Two interviews with entrepreneurs from the WLAN industry
Insights in economic issues, business strategies, markets	Document studies, observations	- Trade press and newspapers, a variety of on-line news - Supplemented by own experiences as users

Table 1. Primary data sources

Our analysis started by a review of the existing policy documents related to convergence, in particular related to UMTS and WLAN. This provided insights into the governments understanding and anticipation of UMTS and WLAN convergence, the governments' recognition of their own role as an enabler in this process (as well as convergence in general) and the status of the process itself (rollout and implementation of the platforms). To complement these perspectives and direct our further research, three unstructured interviews were held. In particular, they guided us towards a more critical study of the strategies behind the different technologies as well as their technical specificities. From the open ended studies of policy documents and interviews, we turned to focus on a more detailed investigation of the design, standardization and market strategies and approaches as well as the technical characteristics of each of the platforms. The analysis was supported by continuous reflections on our findings and frequent discussions between the two researchers. We also presented preliminary findings and early drafts and received feedback from our own research group, as well as at a Norwegian and a Scandinavian IS conference.

2 A Process Framework of Co-Evolution

2.1 Theories of Information Infrastructures

Various studies of large, heterogeneous and integrated information systems crossing organizational as well as geographical borders have shown that theories and models found in traditional management and information system literature are not sufficient (Antonelli 1992; Ciborra et al. 2000; Hanseth et al. 1996; Ives and Jarvenpaa 1991; Rolland and Monteiro 2002; Star and Ruhleder 1996). By conceptualizing such systems as information infrastructures we apply a set of analytical tools to our study of how they evolve (e.g., Monteiro 1998) and more specifically what factors influence their development trajectories (Strauss 1993). We understand II as a shared resource that is enabling, open and general, evolving, standardized and building on an installed base (e.g., Hanseth 2002; Hanseth 2004).

The notion of information infrastructures was first coined by the Clinton and Gore administration in their political plan to build a nation-wide network and information resource based on the Internet and WWW (see e.g., Branscomb and Kahin 1996; Kahin and Abbate 1995; McGarty 1992). This was followed by the Bangemann report and the European Unions plan to build a pan-European infrastructure that should be the basis for the information society (COM 1994). The IS theory of II has gradually developed by building on different theoretical approaches.

The foundation of an infrastructure is its *installed base*. The installed base is comprised of all existing components of the infrastructure, both technical and non-technical, including technology, standards, and the organizational structures, the practices, behavioural patterns and social preferences of the users (Grindley 1995). The very nature of infrastructures implies that they are never built from scratch, but are rather building on, extending and enhancing existing structures. Thus infrastructures are necessarily evolving and will inherit both the weaknesses and strengths of what already exists. A classical and widely known example of this phenomenon is the design and evolution of keyboard layouts, leading to the development and de facto standardization of QWERTY (David 1985) which is a minor though intrinsic part of the general ICT infrastructure. Due to strong technical interrelatedness, economies of scale and irreversibility, the QWERTY keyboard arrangement has outlasted more optimal arrangement of the keyboard based on the efficiency of typing, such as the Dvorak simplified keyboard (David 1985). Very much decided by temporally remote events, the persistence of QWERTY takes on an essentially historical character.

2.2 Different Perspectives on Information Infrastructures

Based on different theoretical approaches, a variety of perspectives on IIs exists. Here, we outline four that have had an impact on recent research in the IS field.

First, IIs can basically be understood as natural *extension of physical infrastructures,* as e.g., “a substructure or underlying foundation; esp., the basic installations and facilities on which the continuance and growth of a community, state, etc. depends as roads, schools, power plants, transportation and communication systems, etc." (Webster 1979). Following this perspective, we see an information infrastructure as a multi-layered collection of various resources for communication and interchange of data, consisting of hardware, software and services along with the necessary support organization and personnel to develop and maintain it. A fruitful distinction can be made by decomposing infrastructures into subsystems (Hanseth 2002) and into different layers: *support* infrastructures upon which *application* infrastructures are implemented, illustrated by e.g., the basic Internet supporting the WWW applications.

Second, IIs can be seen in *contrast to information systems.* While traditional information systems are characterized by being closed and as having a specific purpose for a limited number of users, the essential aspects of an II are that it is "shared, evolving, open, standardized, heterogeneous and socio-technical construction" (Hanseth 2002, p. 7). An II is by its nature built to serve a wide range of users, user communities and types of applications (Ciborra et al. 2000). An II is thus not an end in itself, it is a mean or facility that helps to achieve something else; it is often viewed as an invisible structure that becomes visible only upon breakdowns (Star and Ruhleder 1996). Lyytinen and Yoo (2002) discuss in particular the challenges for future nomadic information environments departing from convergence. They conceptualize the future II as being: "Technically heterogeneous, geographically dispersed, and institutionally complex without any central coordination mechanism" (Lyytinen and Yoo 2002, p. 379). Thus, the II: "… must be based on a common platform of protocols and data standards to ensure interoperability, stability, reliability and persistence" (Lyytinen and Yoo 2002, p. 379). Although this description is rather technically focused, it nicely captures how the evolution of the II is strongly related to its legacy, i.e. its installed base.

A third perspective is that of *network economics*, in which we understand IIs as evolving according to certain economically explained network effects such as increasing returns, positive feedback, network externalities, path dependency and lock-in (for example Hanseth 2000). Theories of network economics can be used to explain the evolving nature of IIs, in particular in relation to end-users (Hanseth 2002; Hanseth and Monteiro 1998; Shapiro and Varian 1999). Due to heterogeneity and its character of being a network, a successful network evolves by *self-reinforcing mechanisms*. When a network attracts new end-users, the value of being part of the network increases (network externalities), and it becomes even more attractive for other end-users to join the network (Arthur 1994). When the user base reaches a certain threshold, the II as a network will attract new users for enrolment almost by itself. The growth of faxes, cellular phones and the Internet has been used to illustrate this pattern of development. However, this base of end-users may also introduce strong conservative forces, in that large numbers of end-users make it difficult to change the network, as for example illustrated by the QWERTY keyboard. As the user-behaviour is not centrally controlled, planned changes in standards or the technical infrastructure should only have small and step-wise effects on the II, as connectivity through compatibility with the existing II is crucial, or users are lost. Further, introducing a completely new network will not attract users as long as old networks provide sufficient services and have a superior number of users, thus the possibilities of introducing new and competing IIs are limited.

Fourthly is the *relational* perspective on IIs. The implementation of an IS will at least from its outset be intended to support certain communities of users while being based on generally accepted practices. As IIs are open systems, they will however also allow for innovation and change, possibly conflicting with existing conventions of use. Such changes may be the result of some shared intentions and efforts among the developers of the II. But it may also happen that the changes are the unintended consequences or unforeseen usages of a new II. This can be illustrated by today's usage of mobile phones and in particular how young people have adopted short message services (SMS) for communication. SMS now comprises an essential infrastructure for communication and interaction between groups of people, although it was not at the outset developed for such usages, and network operators were not pursuing peer-to-peer communication. Star and Ruhleder (1996) point to that: "… infrastructures are fundamentally and always a relation" emphasizing the relational and interdependence between the objects or artefacts and actors and how they mutually shape and reshape the II. Thus, the heterogeneity of the components is not restricted to the diversity of the different artefacts and actors, but also to how the various actors appreciate and interpret the various components related to their perspectives and interests. II will thus be understood differently by different actors' in-action and related to their practices and context. This reveals how choices and politics embedded in such systems become articulated components.

2.3 A Relational Perspective on Co-Evolution of Information Infrastructures

We find each of the four perspectives important to describe and understand the multidimensional character of an information infrastructure and the complex dynamics of its evolution trajectory. Although these perspectives are interrelated and mutually supporting each other, we in particular find the *relational perspective* as useful to support our discussion of the co-evolution of IIs.

The relational perspective points at the diversity and the heterogeneous character of IIs. At the same time, it also directs our attention to the distinction between the users and the developers, the demand and the supply side of an II. While we have to pay attention to the users and their investments, practices and preferences, as illustrated in the network economics perspective as outlined above, the evolution of IIs will also build on mechanisms related to the strategies, practices and investments of designers and developers of the IIs. For example, in the case of UMTS and WLAN, each of the platforms belongs to separate technological and innovative regimes, with different approaches regarding the diffusion of the innovations, focus on the technology, role of R&D and standardization (Godoe 2000). The various developers will, based on their own history understand the development processes and their implications differently. Even if the individual II are evolving towards integration, their developers will most likely promote their own different interests according to how they believe that specific design choices may support such interests. Accordingly, on the demand side, it is important to emphasize the role of the users, individuals as well as user organizations, as the value of an II is to a large extent defined by its users (Hanseth 2002). In the development of an II, as explained from the network economics perspective, the user may play a conserving role related to changes in practices and preferences, in particular where investments in new network terminals are required.

The analytic distinction between the demand- and supply-side is important. It is however also necessary to realize that one infrastructure may appear differently for distinct user groups, and for these different groups it may not make sense to talk about the same infrastructure (Star and Ruhleder 1996). For example, users installing a WLAN at home will focus on different aspects than when used in an office environment. Further, the actors involved with IIs will not just be either users or developers, but will typically have multiple roles. At the same time, even if the demand- and the supply-side can be conceptualized as different parts of an II, they are closely related. For example, the demand for user terminals (e.g., with multi-media functionality) are highly dependent on the availability of relevant services, and the market for new and advanced terminals depends on the existence of appropriate services.

The socio-technical character of the installed base, including technical and organizational aspects explicitly illustrates its heterogeneity. Heterogeneity further implies a distribution and sharing of the totality (its assets and its value) of the installed base among many different components and actors. Even more important, the power of controlling the installed base is shared among a range of actors and components: the technology itself, the network operators, the service providers, the innovation and the regulatory regime as well as the users, thus, “nobody is really in charge of infrastructure” (Star 1999, p. 382). Accordingly, the variety and interests of the constituent actors implies that one can only impose incremental changes, limited to only a part of the II, as other parts are controlled by other actors. The trajectory of development will therefore be an ongoing struggle between the various actors with their various incentives, needs and means to bring about change. While the installed base makes IIs difficult to change, the trajectory of change is highly unpredictable and without any central control.

In figure 1 we sketch our theoretical framework of co-evolving infrastructures inspired by a relational perspective. The boxes are meant to describe different perspectives and should therefore be conceptualized as different parts of the II. While the relation between the demand and supply side (vertical axes) represents the most influential factors for the evolution of each II, their co-evolution will include both the interactions between different demand forces as well as supply forces (horizontal axes) as well as across them (diagonal axes). The varying emphasis (thickness) we put on the different relations in the figure are supposed to illustrate the strength of their interdependency. While evolution of the individual infrastructures is illustrated with the vertical axes, the process of co-evolution also involves the horizontal and diagonal axes.

We believe that a relational perspective captures the duality of the demand- and supply-side mechanisms of co-evolution. Where two IIs are evolving

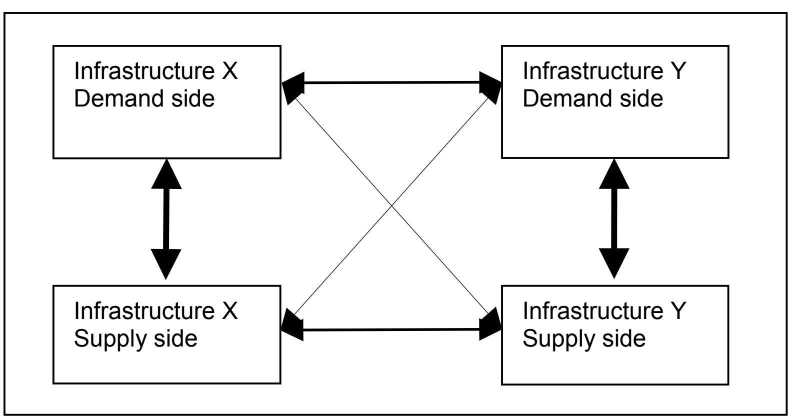

Figure 1. A relational process framework for analyzing co-evolution

under mutual interaction and influence (horizontal and diagonal axes) the process may perhaps end up in convergence. However, as we will show in our discussion of UMTS and WLAN, the tensions between different IIs, based on their inconsistencies and antagonism in interests, strategies and technologies, can be highly influential on whether their co-evolution in fact will lead towards convergence.

3 Converging Communication Platforms

In this section we discuss various conceptualizations of convergence. Relating convergence to our infrastructure perspective, we in particular describe convergence as only one possible outcome of co-evolution. We will here limit our discussion to focus on co-evolution on the network level.

3.1 Convergence in Visions and Reality

The significance of convergence for the European countries is reflected in European visions and action plans, as for example the European commission's emphasis on the importance of converging communication platforms (e.g., COM 1997, p. ii). More specifically, the 6th Framework Programme (FP6) contributing directly to the realization of the *e*Europe according to the action plans emphasizes the importance of research into, as well as application of converged infrastructures related to ICT platforms:

> These [applications and services for the mobile user] should be based on interoperable mobile, wireless technologies and the convergence of fixed and mobile communication infrastructures. Such applications and services will enable new business models, new ways of working, improved customer relations and government services in any context. (COM 2002b)

The *e*Europe 2002 action plan was primarily focused on spurring growth of the Internet, claiming that one of the biggest assets of Europe was its leadership in mobile communication networks. Convergence was not seen as a primary issue, but the need for a new regulatory framework was identified (COM 2000). The succeeding *e*Europe 2005 action plan builds on its predecessor which is assumed to have: "… reshaped the regulatory environment for communications networks and services and for e-commerce and opened the door to new generations of mobile and multimedia services" (COM 2002a). The *e*Europe 2005 plan further sees convergence as having a major impact on the further development of the Internet and in combination with broadband communication (as for example WLAN) bringing: "social as well as economic benefits"(COM 2002a, p. 8). 3G and interactive digital television is seen as opening up for access to services over multiple platforms, and further: "Technological convergence affords all businesses and citizens new opportunities for access to the Information Society" (COM 2002c).

These visions and strategies reflect the significance attributed to convergence by governments. However, little attention is given to how convergence actually unfolds. Convergence is seen as being driven primarily by technological development, in particular by the digitalization of data and further advances in network infrastructure (e.g., Ono and Aoki 1998). They apparently see convergence as the natural continuation of current processes, although the strategies to some extent draw a complex picture of convergence by including discussions of the differences in regulations and economic factors along with technological factors such as user equipment and services.

At the same time we observe a number of developments not favouring convergence, as for example:

- The lack of (or very slow) integration of mobile phones, hand-held computers and PC's
- The slow diffusion of IP telephony related to tradition telephone services
- The media industry pushing towards copyright reinforcement as digital right management systems (DRMS), hampering the integration of various service platforms
- The building of separate networks for broadcast/multi-media and Internet based broadband, such as establishing a separate Digital Terrestrial Television (DTT) in Norway

While it is possible to argue that this is a result of the lack of coordination among as well as by the initiatives of the various European governments, we argue that these developments are the result of partly technical problems, partly diverging business interest and still separate market forces. The co-evolution of the related networks does not seem to move towards convergence. While the intrinsic limited battery and antenna capacity of mobile phones can explain the lack of more PC-like mobile phones, the introduction of IP-telephony have been challenged both with technical quality constraints as well as regulatory issues. The building of a separate DTT network and the current focus on DRMS are rather motivated by the commercial interests of controlling networks and business models.

3.2 The Concept of Convergence

In general, converging means the "*moving toward union or uniformity*" (Merriam-Webster 2003), a concept with many facets and attached meanings. In their work for the EU, the consultancy firm KPMG proposed a more specific definition of convergence: "Convergence is an on-going process which entails the coming together of the following:

- content from the audiovisual and publishing industries;
- potentially separate physical infrastructures (such as those supporting broadcast or telecommunications services) able to carry similar sorts of information at increasingly lower costs;
- the interactivity of information storage and processing capabilities of the computer world; the ubiquity, improving functionality and ease of use of consumer electronics." (COM 1997).

Skogerbø (1997) criticizes this definition for focusing mainly on the technical aspects, neglecting among others the market. She proposes a definition distinguishing between *network*, *service* and *market* convergence. This work has further been extended, distinguishing between four dimensions of convergence (as presented in NMTC 1999):

- *Network Convergence*: Different network platforms provide seamless interconnection and allow for the distribution of any kind of service
- *Terminal convergence*: Equipment may be used to access different network platforms, and/or they may be used for a wide range of services across different platforms
- *Service convergence:* Different services adopt the others format or same services are provided in different formats, e.g., as films, books, or multimedia services
- *Market convergence*: Because of these other kinds of convergence, the actors providing the different platforms and media are becoming intermixed

These definitions provide us with a broad perspective on convergence as it includes several different dimensions. At the same time, however, along with the governmental strategies convergence is still primarily conceptualized as the predefined product. As we have argued, convergence should more appropriately be understood as one possible result of co-evolution. The outcome can at the same time adequately be analyzed and discussed on the different dimensions of networks, terminals, services and markets. Co-evolution will involve all of these dimensions, each of which may evolve at least partly independent of each other, driven by different interests, agendas, means as well as market-logics. In particular, no single actor will have the sufficient power to execute control across all dimensions.

We argue that our theoretical framework can be useful across these dimensions. However, we find it necessary to limit our discussion to the network dimension in this paper. We understand network convergence as "… *a seamless and interoperable integrated telecommunication and computer infrastructure*" (Messerschmitt 1996, p. 66). The understanding of convergence is itself ambiguous as it can be seen as a continuum; from the ultimate vision of Odlyzko to a more pragmatic view where convergence can be a rather loose interconnection and interchange of services across the platforms. We focus on network convergence in this latter pragmatic view. Framing this definition in our theoretical framework points at three important issues: i) the networks must operate seamlessly together, ii) at the same time the converging networks (as information infrastructures) have to co-evolve from their existing installed bases and accordingly, iii) convergence is not necessarily implying one integrated network. Thus, there may still be two distinct technological platforms in terms of protocols and services.

4 UMTS and WLAN as Information Infrastructures

In this section we outline the basic origins of two mobile communication platforms UMTS[3] and WLAN[4] and their installed base both on the demand- and the supply-side. We emphasize their most significant similarities as well as differences. These descriptions underpin our argument that the platforms are both competing and complementary. We further argue that both platforms are developing as radical departures from the underlying business and industry structure they are belonging to, which are their supply-sides, in the sense that new actors are taking part in the value chain and are given the responsibility to develop, maintain and operate certain parts of the network. At the same time, they evolve in conformance with their already existing socio-technical infrastructure on the demand-side of their installed bases.

UMTS is one of several platforms under the IMT-2000 (International Mobile Telecommunications-2000) umbrella making up 3G, the third and next generation of mobile telephony. UMTS primarily enables mobile operators to provide higher bandwidth data services across mobile phone networks. WLAN, here referring to the IEEE 802.11b standard, is a platform designed to extend wired Local Area Networks (LANs), which are networks supporting the sharing of computing resources. Both these platforms provide wireless access to the Internet and are able to carry any type of digitalized information such as text, graphics, sound, movies etc., and thus basically address the same user needs and market segment. UMTS and WLAN are also both based on radio communication technology, they provide broadband connectivity and they offer a certain degree of personal mobility to their users. However, they are also substantively different in the way they enable the transportation of information, which in particular relates to their distinct origin and the development and implementation of the platforms.

UMTS and WLAN are, or at least intended to become part of general infrastructures for communication and information exchange by being generally accessible, standardized and shared by a large number of users and usages (COM 2002a; 2002b). We thus argue that they both have to comply with the fundamental characteristics of IIs if they are going to succeed as general communication platforms; they must be open, enabling and shared while also evolving, and building on their heterogeneous and existing installed base. More precisely, we emphasize their relations to important actors; as for example the developers of terminals, the service providers and the variety of users groups. Both platforms are already composed of a range of heterogeneous, thus interconnected technical and non-technical elements that all are not necessarily centrally controlled, though the structure of UMTS and WLAN are rather different. UMTS on the one hand is generally vertical integrated resulting from a top-down design strategy. WLAN is based on Internet technology, having a horizontally layered architecture, and being more fragmented based on a bottom-up design approach and further less centrally controlled in design, and in particular in implementation.

When discussing the co-evolution of UMTS and WLAN we have to take into account their two distinct installed bases. Their installed bases include the demand- and supply-side respectively, established and customized user practices and user terminals, as well as approaches to design and implementation and related networks (GSM and Internet respectively). We must not only take into account the internal specifics of the installed base of each platform, but also their interrelationship and the possible tensions between them. A potentially converged and integrated network will have to grow out of the already existing; however different installed base of WLAN and UMTS, and the result will not be a discontinuity in relation to these predecessors.

4.1 UMTS: Ubiquitous Access, *de jure* Standardized and Centralized Implementation

UMTS is to be developed and deployed European-wide by mobile network operators and is developed within the framework of the telecommunication sector. UMTS services shall be offered to end-users (mobile phone subscribers) on the basis of subscriptions similar to the current GSM networks. The basic business model is based on mobile network operators owning and operating the infrastructure on a national basis, interconnected nationally as well as globally with wired PSTN (Public Switched Telecommunications Network) as well as other UMTS and GSM networks. The design and operation is thus centralized and managed top-down, while the services are vertically integrated. As centralized, coordinated and vertically integrated networks, UMTS inherits the basic services from the GSM networks such as *authentication, authorization and accounting* (so called AAA-services[5]). The key feature of UMTS from the subscriber-perspective is continuous Internet access with relatively high bandwidth compared to GSM. This enables a range of new services and marks a turn from a focus on voice to data services. Access to the services is provided by a network of interconnected base stations intricately arranged on the basis of the number of subscribers and their patterns of usage. One key cost issue for UMTS is that increasing the bandwidth requires a higher density of base stations as compared to the existing GSM network. Even if the platforms theoretically can support data rates up to 2 Mbps, the real rates are rather expected to be close to 100 kbps (Lehr and McKnight 2003), depending on usage patterns and the density of base stations.

The work on the UTMS platform started in the 1980s by the International Telecommunication Union (ITU). The ITU initiative resulted in the global IMT-2000 standard later adopted by the European Telecommunications Standards Institute (ETSI) in 1991. Already in 1992, frequencies for UMTS were allocated on a world basis at the World Radio Conference in Malaga (WRC-92). In 1995, the UMTS Task Force (SMG5) was established within the ETSI, officially recognized as a standardization organization by the European Commission. ETSI was a founding partner of 3GPP, which was created in December 1998 after pressure from ITU to coordinate the various 3G initiatives globally under the IMT-2000 umbrella.

UMTS has had much attention by the European Union as well as the Norwegian government (see e.g., COM 1997; COM 2002a). The platform is seen as a key for the further development of eEurope, and selected as the *de jure* standard by the European Parliament and the Council in December 1998:

> Member States must take all actions necessary in order to allow the coordinated and progressive introduction of UMTS services on their territory by 1 January 2002 at the latest and in particular must establish an authorization system for UMTS by no later than 1 January 2000. (COM 1998)

In the case of Norway, four actors were granted licenses based on this decision to implement and operate UMTS networks in Norway. These were allocated based on a license competition or as a beauty contest[6]. The license fees for UMTS have been substantial, at least seen in relation to the so far lack of revenues for the licensees. The size of the fees has also had far-reaching consequences for those bidding on and buying them[7]. In late 2001, one of the actors in Norway went bankrupt resulting in the withdrawal of their license, while another actor later returned the license. The two vacant licenses were auctioned again during the summer of 2003, and the only new bidder for this license is one of the current three licensees. This reflects the limited interest in the market that can at least partly be attributed to the late freezing point of the standard and the resulting delays in network equipment and end-user devices. According to the licensees they are however on track related to the implementation of the infrastructure and the networks (one of them covering 1.7 million people). However, due to lack of sufficient user terminals available (in terms of brands and quality), lack of services as well as varying quality in the test-networks, the first commercial network in Norway was launched as late as December 2004.

The introduction of UMTS networks in Norway are based on a *revolutionary* approach, implying the building of new, monolithic, nation-wide networks, necessarily in competition and possibly cannibalizing existing GSM-traffic and -networks. This approach is at least partly a result of the standardization approach. With the centralized and top-down manner approach adopted by ETSI and 3GPP, network operators as well as manufacturers will have to wait until the standard is somehow stabilized in line with earlier standardization approaches (e.g., NMT and GSM). Even if the standard is strongly supported by governments, the willingness of the operators to implement operational as well as test networks has been limited, in particular due to the lack of return on investments. Another important factor behind the revolutionary approach is the UMTS licenses not accepting licensees to share network infrastructure (in particular in rural areas), but dictate the UMTS networks to appear as independent (NMTC 2000; 2002; 2003). The primary argument for these regulations was to secure real competition as well as to reduce the vulnerability of having only one network. Due to delays in the rollout of the UMTS network, however, suggestions have been made from a range of actors, in particular the network operators, as well as the authorities to allow for cooperation. This is primarily related to national roaming, in particular in sparsely populated areas. However, no decision has yet been taken. Somehow lessening the pressure on the licensees, they have been allowed to delay their roll-out schedule for up to 15 additional months.

Even if one of the licensees launched their UMTS network commercially 1st December 2004, there are few if any new services (related to old GSM services) available, the network only covers half the populated areas of Norway and only one (high-end) phone is available and supports roaming between the GSM and the UMTS network. Thus, the platform still has to show its appropriateness for more than making phone calls. It seems that the different stakeholders related to UMTS are still in some kind of a dead-lock, since operators have been waiting for services and handsets, service providers for operational networks and appropriate end-user equipment, while the end-users for all of it, and so forth. The problem that UMTS faces in entering the market is also amplified by the fact that enhancements of 2G networks such as GPRS[8] and EDGE[9] have provided a number of the services that were thought to be the killer application for UMTS, such as for example Multi Media Services (MMS).

4.2 WLAN: Semi Mobile Access, *de facto* Standardized and Decentralized Implementation

WLAN has grown out of the computer industry as an extension of LANs (local area networks), and is implemented by a range of different actors, such as private persons, corporations and so called *Wireless Internet Service Providers* (WISP). The key feature of WLAN from the user perspective is providing wireless, mobile high-bandwidth data communication facilities and LAN access within a limited geographical area. Even if roaming between networks is possible, WLAN is usually implemented as distinct networks, typically only available within a home, a building or a campus, providing no seamless interoperability between these locations. The different WLAN standards operate on a license-exempt frequency band, allowing everybody to set up a local WLAN network without a license and thus without any additional costs.

WLAN entered the business environment in the early 1990s. In 1997, IEEE introduced 802.11 as a part of the 802 LAN families of standards, with the aim to ensure interoperability between equipment vendors as to secure the growth in the WLAN market. In this way, WLAN and LAN offer the same interface upwards to the network layer (typically IP), which is in accordance with the

Internet network architecture. In 1999, the 802.11 standard was amended to increase the performance (speed) with 802.11b providing 11 Mbps. Today, the most frequently used 802.11b standard is also accompanied with 802.11a, and 802.11g, providing respectively more secure connections and higher bandwidth.

WLAN implementations are basically based on the installation of one or more base stations (so called access points) that are connected to a wired LAN. In addition, each user device must be equipped with an appropriate WLAN card, being configured for this specific access point. Within the reach of the access point (normally about 50 meters) the network is accessible, which reduces the need for wiring office areas as well as private homes. The common business model for equipment producers is to sell this equipment to companies and the consumer market. WLAN connectivity and usage is commonly provided free of charge (in the case of the home), even if usually restricted to a certain user group (in the case of a campus or a company). Lately, however, WISPs provide Internet access in public areas (so called hot spots), typically in airport lounges, restaurants or hotels, for a smaller or larger fee. While being attractive regarding bandwidth speed and ease of installation, local implementations of WLAN have suffered from much negative attention in the media regarding its lack of security services compared to that of a wired LAN, enabling attackers to monitor and tap the networks for non-encrypted information. These challenges, however, have become visible as a result of experiences and changes in usages over time.

The current de facto WLAN standard IEEE 802.11b does not include AAA-services (see 4.1). Thus, each WLAN implementation has to implement its own regime. This include hotspots which must implement payment services, implying rather complicated and time consuming registration and access routines for the user, in particular if accessing different networks with their idiosyncratic access and billing regimes. This is however the nature of a standard designed to offer wireless access as an extension of existing LANs i.e. that is horizontally integrated. At the same time, the success of public WLAN (provided by WISPs) is dependent on the provision of seamless connection between different local WLAN networks without the user having to enter new registration information every time he switches to an access point connected to a different network. Rendering this possible will require the establishment of contractual agreements between the WLAN providers to be able to offer seamless discrete mobility and roaming between the independent hotspots (e.g., agreeing upon business models and billing policy).

The standardization process of WLAN and the implementation of the networks have been open and out of central control, resulting in competing standards and proprietary services, as for example a variety of security and billing solutions implemented by WISPs. This competition is still going on, in parallel with the operation of existing networks.

4.3 The Role of the Installed Base in the Evolution of UMTS and WLAN

As a basis for our further discussion of co-evolution and the various mechanisms of the installed base of UMTS and WLAN, table 2 briefly summarizes their primary properties and highlights the difference between them according to the framework described in figure 1 in section 2. We argue that these differences, both on the demand- and the supply-side will strongly influence their future evolution and thereby also their future interrelationship.

In general, the platforms are strongly interrelated with their predecessors, respectively GSM and LAN. In the case of UMTS, the physical network including base stations and network management hardware and software has to be built from scratch, and in that respect will not be built on any existing network. However, UMTS operators will most likely utilize part of the existing installed bases of their infrastructure, as for example systems for accounting and customer management etc., as well as roaming with the existing GSM network in rural areas and interconnection with the fixed phone network. This installed base will of course be a valuable asset concerning the existing operators, however possibly bringing barriers for entrants in the market without such networks.

The case of WLAN is quite different, as it has grown out of the data communication world, dominated by small and mostly independent networks and network providers. The WLAN network is comprised of a large number of small networks, developed and implemented in an uncoordinated manner. At the same time, they have one important part of the installed base in common, the backbone Internet. This implies that their installed base includes the service providers as well as the services and existing Internets users. The use of WLAN has developed over time, and in conjunction with the Internet. As the current WLAN (IEEE 802.11b) standard has become a de facto, the installed base of existing implementations requires backward compatibility for new and enhanced standards (as with for example IEEE 802.11a or IEEE 802.11g).

Dimension	*UMTS*	*WLAN*
Demand-side		
User base	Subscribers from GSM and contents service providers	All PC users and existing Internet service providers
User needs	Largely unknown, usage frowing out of 2G	High bandwidth and semi-mobile access to Internet
Supply-side		
General architecture	Verticallly integrated, network operator-based approach	Horizontal integrated, end-user centric decentralized approach to service provision
Technological base	Interconnected with 2G	Extends Internet/WLAN
Development approach	Comprehensive, top-down oriented and specification-driven formal standardization by ETSI/ISO	Layered, incremental, bottom-up, IP/TCP-compatible *de facto* standardization
Physical/ technical characteristics	Coordinated network of base station aiming at national coverage providing seamless roaming	Distinct, uncoordinated access points connection to Internet. Roaming between different networks not provided by standard
Security	Extensive security including authentication and authorization	Limited security functionality in standard
Billing/ accounting services	Interconnected with existing billing/accounting services from 2G/ wired phones	Idiosyncratic and uncoordinated billing regimes across networks
Implementation strategy	Revolutionary, centrally controlled	Incremental, partly decentralized, evolutionary

Table 2. Key factors of installed bases important in the co-evolution of WLAN and UMTS

4.4 The Parallel Evolution of UMTS and WLAN

WLAN and UMTS have been growing as individual platforms and out of distinct industries, but their evolution has at the same time been mutually influential. Their interaction can be characterized both complementary and as

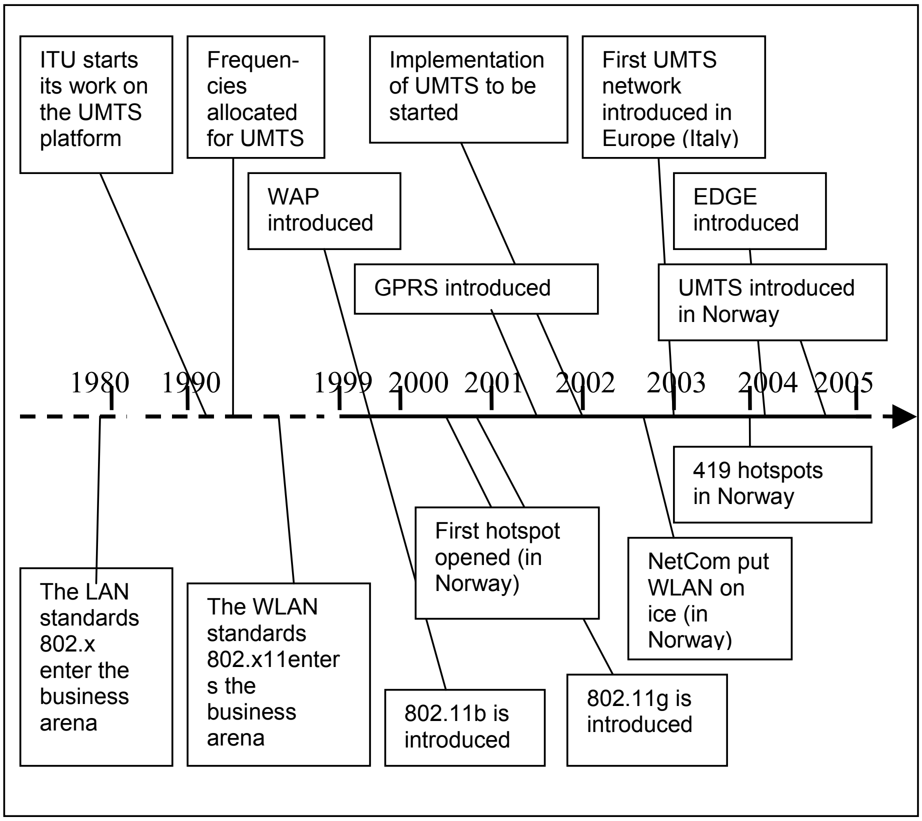

Figure 2. Milestones in the evolution of UMTS and WLAN

competing. Figure 2 highlights important milestones in the evolution of UMTS and WLAN.

Below, we provide some illustrations of the mutual influence in the co-evolution of WLAN and UMTS related to the platforms themselves, the user equipment and the strategies of the various actors.

The penetration of mobile phones in Norway is 96 percent[10] and more than two million mobile phones were sold in 2004 (to a population of 4.6 million citizens). Furthermore, there is a current trend where people are migrating from fixed phones to mobile phones, i.e. they no longer have a fixed line phone at home. At the same time, more than 60 percent of the households have Internet access, and most PC's and laptops come with WLAN capabilities. Through an increasing number of private WLAN's, consumers are provided with high bandwidth access to the Internet in a semi-mobile way. In parallel, GSM subscribers (and gradually UMTS in the future) are provided reliable, secure and ubiquitous network access, however primarily used for voice and SMS services. As an increasing number of users have access to and use WLAN and UMTS there will also be an increasing need for interoperability. However, the users' experience with the characteristics of the respective platforms is very different, in particular when it comes to bandwidth and network accessibility along with pricing policies. While the further development of WLAN from a user' perspective will be related to additional enhancement of bandwidth, the interest in UMTS will foremost be related to the provision of content services and pricing structures. These developments seem to have strengthened rather than weakened the separation of the platforms, as the users' experiences and practices are constantly confronted. However, this calls for novel strategic thinking and innovations that may lead towards greater interoperability.

The attempt from the network operators to provide information services and access to Internet with WAP[11] was more or less a failure. In parallel, WLAN, which was originally designed as an extension to LANs in the office environment, successfully moved into hotels, cafes, airports and homes, even tough this occurred in a decentralized and unplanned manner. The success of WLAN outside the office environment can at least partly be attributed to the lack of adequate Internet access through GSM (WAP) and the delays of UMTS. In response to the delays of UMTS and probably also the success of WLAN, the bandwidth of the GSM networks have been extended with GPRS (2001) and recently EDGE (late 2004). Based on different efforts to capture the mobile Internet market, these processes show how the different actors and their respective platforms (GSM with WAP, GPRS and EDGE, UMTS and WLAN) have mutually influenced each others in rather unforeseen ways, illustrating the dynamics of their co-evolution.

According to the Norwegian Post and Telecommunication Authority the number of WLAN hotspots was reduced from 518 in 2003 to 419 in 2004. After two years with WLAN on ice, one of the network operators (NetCom GSM) announced further developments and expansion of their network of hotspots in November 2004. Currently, the largest WISPs (and thus providers of hotspots) are the telecommunication network operators. Network operators do obviously have an ambivalent relationship to investments in WLAN as long as there is a risk of cannibalization, in this case related to GSM and UMTS. Their position as the largest actor in the hotspot market does show that they find the platform of strategic importance. The delays in their implementation strategy do, however, indicate that the future developments are rather uncertain. When planning for further expansion of WLAN, they have to take into account their installed base of GSM technology and users, and vice versa. Having a strong market position related to GSM and UMTS, network operators will necessarily act cautiously to not make users migrate to other platforms, out of their own control. Thus, with their strategic position, network operators do have a key role in the further co-evolution of WLAN and UMTS.

5 WLAN and UMTS as Co-Evolving Information infrastructures

According to our previous discussions, and deriving from theories of information infrastructures, the future evolution of both UMTS and WLAN will be strongly influenced by the characteristics of their respective installed bases. As discussed in chapter 4, a possible co-evolution of these platforms towards convergence, by which we mean seamless interoperability, may not imply one integrated network and there may still be two distinct technological platforms in terms of protocols and services. At the same time, we argue that their co-evolution necessarily will involve coordination at both the demand- and the supply-side, and include a range of different factors, as illustrated in table 2. We start the next section by discussing the further evolution of the platforms, followed by a discussion on whether convergence is a likely outcome of these processes.

5.1 What Will Drive the Evolution – The Users or the Suppliers?

The demand and supply sides of the installed bases of each of the platforms are not independent; the relations between the suppliers and users imply that they are mutually influencing each other and changing over time. For example, user preferences and practices do strongly impact design choices and the possibilities to implement such changes, and at the same time, the user habits are changed through the marketing efforts by the developers. The nature of and the strength of these installed bases (for example the importance of backward compatibility, the significance of existing user practices, etc) will influence the platform's ability to accommodate changes. At the same time, being both competing and complementary platforms, their co-evolution will be linked to both the demand- and the supply-side of each of the platforms (the vertical axes in figure 1) as well as their mutual influence (the diagonal axes).

A successful implementation of UMTS networks will heavily depend on the type of business models that are applied, i.e. the revenue sharing between network operators and third party service and content providers, as illustrated below. To implement such systems is not primarily a technical challenge, and a variety of business strategies from the different network operators are likely to be developed as extensions to vertically integrated and detached networks. Even if networks become interconnected, the question that still remains open is whether the network operators will approach the users, both service providers and subscribers with specialized and exclusive services to obtain a competitive advantage. For example, NTT DoCoMo has implemented an exclusive service offer with i-mode (providing services such as email, weather information, news and entertainment for mobile phones) in Japan (e.g., Funk 2001). Alternatively, network operators can provide open and public access to such services across the networks, as for example the loosely interconnected implementations of CPA-platforms by the GSM network operators in the Norway (Nielsen and Herstad 2004). These different business models are in both cases dictated by the network operators.

To introduce new products or services in an open market is a demanding challenge. In the case of UMTS it may for example take several years before investments will be recollected. In spite of having promised to open the UMTS network, the telecommunication operators have instead been enhancing their already existing networks with new services such as GPRS and EDGE. Thus, UMTS network operators will have to provide attractive services in order to persuade subscribers to upgrade from GSM/GPRS to UMTS handsets. The content service providers must at the same time be attracted towards UMTS, which depends on whether the business models from GSM will be adopted with UMTS. However, this is not only in the hands of the telecommunication operators, but much depends on the manufacturers of user equipment, as well as the service providers. The heritage of the installed base thus has ambiguous effects; delaying the implementation and use of UMTS on a short term basis, while possibly driving it in the longer term.

While commercially available UMTS networks and handsets are just in their infancy, WLAN implementations have been flourishing for a while. The WLAN standard has evolved to accommodate the emerging user practices as well as security breaches, even if the heterogeneity of users, usages and additional services makes upgrades to new standards challenging. Since the networks are not centrally coordinated, all changes must be backward compatible. For the users, possible changes in hardware and software may not be seen as necessary or appropriate as long as the local configuration provides a satisfactory (wireless) extension of the LAN. This end-user-oriented, decentralized approach has created highly successful local implementations, but has also resulted in distinct and uncoordinated networks, in particular related to billing regimes and roaming. Furthermore, a variety of business models also exist. For example, some restaurants provide WLAN access for free, while many hotels charge their guests for their facilities. This may in particular act as a barrier for users with cumbersome registration processes whenever they have to roam from one network to the other. Some WISPs (in particular the network operators) have tried to implement a range of hotspots as to pursue economies of scale and capture a larger share of the market, but they have not managed to cover a significant portion of Norway, and one single WISP has not turned out to be the market leader. It does not seem that one, coherent strategy will dominate the WLAN evolution.

5.2 The Further Co-Evolution of WLAN and UMTS - As Converging or Diverging Platforms?

A co-evolution of UMTS and WLAN that results in seamless interoperability or at least facilitate roaming across the platforms, implies harmonization and coordinated development of functions and services at the transport-, service- and application layers. Currently, we do not see full integration at the transport layer as a realistic option, as user requirements of the two platforms; their utilization of frequencies and their regulatory environment are far from consistent. However, gateway solutions may provide acceptable interlinking and roaming capabilities between the platforms (Messerschmitt 1996). On the regulatory level, the recent Norwegian Telecommunications Act of July 2003 suggests common terms for any digital transportation network, but it remains to be seen what the consequences of this will be. Furthermore, we see several obstacles related to smooth interoperability, e.g., related to security, billing and other administrative matters.

A possible co-evolution towards greater interoperability thus implies that actors previously independent of each other now will have to interact. This may be particularly difficult in the case of WLAN were many different and independent actors, both providers and users of communication services do not have institutions to support the coordination of common problems related to issues such as interoperability. Having rather different views on the world (Neumann and Star 1996), the different actors will most likely view the process of co-evolution and its results differently, and act strategically to protect their own interests. As illustrated in 3.1, such different interests may rather benefit from maintaining the existing separation of the networks. In particular, network operators with their strong market position (e.g., the duopoly situation in Norway related to GSM) will be reluctant to support interoperability if it implies that they will lose their control over important assets such as their user base and strategic position in the value chain.

Providing extensions to local area networks, the installed base of WLAN networks has developed rather uncoordinated over time. Gradually changes that also include facilities for interconnection to UMTS networks may be feasible, but this is only likely if driven by changing user requirements. Since local implementation of WLAN in this respect will be open to local adaptations and out of any central control, this may be difficult to achieve. While telecommunication operators are used to coordinated, big-bang type implementations of networks (as in the case of GSM), changing all the WLAN networks will require a more evolutionary and step-wise approach and will be much more difficult to achieve.

While vertical integration will discourage diversity of applications, horizontal integration will encourage this diversity (Messerschmitt 1996). Being based on horizontal integration, WLAN eases the entry for application developers. On the contrary, telecommunication network operators have historically favoured vertical integration, and this approach may again be favoured, along with it proprietary solutions and exclusive services for the different UMTS networks. However, the existing GSM network operators are facing stagnation as their traditional markets become saturated (for example Vincent 2001) and will have to seek new areas and support to increase network traffic. Providing open interfaces for third party developers is obviously one such approach. Messerschmitt argues that such powerful economic and technological forces are driving towards horizontal integration (Messerschmitt 1996). On what terms such developments will unfold and how to solve the fundamental incompatibility between vertical and horizontally integrated platforms, however, are still open issues. One scenario could be that telecommunication operators open their UMTS networks and for example detangle the so called AAA-services from the transportation services. Another alternative could be that WLAN are being utilized as a UMTS carrier enabled by additional AAA-services provided by telecommunication network operators. At the same time, we only find telecommunication operators to have the power and the potential to create a uniform move towards integrating these networks. Even if the telecommunication operators may initiate work to include AAA-type service interfaces in their networks in order to integrate WLAN networks, it is not likely that a corresponding interface will be available in all the various WLAN implementations, and unanimously for subscribers regardless of the operators. At the same time, the telecommunication network operators' control of UMTS as well as WLAN is limited to the supply side. The authorities are also closely monitoring them to avoid a continuation and extension of the current duopoly in Norway.

We have argued that the two platforms are evolving through a complex interplay between various actors, among them the designers of standards, the product developers, the service providers and the different user groups along with the organizational and institutional context they are growing out from and into. Efforts to stimulate a distinct trajectory will therefore be intrinsically challenging, since no one is really in control of any II and the process is not linear from specification to construction and implementation (e.g., Ciborra 2000).

6 Conclusion

In this paper we have introduced a theoretical process framework of co-evolution, drawing upon a relational perspective on IIs and their installed bases. Based on this framework, our case description and discussions are aiming at illustrating the multi-dimensional character of the factors that influence the evolution of communication platforms. To understand their separate evolution as well as their interrelated co-evolution we have to move beyond a simple network perspective and include issues as e.g., roaming, security, accounting and billing. Thus, even if available gateways between the platforms provide seamless interconnection, they do not necessarily fulfil the requirements from the users or from the network operators and service providers to become successful.

In the case of UMTS, it has its roots in monopolistic organizations, accustomed with centrally controlled development and revolutionary implementation strategies – which is in contrast to the computer industrial tradition that WLAN has grown from: Small, competing companies, bottom-up approaches and independent networks. While implementing UMTS as vertically integrated sets of well-defined functions and services, WLAN implementations resemble the horizontal integration of compatible function and services, but also lack important facilities such as roaming, authentication, authorization and accounting. We claim that even if the UMTS network operators may initiate work to include interfaces for such services in order to integrate WLAN networks, it is not likely that corresponding interfaces will be available in the various WLAN implementations within a short time frame. Interoperability will imply coordinating activities on a number of issues, which we believe will require negotiations between various actors related to different and conflicting needs and agendas. In addition, some issues will only become apparent when

UMTS implementations are readily available, as usages will develop over time. However, this may not hamper seamless interoperability as a possible result, as incremental and experimental development approaches may very well be the best (and only acceptable) strategy.

A possible final convergence of communication platforms will have to include a range of dimensions (such as network, terminal, service and market), with different platforms integrated into one common II, serving common markets with common services accessed by common terminals. We therefore underline the need for an adequate understanding of the IIs involved in co-evolution, including the demand- as well as the supply-side of the installed bases and their intra- and interlinkages, to capture the possible trajectories of co-evolution. By focusing on the installed base we have drawn the attention to the inherent and conserving parts of the II related to investments in technology, organizational structures, understanding of design and implementation as well as user preferences and practices.

We argue that co-evolution provides an appropriate framework to study how interrelated information infrastructures evolve by providing a perspective where the process of co-evolution is analytically open for many different trajectories, some towards convergence while others may have a more diverging character.

Notes

1. Co-evolution was first used in biology to describe exertion of mutual selective pressure between different species in their evolution. It have also been applied in science and technology studies, for an overview see (Geels 2004).
2. Interestingly, the very first provision of WLAN outside a traditional LAN environment (a so called hotspot) was at Park Hotel Halden (August 2000) situated in the small city Halden south of Oslo, Norway.
3. For more information see for example http://www.umts-forum.org and http://www.imt-2000.org/portal/index.asp.
4. For more information see for example http://www.wi-fi.org.
5. A service is understood as a functionality that is generic, or common to many applications, as, e.g., data transportation, while an application as a collection of functionality of value to an end-user.
6. An alternative selection strategy in other European countries has been auctions, where the highest bids have been the criteria for selecting among the candidates.
7. German licensees have paid approx. 50 billion €, correspondingly 38 billion € in the UK.

8. General Packet Radio Service (GPRS) is an enhancement of GSM providing up to approx 115 kbit/s of bandwidth.
9. Enhanced Data for Global Evolution (EDGE) is a more advanced enhancement of GSM, providing up to 384 kbit/s.
10. Telecom statistics, Half-year 2004, Norwegian Post and Telecommunication Authority.
11. WAP - Wireless Access Protocol, allowing for efficient transmission of optimized Internet content to mobile phones.

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