Evolution of wireless access provisioning:
A systems thinking approach

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Abstract

In this paper we examine the evolution and dynamics of value systems around GSM based mobile communications and Wi-Fi based wireless local area access. Drawing basis from value system modeling and systems thinking research a holistic framework, describing the underlying structure and dynamics of a value system at different stages and levels of service production, is created and used retrospectively to model the evolution of GSM based mobile communications and Wi-Fi based wireless local area access. The analysis based on the framework highlights that an important factor in the wide spread diffusion of GSM and Wi-Fi has been the structural fit of the business and technology architectures as well as the alignment and synchronization of the different stages of service production and markets. The analysis also shows how the value systems around GSM and Wi-Fi follow distinctly different dynamics and evolution paths and how they are on a colliding course.

Keywords – technology evolution, value system, wireless communications, systems thinking

1 Introduction

Wireless and mobile communications have developed rapidly during the last few decades and have made a significant contribution to society. When it comes to wireless access provisioning we have witnessed two megatrends in the recent years: the diffusion of mobile communications where the GSM family of technologies (Hillebrand, 2002) have become dominant, and the wide spread of wireless local area access and networking solutions, spearheaded by IEEE 802.11 based Wi-Fi certified technologies (Lemstra, Hayes et al., 2010). GSM family of technologies have currently an over 80 % global market share of all mobile communications with over 5 billion subscribers worldwide, and GSM networks currently cover more than 80% of the world's population[1]. Wi-Fi on the other hand is already used by over 700 million people globally with roughly 800 million new Wi-Fi devices being sold every year[2].

Although these technologies and services have had a great deal of stand-alone value, their wide spread diffusion has required a large degree of coordination between different actors (Lemstra, Anker et al., 2011) that has in turn been a major contributor to their overall value. Fueled by such co-ordination mobile communications for example has evolved from a set of national monopoly operators using incompatible technologies to a globally harmonized GSM value system with standardized technical interfaces enabling multi-vendor solutions, end-user device ownership and network selection, mobile operator competition in terms of price and service quality and international roaming. Such co-ordination has also driven wireless local area access provisioning from a set of fragmented technologies to a global value system of IEEE 802.11 based Wi-Fi certified equipment with large international device circulation and economies of scale, facilitating wireless access to the Internet in private households and enterprises globally. Although these value systems have followed different evolution paths it can be argued that their wide spread diffusion has been, to a large degree, a result of the collaboration, alignment and synchronization of a large set of different business actors and technologies.

In order to understand the underlying reasons for this wide spread diffusion, a broad understanding of all interdependent entities and the corresponding underlying structure is needed. A holistic view can, for example, be attained using different forms of value system modeling (Porter, 1985), i.e. expanding from modeling single economic actors individually to modeling how they work together to co-produce value. This approach can be further expanded by examining the relationship of technology and business architectures and by studying the evolution of value systems with cycle theories. On a more theoretical level, systems thinking principles can be applied, which study how things are linked to each other and how they influence one another within a whole (Sterman, 2000; Strogatz, 2001).

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[1] GSM Association (http://www.gsm.org/ , accessed on 25th of May, 2012).

[2] Wi-Fi Alliance (http://www.wi-fi.org/ , accessed on 25th of May, 2012).

The purpose of this article is to examine the evolution and dynamics of value systems around GSM based mobile communications and Wi-Fi based wireless local area access and to gain more understanding on what kind of structures have given rise to their wide spread diffusion. We do this by first reviewing prior value system modeling and system thinking research and methods and then combining them into one holistic framework. The framework is then applied retrospectively to the evolution of value systems around GSM based mobile communications and Wi-Fi based wireless local area access.

The structure of the article is as follows. In Section 2 we will go over the theoretical background. In Section 3 we will introduce the framework. In Section 4 we will provide a short historical overview of the evolution of GSM and Wi-Fi and apply the framework to both evolution tracks. Finally, in Section 5 we will discuss our contributions and draw conclusions.

2 Theoretical background

2.1 Value system modeling

The description of business architectures around products and services has received much research attention. The concept of a value chain, modeling the functionality of a single firm, was introduced by Porter (1985) who also introduced the concept of a value system consisting of several individual companies working together[3]. Later on focus has been put on how roles and relationships are configured among different economic actors and how they work together to co-produce value (Normann and Ramirez, 1993; Allee, 2000; Iansiti and Levien, 2004; Jacobides, Knudsen et al., 2006). Different value creation modes have also been proposed. Stabell and Fjeldstad (1998) present three value creation logics: 1. a long linked technology, where value is created by transforming inputs into products (e.g. network or device equipment; corresponds to Porter's value chain concept), 2. an intensive technology, where value is created by solving unique customer problems (e.g. network planning and deployment), and 3. a mediating technology where value is created by linking customers to each other or to other service providers (e.g. operating a wireless access network).

[3] In this article we will use the word value system to describe both business and technical architectures.

The relationship between business and technology architectures is also of critical importance (Tee and Gawer, 2009). Technology architectures have been discussed e.g. in literature related to platforms (Gawer and Cusumano, 2008) and standardization (Gandal, 2002). Gandal (2002), for example, defines three ways that standards get set in practice: 1. de facto standards, i.e., standards set primarily by the market (often proprietary), 2. voluntary industry agreements, where standards are often jointly developed and 3. standards imposed by national standards bodies or agreed upon by regional or international standards development organizations. With market driven de facto standards there may first be several competing proprietary technologies creating a chaotic and unpredictable situation to the market. However, once a de facto proprietary dominant design emerges the market stabilizes and the corresponding business actor becomes a de facto regulator of its platform (Boudreau, 2008), i.e. a platform leader (Gawer and Cusumano, 2008), and thus the final situation is very similar to mandatory standards imposed by national standards bodies. A combination of design and spontaneous (Lemstra, Anker et al., 2011) or market and committee based standardization is also possible where the role of national governments can be critical as was the case with 1st, 2nd and 3rd generations of cellular radio standardization activities (Funk and Methe, 2001).

More generally, the evolution and change of technology and business architectures has been researched by many scholars and has a long history of theories. Anderson and Tushman (1990) introduced an evolutionary model of technological change where technological breakthrough, or discontinuity, initiates an era of ferment featuring intense technical variation and selection and culminating in the selection of a single dominant design. In the model this is followed by a period of incremental technical progress, which may again be broken by a subsequent technological discontinuity. The model has been extended to describe how products, produced by a value system, evolve in the form of a nested hierarchy of technology cycles (Murmann and Frenken, 2006). Henderson and Clark (1990) discussed four types of technological change: incremental innovation, modular innovation, architectural innovation, and radical innovation. The more radical, disruptive innovation has been further categorized into high-end and low-end disruption (Christensen, 1997).

Fine (2000) introduced a double helix model where the value system follows a cyclical change between a configuration where the business architecture is vertical and the technical architecture is integral, and a configuration where the business architecture is horizontal and the technical architecture is modular. When the value system is vertical and integral, forces of disintegration emerge: e.g. entry of niche competitors and organizational rigidities arising from over extensive vertical integration. On the other hand, when the value system is horizontal and modular, forces of integration emerge: one subsystem becomes the scarce resource in the chain encouraging bundling and proprietary integration with other subsystems. The double helix model has also been applied to model differences in mobile communications markets (Vesa, 2007).

As it relates to technical changes and evolution, network externalities and non-linearity play an important role (Katz, 1985) especially when it comes to the value and diffusion of communications technologies and platforms (Allen, 1988; Schoder, 2000; Eisenmann, Parker et al., 2006). When network externalities are strong small issues can determine the evolution path of an entire industry (Arthur, 1990). Examples of such path dependence emerging from technical interrelatedness range from containerization to the standard gauge used in railway tracks and from right- and left-hand traffic to the seven-day week. Once a dominant design or standard has emerged, the cost of switching become prohibitive, and a lock-in persists until an architectural shift or large external shock renders the dominant design obsolete (Sterman, 2000).

2.2 Systems thinking methods

On a more theoretical level, the relationships in complex systems typically contain feedback loops. Foundations of feedback theory date back to cybernetics and system dynamics which extends cybernetics to computer simulation (Sterman, 2000). In general, feedback structures can be hard to distinguish and prior research has shown that feedback is difficult to understand for policy makers (Sterman, 2000).

The motion of systems can be studied with dynamical systems (Strogatz, 2001) where the possible states of a system can be represented with a mathematical rule in a phase space. A dynamical system can be characterized by an attractor, whose type can roughly be divided into three groups: fixed point, limit cycle and strange attractor. If a system is directed by a fixed point attractor the system remains static and will consist only of negative feedback, much like a damped pendulum. A limit cycle attractor produces periodic regular change where a system has some positive feedback but negative feedback still dominates, much like continuously swinging pendulum. A strange attractor produces deterministic irregular change that is highly sensitive to initial conditions (Lorenz, 1963) and can be seen as functioning on the edge of chaos where positive feedback in the system is stronger than negative feedback. In principle one can also classify a system that has no attractor at all and exhibits complete disorder. Such a non-deterministic system has only positive feedback and no negative feedback to keep it together. The topological structure of the system can also change with a bifurcation (typically modeled with a bifurcation parameter), which can also change the type of the attractor. Dynamical systems theory has found applications in various disciplines ranging from the modeling of oligopolies in economics (Chiarella and Khomin, 1996) and formulation of business strategies (Fowler, 2003) to organizational psychology (Losada and Heaphy, 2004) and government regulations (Longstaff, 2003).

The interaction of many dynamical systems has also been studied. Strogatz (2001) examined the structure and dynamics of complex networks trying to understand how a very large network of interacting dynamical systems will behave collectively, given their individual dynamics and coupling architecture. If the dynamical system at each node has stable fixed points and no other attractors, the network tends to lock into a static pattern. An equally coupled network of limit-cycle oscillators on the other hand can self-organize itself and become completely synchronized. Furthermore, a network of identical strange attractor nodes can also synchronize their erratic fluctuations, although it requires that the coupling be neither too weak nor too strong. Dynamical systems with no attractor can be seen as producing random graphs.

Recently much research focus regarding complex networks has been put on the emergence of scaling in random networks and the formation of scale-free networks. Scale-free networks are networks that contain a small number of highly connected hubs and tend to follow a power-law distribution (Barabási and Bonabeau, 2003). Random networks have a tendency to follow a normal Gaussian distribution and to consist of nodes with randomly placed connections. Examples of scale-free networks are the network formed by airline connections (as opposed to the road network which is randomly distributed), the world wide web (Barabási and Bonabeau, 2003) and the Internet router infrastructure (Faloutsos, Faloutsos, et al., 1999) (although some debate about the issue is still ongoing (Willinger, Alderson et al., 2009)).

A power-law distribution has also been used to describe new business models where products and services are produced by the crowds in a decentralized manner. This sort of a long tail distribution of services and service producer’s results when the tools of production and distribution are democratized and supply and demand is connected (Anderson, 2008). These long tail models rely on the removal of artificial scarcity and on abundant resources for production and distribution. Scarcity in resources for production and distribution, on the other hand, produces a truncated long tail distribution, i.e. a power-law degree distribution with exponential cutoff.

Complex networks grow through a method of preferential attachment. In a scale-free network the mechanism of preferential attachment tends to be linear meaning that a new node is twice as likely to link to an existing node that has twice as many connections as its neighbor. Faster than linear (non-linear) preferential attachment on the other hand leads to "winner takes all" scenarios where the network eventually assumes a star topology with a central hub (Barabási and Bonabeau, 2003).

Complex dynamic networks are often characterized as complex adaptive systems (CAS) that have a large number of interacting and learning agents (Holland, 2006). Such decentralized systems are quick to adapt to new circumstances, and are constantly evolving and unfolding over time. While the interacting agents are governed by simple rules their aggregate activity is highly complex and non-linear and typically exhibits hierarchical self-organization (Arthur, 1999). The Internet, for example, resembles a large scale complex (adaptive) system (Park and Willinger, 2005).

3 Value system modeling framework

In this section the above reviewed concepts are combined to a holistic framework that can be used to model the underlying structure and dynamics of value systems. Here, a value system is modeled as a network of interconnected and layered subsystems where each subsystem represents a given stage of service production (e.g. mobile network operation or device manufacturing) both on a technical and business level. The framework also describes four states a subsystem can take, the corresponding underlying dynamics and the transition dynamics between the subsystem states.

3.1 Four subsystem states

An individual subsystem consists of a group of actors collaborating and competing with each other in a given stage of service production in the value system. The subsystem can be in four states[4] following the above described attractor distributions: fixed point, limit cycle, strange and no attractor. The characteristics of the four subsystem states are summarized in
Table 1 and Figure 1.

[4] The internal structure of the actors is not modeled but it is assumed that it is aligned with the dynamics of the subsystem it is part of.

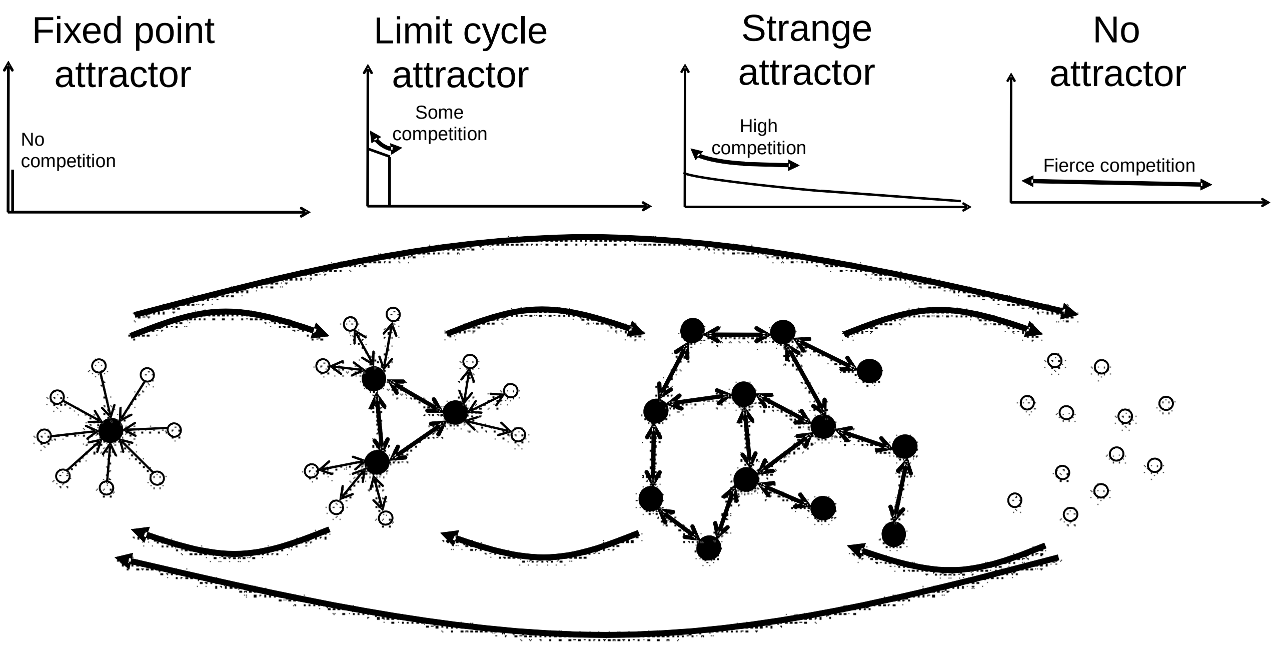
Table 1. Characteristics of four subsystem states

Attractor	Fixed point	Limit cycle	Strange	No
Degree of centralization	Fully centralized	Semi centralized	Decentralized, self-centralized	Decentralized
Degree of openness	Closed subsystem	Partially open subsystem	Open subsystem	Separate closed actors only
Switching costs	High (lock-in)	Moderate	Low	None
Availability of tools for service production	Controlled by a single entity	Controlled by (or licensed to) a few	Democratized and used by all for all	Democratized but used by all for self only
Actor interaction	One actor directs the subsystem	Few actors co-operating and competing	Many actors co-operating and competing	Many (isolated) actors competing
Degree of planning	Fully designed and optimized	Moderate planning	Emergence, limited planning	No planning
Rules	Many rules, centrally optimized	Medium set of global rules	Few simple local rules	No rules
Speed of adaptation	Very slow or no adaptation	Medium, cyclical	Fast	Random
Coupling	Static coupling	Harmonized, tight coupling	Heterogeneous, loose coupling	No coupling
Scalability	Limited	Somewhat limited	Unlimited	None (local, isolated)
Complex network	Fixed point node network	Limit cycle node network	Strange attractor node network	Random/isolated network
Feedback structure	Only negative feedback	More negative feedback than positive	More positive feedback than negative	Only positive feedback

A stage of service production following the dynamics of a *fixed point attractor* can be characterized as a fully centralized and closed subsystem. Such a subsystem is directed by one actor who controls the tools for service production and distribution (e.g. capital, labor, infrastructure, usage rights for spectrum and intellectual property etc.) resulting in an impulse distribution in terms of value creating actors. The subsystem is centrally optimized and thus has many rules and is slow to adapt to changes coming from outside. The growth model follows a faster than linear (non-linear exponential) preferential attachment (Barabási and Bonabeau, 2003) with static coupling, high switching costs and “winner takes all” dynamics. If other fixed point subsystems up and downstream of the overall value system become synchronized, the value system tends to lock into a static pattern (Strogatz, 2001) and remains limited in terms of scalability.

A stage of service production following the dynamics of a *limit cycle attractor* can be characterized as a semi centralized and partly open subsystem. Such a subsystem features a limited set of actors co-operating and competing (e.g. oligopolistic competition between large mobile operators). Tools of service production are controlled by (or licensed to) a few resulting in a truncated power law distribution in terms of value creating actors where moderate planning is conducted and rules are formulated to some degree. The subsystem cyclically adapts to find the best fit with the environment thus following an incremental innovation type of evolution pattern (Anderson and Tushman, 1990). The growth model follows a preferential attachment process, where the selected few partner tightly with each other resulting in moderate switching costs. An equally coupled network of limit-cycle subsystems has a tendency to self-organize itself and become completely synchronized up and downstream the value system (Strogatz, 2001) leading to rather good scalability.

Figure 1. Dynamics of each subsystem state and transitions between the subsystem states (In the value distribution figures the x-axis depicts the value creating actors in order of popularity and the y-axis their popularity)



A stage of service production following the dynamics of a *strange attractor* can be characterized as a decentralized but typically self-centralized subsystem where actors are open to each other. Such a subsystem features a large set of actors co-operating and competing where tools of service production and distribution are democratized and used by all for all (Anderson, 2006) resulting in a power law distribution in terms of value creating actors. Planning is limited and most of the structure emerges on its own as a result of a few simple and local rules. The subsystem is a complex adaptive system which is able to quickly adapt to changes and constantly, but irregularly, re-organizes itself to find the best fit with the environment following an era of ferment type of evolution pattern (Anderson and Tushman, 1990). The growth model is linear preferential attachment (Barabási and Bonabeau, 2003), with loose coupling and low switching costs. A loosely coupled network of strange attractor subsystems can synchronize up and downstream the value system (Strogatz, 2001) leading to unlimited scalability.

Finally, a stage of service production following the dynamics of a *no attractor* distribution can be characterized as a decentralized set of actors which are closed to each other and the subsystem level itself does not have any structure. Such a subsystem features a large set of isolated actors competing with each other with minimum or no collaboration (e.g. private Wi-Fi deployments). Tools of service production and distribution are democratized but are used only for self, resulting in a normal (Gaussian) distribution in terms of value creating actors. There is no planning or rules and the speed of adaptation is too fast and the switching costs are too low for any permanent structure to emerge. The growth model is random attachment (Barabási and Bonabeau, 2003) and the subsystem remains local and isolated and cannot scale itself up leading to an isolated (random) network.

Overall, as depicted in Figure 1 a subsystem at a particular stage of service production can transition from one state to another much like a bifurcation can occur in dynamical systems. In a *no attractor* subsystem state, competition is fierce and there is no possibility for any of the actors to get sufficiently ahead so that structure could emerge meaning that there is essentially only positive feedback in the subsystem, as discussed in section 2.2. In a *strange attractor* subsystem state competitive activity is high and positive feedback in the subsystem dominates but there is enough negative feedback to keep the subsystem together and for structure to emerge. In a *limit cycle* subsystem state competition slows down and negative feedback in the subsystem starts to dominate, but there is still some positive feedback to keep the system moving. In a *fixed point* attractor subsystem all resources accumulate to one actor, competition stops and the subsystem becomes governed by only negative feedback.

A subsystem transition can come from within the subsystem, e.g. if the strength of preferential attachment changes, or it can come through synchronization or alignment with other subsystems, e.g. adjacent stages in the value system, nearby markets or architectural levels or from other external forces. For example, causes for convergence can come from industry consolidation or dominant design selection and for divergence from a technological discontinuity or regulatory actions (e.g. democratization of the allocation process of resources or a re-division of the market). When observed on a larger time scale, the transitions form a cyclical process where the value system revolves around a centralized and decentralized structure (Anderson and Tushman, 1990; Fine, 2000).

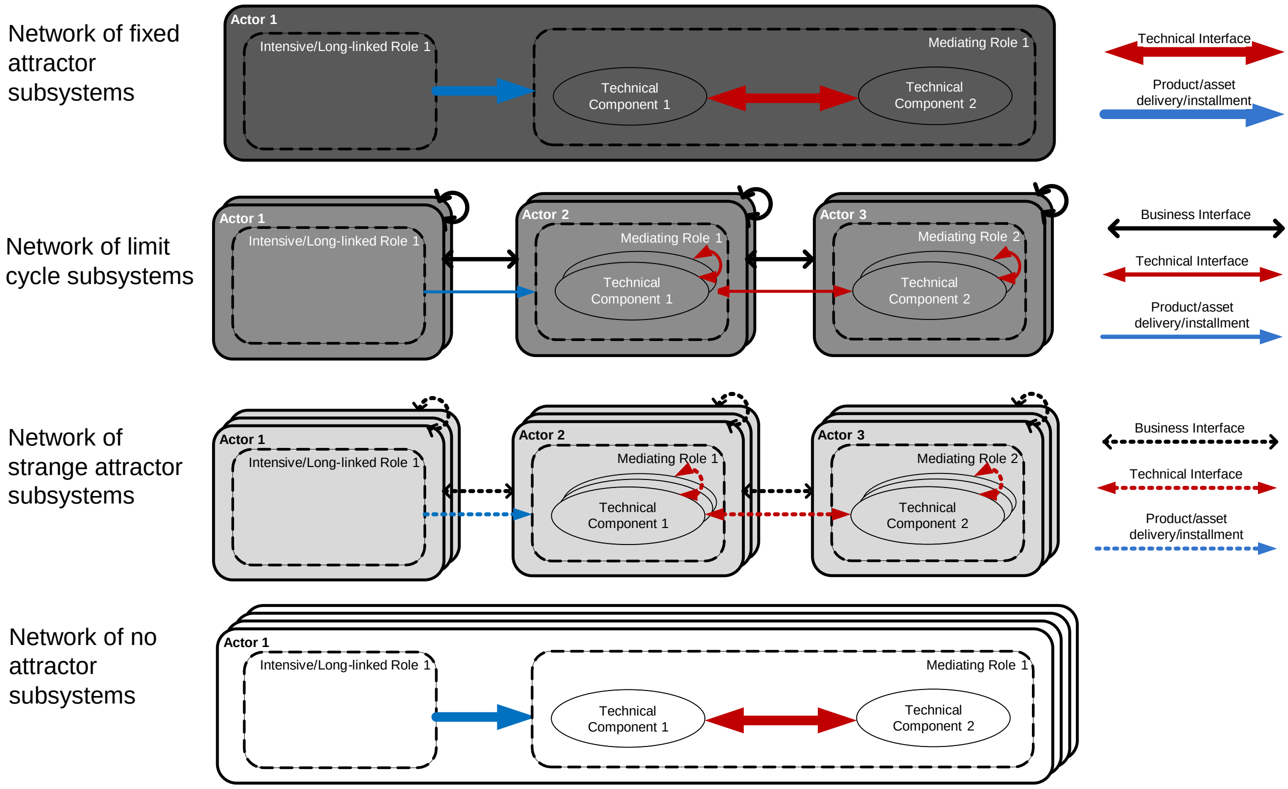
3.2 Value system representation

The value system as a whole consists of many subsystems, i.e. different stages of service production having both technical and business architectural levels. The notation methodology depicted in
As defined in **Figure 2 in a value system consisting** of a synchronized network of subsystems following fixed attractor dynamics all business roles and technical components are controlled by one business actor. Correspondingly under limit cycle dynamics, a few actors and technical components are tightly coupled and under strange attractor dynamics, many actors and technical components are loosely coupled to each other. In a value system consisting of subsystems following no attractor dynamics, actors and technical components are isolated from each other but can have a fixed attractor structure nested into them.

Figure 2 describes the value system as a set of interconnected technical components, business roles and actors and distinguishes between the three value creation logics defined by Stabell and Fjelstad (1998). Interfaces exist both on the level of a technical and business architecture and system states are also depicted on both levels.

As defined in Figure 2 in a value system consisting of a synchronized network of subsystems following fixed attractor dynamics all business roles and technical components are controlled by one business actor. Correspondingly under limit cycle dynamics, a few actors and technical components are tightly coupled and under strange attractor dynamics, many actors and technical components are loosely coupled to each other. In a value system consisting of subsystems following no attractor dynamics, actors and technical components are isolated from each other but can have a fixed attractor structure nested into them.

Figure 2. Value system notation depicting 1) a network of fixed attractor subsystems dominated by one actor and integrated technical components, 2) a network of limit cycle subsystems with few tightly coupled actors and technical components, 3) a network of strange attractor subsystems with many loosely coupled actors and technical components, and 4) a network of no attractor subsystems with isolated actors and technical components[5]



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[5] The notation methodology builds on the elementary notation presented in (Heikkinen, Casey et al., 2010) and (Casey, Smura et al., 2010) which describes only the static structure of a value system. Overall these value systems correspond to the concept of a synchronized network of nodes following a certain attractor dynamics as discussed by Strogatz (2001), i.e. the terms subsystem and node are interchangeable.

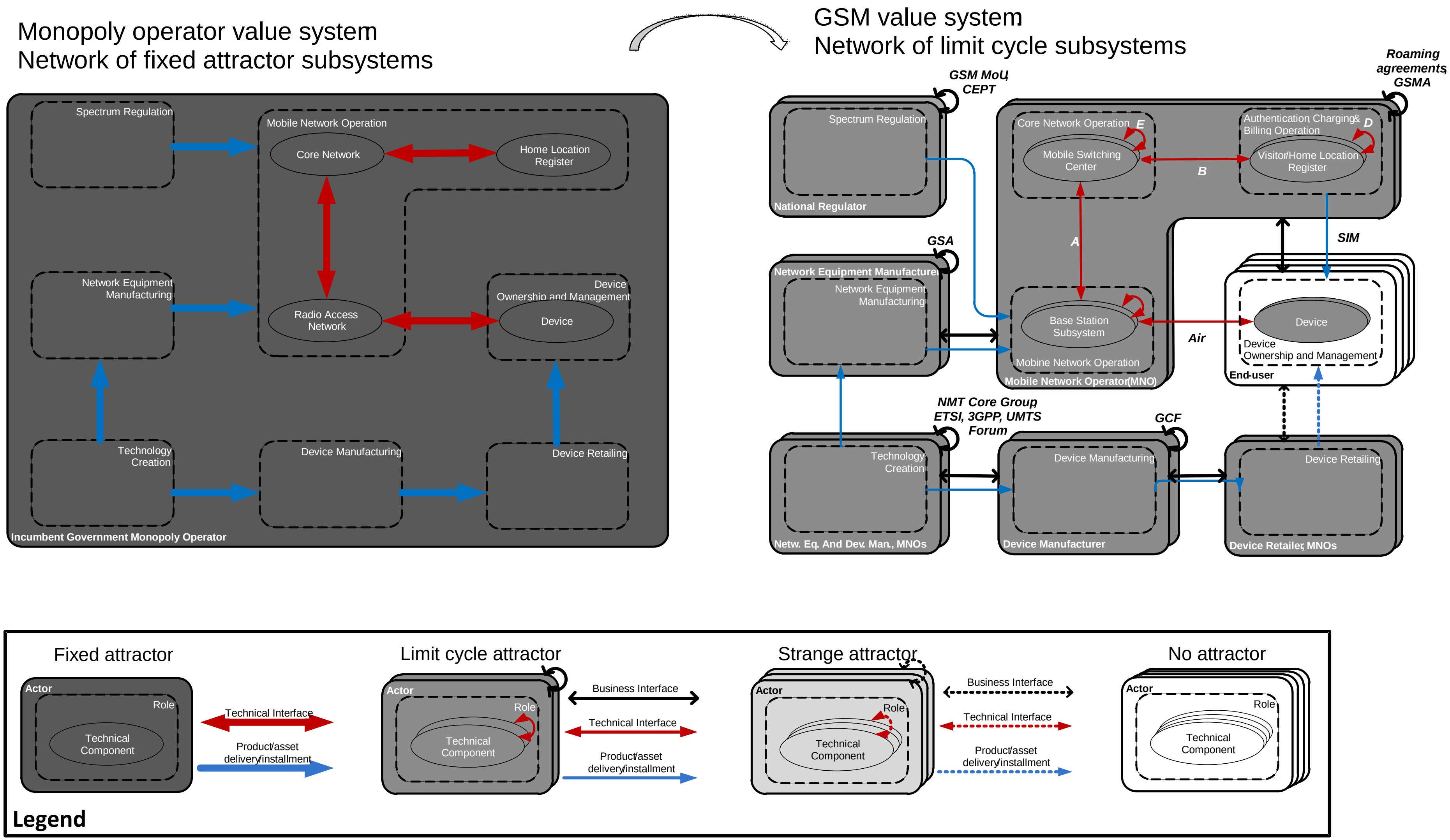
4 Systems thinking view of the evolution of GSM and Wi-Fi

In this section we will retrospectively apply the created framework to the evolution of GSM based mobile communications and Wi-Fi based wireless local area access. We will draw basis for both from prior research related to the topic areas and from 18 semi-structured expert interviews including representatives of device and network equipment vendors, mobile operators, regulators and academia.

4.1 Evolution of GSM based mobile communications

The roots for cellular mobile communications can be traced back to 1947 when Bell Labs introduced the concept of cellular networks to resolve capacity constraints of mobile systems through the geographical re-use of frequencies (Manninen, 2002). The technology became more widely available in the 1970-1980s where in most markets cellular networks were typically operated by government monopolies that centrally controlled the entire value system. Thus the value system and its characteristics followed a fixed attractor type of dynamics from spectrum licensing to mobile network operation and from device retailing to the ownership of the equipment as depicted in Figure 3. The only technically open or semi-open interface was the air interface, which in practise was closed by the subscription rules and thus there rarely was any compatibility or possibility of roaming between national systems (e.g. at one point in time Europe alone had over 20 different systems (Manninen, 2002)).

Figure 3. Evolution of NMT and GSM based mobile communications as a transition from a network of fixed attractor subsystems to a synchronized network of limit cycle subsystems (technical interfaces modified from GSM specifications)



In the 1970s the Nordic countries, who had a history of promoting open exchange of capital, products and services, and ideas (Steinbock, 2003), began to transition from a network of fixed attractor subsystems to a network of limit cycle subsystems (see Figure 3 and Table 2) by starting the development of a pan-Nordic first generation mobile network that would ensure interoperability and roaming between national networks[6]. Compatibility in the system standardized by the NMT Core Group came through tightly coupled but open interfaces that enabled a more modular architecture where operators could use multi-vendor solutions in their networks. This meant that a small group of network vendors could openly compete and offer their products in all NMT markets (i.e. network equipment manufacturing subsystem transitioned to follow the limit cycle dynamics). Furthermore device ownership was given to the end-users and sales was liberalized which promoted competition between device vendors. These changes had far-reaching consequences for the development of the Nordic manufacturers (Manninen, 2002).

Subsequently, although the Nordic operators still sustained a monopoly position, NMT started to diffuse rather quickly in the Nordic countries (see Figure 4). NMT was also deployed in the Netherlands but without device liberalization and it was observed that when network capacity problems emerged, growth stopped whereas in the Nordic countries, retailers worked as an efficient proxy between the end-users and operators and thus expansion was driven by the market[7] (Karlsson and Lugn, 2010) (see Figure 4).

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[6] For an extensive study of the development of NMT and GSM standards the reader can refer to Manninen (2002) and Hillebrand (2002).

[7] This can be seen as an indication of the better scalability of the limit attractor node network when compared to the fixed attractor node network.

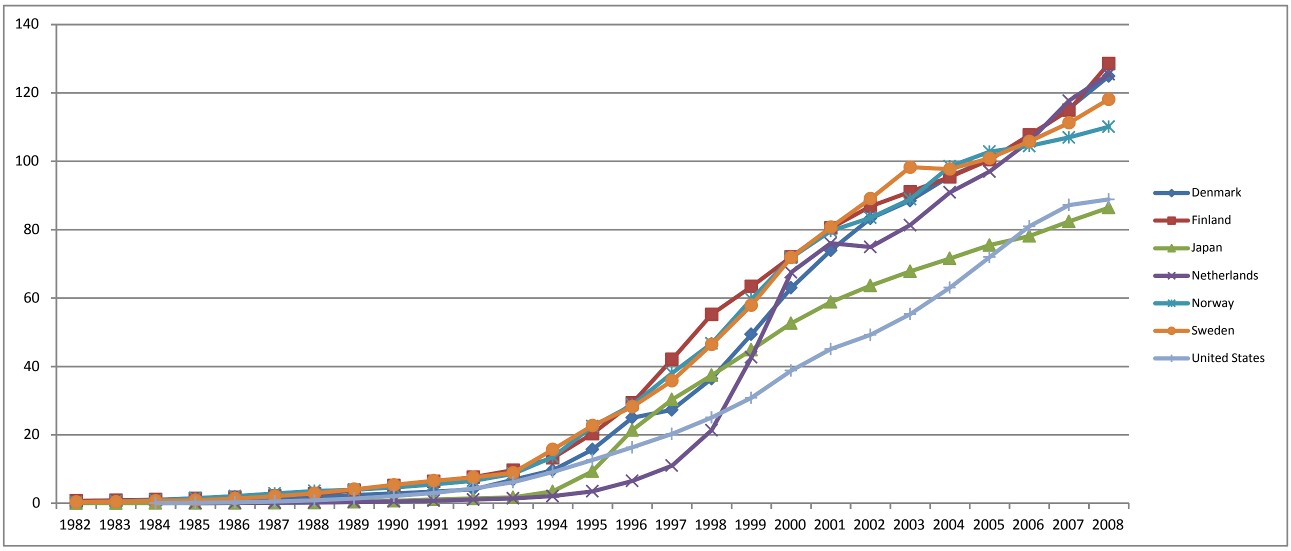
Table 2. Subsystem transitions in the evolution of NMT and GSM based mobile communications

Subsystem	**Old state: Fixed point**	**New state: Limit cycle**
Technology creation based on service requirements	Created solely by government operator	Nordic countries: Launch of NMT service in 1981 Europe: Launch of GSM service in 1992 in Europe and consecutive launches of 3G and 4G in 2002 and 2012 respectively. Cyclical standardization process with strong pan-European and later global requirement of voice and sms full interoperability and compatibility.
Network equipment manufacturing	Dedicated vendor(s) for government operator	Multi-vendor solutions, open competition between network vendors in NMT and increasingly open competition with more open interfaces in GSM
Mobile network operation (covers access and core network elements and registers)	Government operator controlled	National and international competition in GSM. GSM MoU (1987), GSMA Roaming agreements for voice 1992 onwards and SMS 1994 onwards, SIM-cards, multi-operator market, virtual operators.
Device manufacturing	Dedicated vendors for government operator	Open competition between independent device vendors started with NMT, liberalized type approval for GSM.
Device retailing	Government operator controlled	Liberalized, but operators remain a strong retail channel.
Device ownership and management	Government operator controlled, devices only leased to consumers	End-user controlled (no attractor dynamics on actor level), in many markets significant number of features controlled by the retail channel, especially operators.
Spectrum regulation	Government operator controlled	Harmonized regulation with strong national interest. Gradually going towards increasingly liberal concepts in LTE (4G) and beyond.

At the same time a shift from analogue to digital technologies was ongoing and second generation digital mobile systems were being standardized. In response to the technology fragmentation an idea of a harmonized pan-European mobile network had risen in the early 1980s. Subsequently Europe decided to create a common second generation standard that would be deployed throughout Europe. The NMT market and technology provided a good basis for the introduction of open interfaces and other critical functionality such as the SIM-card and roaming that demanded interoperability and enabled multi-vendor and multi-operator solutions. The European Conference of Postal and Telecommunications Administrations (CEPT) formed Groupe Spécial Mobile (GSM) to develop the standard, the responsibility of which was later transferred to the European

Telecommunications Standards Institute (ETSI), which enabled also equal participation and fully open contribution from manufacturers and any members of ETSI rather than just the administrations of CEPT countries. Drafting of the GSM specifications and its subsequent versions continued with the cyclical open process following the model set by NMT standardization and further expanding the limit cycle network (see Figure 3)[8].

Figure 4. Number of mobile cellular subscriptions per 100 people (1982-2008) (Data source: World Bank)



The culmination of harmonized technology and spectrum policy in Europe came on 7th of September 1987 when 15 operators from 13 countries signed the GSM Memorandum of Understanding (MoU) stating that they would deploy GSM on the 900 MHz spectrum band (Hillebrand, 2002). GSM MoU later on evolved to GSM Association (GSMA), a group of GSM operators and their suppliers and other partners supporting the deployment and promotion of GSM. Several other similar associations have subsequently emerged around the 1987 GSM MoU to support the limit cycle characteristics of the GSM system (e.g. Global Mobile Suppliers Association (GSA), Global Certification Forum (GCF), UMTS Forum, and the Next Generation Mobile Network Alliance (NGMN)).

The 1980s was the era of deregulation where governments, especially led by actions in the U.S. and U.K., started to gradually liberalize their national telecommunication regulation. Driven by

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[8] Later on a major infusion of new companies took place when the 3GPP (3rd generation Partnership Program) was set up. The first full year of 3GPP standardization reflects the evolution from GSM where a small group of actors had a strong position (see Figure 5).

increasing pressure from the technical and business communities for a more liberal and decentralized structure, national monopolies were broken down around the world, by clearly separating the regulation and network operation activities to two different entities. In Europe competition was mandated by multiple spectrum licenses in each country and the multi-operator approach that GSM enabled was well aligned with this. Subsequently the regulators of European countries pursued a licensing policy that combined technology harmonization and market competition[9]. Thus the limit cycle type of dynamics expanded to mobile network operation stage of service production in the value system (see Figure 3), with a transition from a monopoly to cyclical oligopoly type of competition between the mobile operators. A critical element, that has enabled the limit cycle dynamics, has been the policy of licensing spectrum only to a limited number of operators while ensuring that resources do not accumulate to one operator and that competition exists. At the same time, pressure to provide pan-European voice service forced the services and network functionalities to be fully interoperable and compatible from end user's as well as from technology suppliers' perspective.

New entrants were especially eager to deploy GSM, whereas for incumbent monopoly operators the change was less welcomed and slower due to the needed migration away from their own systems towards new technologies and behaviors. GSM based mobile voice was accompanied with a Short Message Service which, after some delay, started to also follow the limit cycle dynamics as operators interconnected their SMS networks. This in turn further motivated the formation of roaming agreements between operators.

The tightly coupled but open technical architecture of the GSM system provided a ground for potential regulatory actions to promote competition such as structural separation, prohibiting SIM-card bundling and enforcing mobile number portability which subsequently led to the entrance of mobile virtual network operators (MVNO) and mobile service providers (MSP) in many markets. SIM-cards have also enabled a wide adoption of pre-paid subscriptions that in turn has had a crucial role in the diffusion of mobile communications in developing countries. As the rest of the market in Europe synchronized with the limit cycle subsystem network, markets that were falling behind the Nordic countries in terms of diffusion quickly caught up (see e.g. Netherlands Figure 4).

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[9] This has been later found to be a critical combination for fast diffusion of mobile communications (Rouvinen, 2006).

As opposed to the harmonization approach enforced in Europe, policies e.g. in the U.S. and Japan have been less favorable to harmonization in the wireless communications. The U.S. for example relied heavily on promoting technology competition (i.e. no attractor dynamics), which in turn made interoperability between networks challenging. It can be seen that this created a misalignment in the value system (i.e. with other subsystems working on with the limit cycle dynamics) that prevented the system to synchronize and scale to the same degree as it did in countries where GSM was solely deployed according to its original system model. Technology competition reduced the liquidity of the market and the possibility for end-users, whose devices are locked to one mobile operator's network, to respond to market based competition which in turn has slowed down competition and led to lower diffusion rates (Jang, Dai et al., 2005) (see also Figure 4).

The alignment and good scalability of a network of limit cycle subsystems could also be seen globally in the growth and expansion of GSM MoU (which later became GSM Association (GSMA)) that gradually started expanding outside of Europe and went on from having 32 networks in 18 countries in 1993 to nearly 200 operators in nearly 100 countries in 1996 to exceeding the 200-country barrier in 2003[10] [11]. Also, as capacity became limited GSM was deployed on the newly allocated 1800 MHz band (an effort that began in the UK) leading to many new entrant operators deploying local city networks in many markets. GSM900 and GSM1800 operated as isolated networks until dual band devices were introduced in the late 1990s. Globally, with the exception of Japan, South Korea and the American markets, the regulatory policy of assigning GSM on 900 and 1800 MHz bands has diffused to most of the world. The North and South American markets gradually joined the limit cycle network as a GSM band-variant was deployed on the 850 MHz and 1900 MHz spectrum bands. Subsequently a GSM quad-band chip (850/900/1800/1900 MHz) has become a standard feature in many handsets globally. All in all, the evolution of NMT and GSM based mobile communications can be summarized as a transition from a network of fixed attractor subsystems to a synchronized network of limit cycle subsystems as depicted in Figure 3 and Table 2.

[10] http://www.gsma.org/ (accessed on 25th of May, 2012).

[11] The main rival of GSM based technologies, CDMA has been heavily dominated by Qualcomm and has scaled less efficiently worldwide. For example in 2004 when the worldwide subscriber base for GSM exceeded 1 billion the worldwide subscriber base of CDMA was 240.2 million.

Furthermore, the global growth of GSM can be seen as an expansion and synchronization of the network of limit cycle subsystems to markets outside of Europe[12].

However, although towards the end of the 1990s, it was clear that the harmonization based model had won (Steinbock, 2003), the GSM based voice and SMS services had reached such large scale that it led to considerable inertia and rigidities which in turn slowed down the diffusion of new innovations. In countries that have been in the forefront of GSM diffusion, this led to the inability of operators to differentiate themselves, to the commoditization of mobile voice and SMS services and in some markets to fierce price competition. Furthermore, for the GSM value system, the introduction of data services has proved challenging and as the adoption of e.g. WAP and 3G based data services has been rather slow, low cost high bandwidth connectivity to the Internet and its rapidly growing applications and contents has recently become the main driver for the deployment of new mobile technologies with e.g. operators refarming GSM spectrum bands for next generation access technologies (e.g. WCDMA on 900 MHz and LTE on 1800 MHz)[13].

As suggested by prior research (Faloutsos, Faloutsos et al., 1999; Barabási and Bonabeau, 2003; Park and Willinger, 2005) the value system around the Internet can be seen as following the dynamics of a network of strange attractor subsystems. The GSM/3G value system has recently shown signs of transitioning towards a strange attractor type of dynamics with e.g. the introduction of flat rate type of pricing but also structurally by migrating towards technologies such as HSPA with a more flat and loosely coupled architecture that have a better compatibility with the Internet. Although connectivity to the Internet has thus far been implemented by simply tunneling it through mobile operator networks, as the move towards fourth generation GSM based mobile technologies with LTE has begun, flat Internet Protocol (IP) based architectures (e.g. SAE) and all-IP services are increasingly endorsed. Furthermore, intelligence is gradually decentralized to the devices, e.g. to smart phones. However, at the same time, the GSM value system is continuing its expansion and

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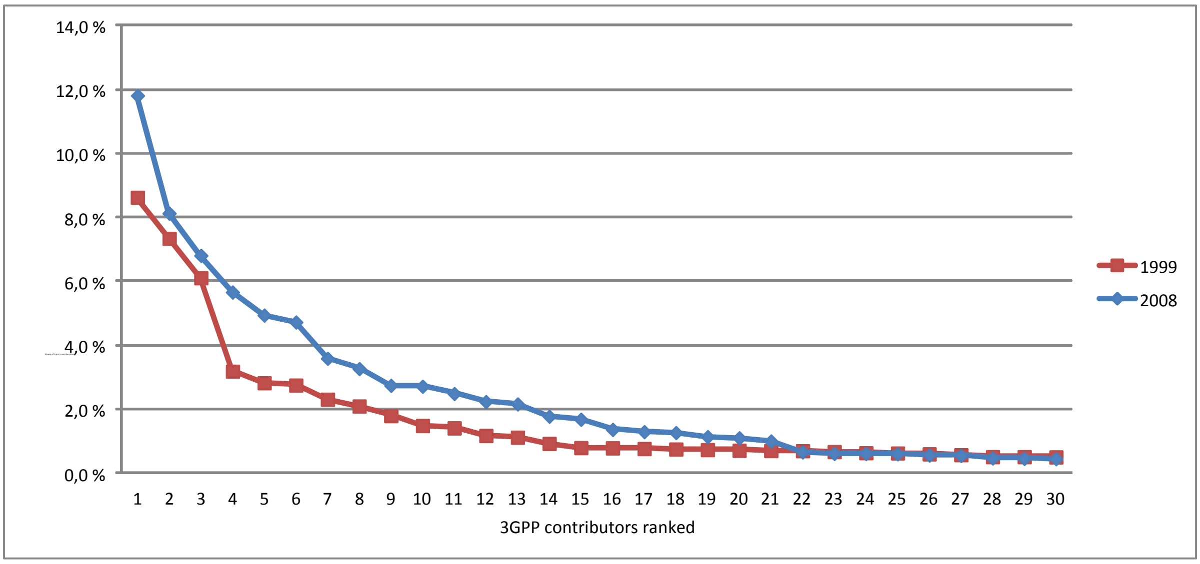
[12] It should be noted that in reality a large value system can consist of subsystems following different dynamics. For example, many markets outside of Europe that have deployed GSM do not follow the limit cycle dynamics (e.g. U.S., India and China).

[13] Currently data usage is growing fast in national networks but similar roaming use for data as what we have seen for voice and SMS has not really taken place. This has caused European commission to push exceptional measures to regulate the price of EU wide data roaming tariffs. The use case for data (client to server) is different from voice (client to client) and does not follow the limit cycle model which has in turn has caused synchronization challenges in the value system.

seems to be winning the global battle for mobile communications radio systems as CDMA operators are also migrating to LTE technologies[14]. It is unclear what will be the resulting dynamics for mobile communications as the original value systems of Internet and GSM collide. All in all, much of the driving power has been shifted to the higher level protocols and applications which are beyond of the scope of this research.

Finally, the standardization environment in the 3GPP is also changing from that of original GSM with a large number of new companies entering the forum and with a substantial increase in the number of contribution documents. Although some of the traditional GSM actors still hold a strong position, some new entrants (mostly Asian actors) have to some degree substituted the incumbents, and as shown in Figure 5 are clearly increasing their share of the contributions.

Figure 5. Share of total annual 3GPP contributions of top 30 contributors in 1999 and 2008 (source: computed based on data from 3GPP)



4.2 Evolution of Wi-Fi based wireless local area access

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[14] In the U.S., the migration to data services has been radically faster after the introduction of nationwide flat rate pricing and will be enhanced by fast migration to LTE/SAE by all major U.S. operators. The disadvantage of non-interoperable networks has been turned around as an advantage of such networks and their suitability for dynamics of data and the Internet.

The roots of wireless local area access can be traced back to the 1940s and to the invention of spread spectrum technology which has become a key physical layer technology for enabling decentralized radio communications (Lemstra, Hayes et al., 2010). Another critical technology milestone was the invention of the ALOHA protocol in the 1970s which provided simple rules for wireless nodes to co-exist and be less greedy on the wireless channel using a carrier sense multiple access with collision avoidance (CSMA/CA) scheme. Prior to wireless local area networking a venue owner culture existed where venue owners had a kind of a local monopoly and could deploy and apply technologies (e.g. private branch exchanges (PBX) and local area networks (LANs)) in a manner that they saw best without concerns about compatibility with other systems or collaboration with other venue owners (i.e. no attractor type of dynamics).

In 1985 in the U.S. the national regulator, FCC, decided to allow the unlicensed use of spread spectrum technologies in the bands designated for industrial, scientific and medical (ISM) applications (Lemstra and Hayes, 2009) which in principle gave a local spectrum license for venue owners to build wireless networks. This new opportunity spurred a vast number of competing technologies and applications that ranged e.g. from wirelessly connecting cash registers to retailing, healthcare, and logistics applications, and from university to enterprise wireless local area networks (Negus and Petrick, 2009). The systems were, however, mostly incompatible and remained isolated from each other thus following the dynamics of a network of no attractor subsystems (see Figure 6 and Table 3).

Figure 6. Evolution of Wi-Fi based wireless local area access as an ongoing transition from a network of no attractor subsystems to a synchronized network of strange attractor subsystems

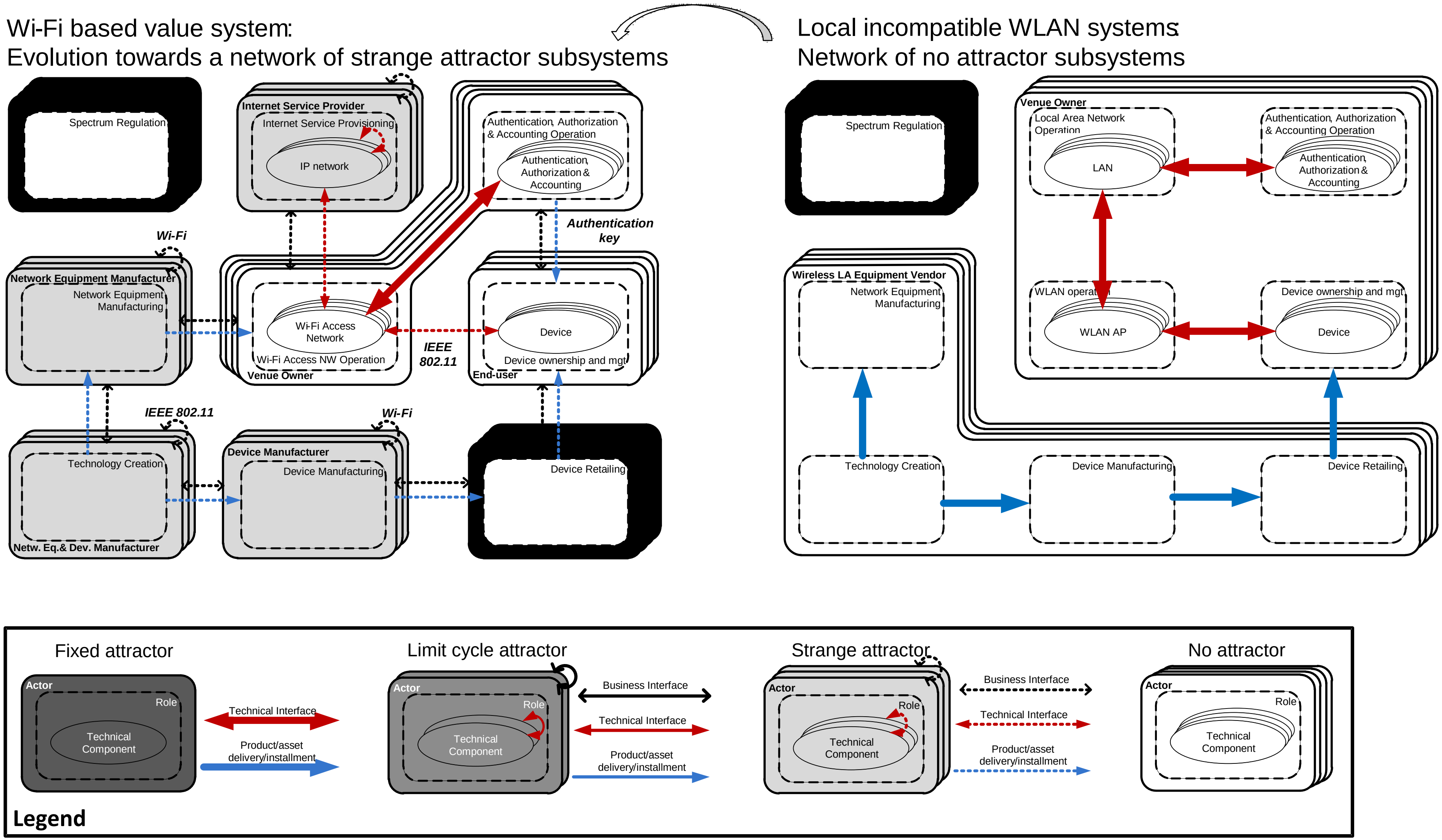


Table 3. Subsystem transitions in the evolution of Wi-Fi based wireless local area access

Subsystem	Old state: no attractor	New state: strange attractor
Technology creation	Proprietary equipment vendor controlled	Large number of stakeholders together creating and standardizing the technology in IEEE 802.11. Core network routing based on IETF standardized IP technologies in most cases.
Network equipment manufacturing	Proprietary equipment vendor controlled	Large number of vendors producing Wi-Fi alliance certified equipment.
Authorization, Authentication & Accounting Operation	Isolated/venue owner controlled	Transition has not happened yet. Some attempts to build authentication based on social communities like FON. On-going standardization effort for Hotspot 2.0 (i.e. Wi-Fi Alliance's Passpoint certification technology).
Local area network operation/Internet service provisioning	Isolated/venue owner controlled	Large number of interconnected Internet service providers.
WLAN/Wi-Fi network operation	Isolated/venue owner controlled	Transition has not happened yet. Various new business models emerging from operator driven to corporate driven networks.
Device manufacturing	Proprietary equipment vendor controlled	Large number of vendors producing Wi-Fi alliance certified equipment. New features introduced competitively.
Device retailing	Proprietary equipment vendor controlled	Several models exist: Devices directly from independent retailers, bundled contracts from Internet service providers, provided by employers/corporates.
Device ownership and management	Isolated/venue owner/end-user controlled	Transition has not happened yet. Typically manual configurations without further co-ordination.
Spectrum regulation	Venue owner controlled	Transition has not happened yet.

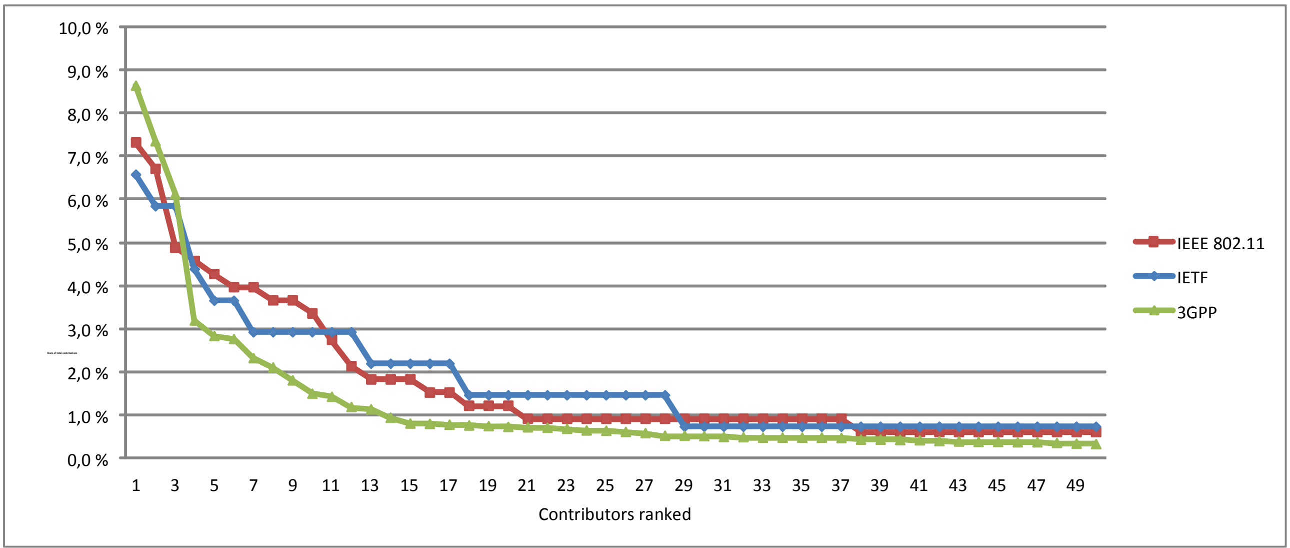
As concerns were raised about incompatibility problems, standardization began in IEEE 802.11 (Lemstra and Hayes, 2009)[15]. This started a transition from a no attractor type of dynamics to a strange attractor type of dynamics, where on the technology creation stage of service production a rather large and heterogeneous set of network equipment manufacturers started collaborating. As opposed to GSM based standardization where standards and interfaces are agreed first and systems

[15] For a more elaborate study of the developments around IEEE 802.11 the reader can refer to Lemstra et al. (2010) and Negus and Petrick (2009).

are implemented based on this, the standardization model following the strange attractor type of dynamics was one where the systems were build first and then standardized and made loosely compatible afterwards based on the emerged application need. Furthermore, as it relates to the standardization of strange attractor systems e.g. by IEEE 802.11 and also by Internet Engineering Task Force (IETF) (which standardizes protocols for the Internet), the range of contributors is wide, with e.g. universities and individual actors having an important role. As depicted in Figure 7, the distribution of the share of contributions by actors in these forums tends to be flatter than e.g. in 3GPP.

FCCs decision to allow spread spectrum technologies in the ISM bands was followed also by regulators in Europe in early 1990s where competing standardization efforts were driven by ETSI with the HIPERLAN standard. HIPERLAN had to compete with a much more mature IEEE 802.11 standard (Lemstra, Hayes et al., 2010) and eventually had only limited diffusion. The standardization model for HIPERLAN can be seen as following a limit cycle type of dynamics since it was standardized by ETSI (which was in charge of GSM standardization), was more complex featuring many functionalities (e.g. quality of service) and in general was more centrally planned (Negus and Petrick, 2009).

Figure 7. Share of total annual contributions of top 50 contributors in IEEE 802.11 (in 2003), in IETF (in 1991) and in 3GPP (in 1999) (source: computed based on data from IEEE, IETF and 3GPP)



Source: computed based on data from IEEE, IETF and 3GPP

While standardization in IEEE 802.11 was proceeding there was still internal fragmentation and with the approval of the IEEE 802.11 standard in 1997 a number of implementation variants were allowed which could in theory lead to two companies claiming to be compliant with the standard even while their products were incompatible (Lemstra, Hayes et al., 2010). The situation forced the leading wireless LAN companies to collaborate and create the Wireless Ethernet Compatibility Alliance (WECA) which was formed around the IEEE 802.11b standard of 1999. WECA, which subsequently became the Wi-Fi Alliance, began operation as a non-profit organization and provided a multi-vendor interoperability certification mechanism for IEEE 802.11b products (Negus and Petrick, 2009)[16] and thus extended the strange attractor dynamics to device and network equipment manufacturing (see Figure 6 and Table 1).

As the deployment and configuration of Wi-Fi access points became easier, Wi-Fi based systems started expanding from enterprises to households where the driving use case was access to the Internet (Negus and Petrick, 2009) (see Figure 8). Thus it can be seen that Wi-Fi started to gradually synchronize with the network of strange attractor subsystems driving the Internet (see Figure 6). As volumes grew the network of strange attractor subsystems expanded to a large group of network equipment, device and chipset manufacturers which started to gradually endorse Wi-Fi (see Figure 8) and it was subsequently integrated deeply into chipsets and became a standard feature in devices[17]. The regulations set out by FCC in 1985 have subsequently spread globally and Wi-Fi alliance certified IEEE 802.11 b/g technologies operating on the 2.4 GHz license-exempt spectrum band have become a standard feature in laptops and high-end mobile phones all over the world.

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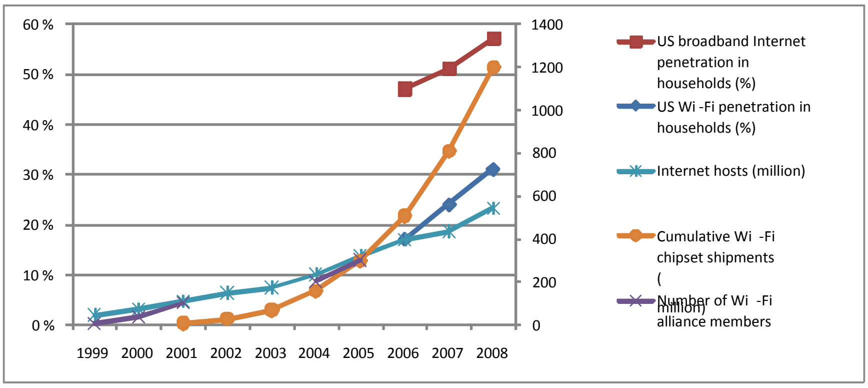
[16] Wi-Fi alliance faced competition from a system based on HomeRF that created a more complex hybrid MAC layer that in addition to data access also enabled quality of service and DECT local cordless phones (Negus and Petrick, 2009). Proponents of HomeRF created the wireless LAN Association (WLANA) which was however heavily dominated one company (Proxim) (Lemstra et al., 2010).

[17] The diversity of devices that have an integrated Wi-Fi chipset has also grown over time and ranges currently from laptops and mobile phones to office equipment and consumer electronics.

Figure 8. Growth of Wi-Fi compared to the growth of the Internet (y-axis on the right depicts the values for Internet hosts, cumulative Wi-Fi chipset shipments and number of Wi-Fi alliance members)



Sources: Wi-Fi alliance (www.wi-fi.org), Internet Systems Consortium (www.isc.org), Technology Policy Institute (http://www.techpolicyinstitute.org/publications/show/23063.html), Morgan Stanley (http://www.morganstanley.com/institutional/techresearch/pdfs/Mobile_Internet_Report_Key_Themes_Final.pdf) (websites accessed on 25th of May, 2012).

Since no co-ordination with external parties (e.g. in terms of spectrum licenses) or neighboring venue owners are needed Wi-Fi has been well aligned with the private deployment model of enterprises and households[18] [19]. On a technical level the simple rules of IEEE 802.11 Medium Access Control (MAC) following the CSMA/CA scheme have enabled the co-existence of access points and even rather dense deployments of isolated access points. Although it has been argued that the MAC protocol does not utilize the spectrum efficiently, it has thus far worked sufficiently well to enable typical Internet access and thus has, on a technical level, enabled the co-existence of millions of devices.

However, scalability of the 802.11 MAC protocol is limited and as the number of devices and the density of access points exceeds a certain limit throughput drops and the unlicensed spectrum band can become highly congested. Additionally, the Wi-Fi certified access points have to co-exist with many types of devices working on the same ISM band (like devices using Bluetooth communications) which can in turn also have a negative effect on throughputs. Although improved capacities are coming with IEEE 802.11n/ac and extensions to 5.8 GHz license-exempt band it can

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[18] For example Morgan Stanley estimates U.S. Wi-Fi household penetration will reach 58 % in 2012.

[19] While household deployments have been based on interoperable Wi-Fi technologies, proprietary solutions have diffused to the enterprise segment, which has been dominated by Cisco.

be argued that a completely decentralized system will not be feasible in the long term and that more co-ordination is needed.

While private Wi-Fi deployments have been a success, public Wi-Fi deployments have remained fragmented (i.e. still follow a no attractor type of dynamics; see Figure 6). Venue owners offering public access have thus far resorted to themselves distributing access keys, to the global credit card network or to leaving the access point unencrypted thus making it available for all[20]. Although some form of best practices for roaming have been defined (e.g. by Wi-Fi alliance and Wireless Broadband Alliance (WBA), a joint collaboration organization of large public Wi-Fi operators) and some open standards also exist (e.g. Linux based openWRT) the roaming solutions have mostly been proprietary and no widely diffused common Wi-Fi roaming solutions exist. Thus, while Wi-Fi has democratized the tools of wireless access service production and distribution the new supply is not meeting all the demand it could due to lack of co-ordination between the access points.

The above suggests that some stages of service production in the value system are still to be synchronized with the strange attractor subsystem network and that a loosely coupled open roaming network could emerge between the millions of households, enterprises and other venue owners acting as isolated Wi-Fi operators. The same goes for spectrum regulations which could evolve from enforcing a policy where a band is allocated and assigned for unlicensed local use to lighter and more flexible licensing schemes where end-users and devices could co-operatively negotiate and share spectrum access rights (i.e. regulations could evolve from almost no regulation towards self-regulation). Thus, all in all, the evolution of Wi-Fi based wireless local area access can be seen as an ongoing transition from a network of no attractor subsystems to a synchronized network of strange attractor subsystems as depicted in Figure 6 and Table 3.

In terms of the relationship between Wi-Fi and mobile networks it has been unclear whether they are complements or substitutes (Lehr and McKnight, 2003; Lemstra and Hayes, 2009). Many interworking solutions between WLAN systems and mobile networks have been specified (e.g. Interworking-wireless LAN (iWLAN)) but none have diffused widely which could be explained with the incompatibility of the limit cycle type of dynamics (followed by GSM based mobile communications) and no attractor (or strange attractor) type of dynamics. The convergence between

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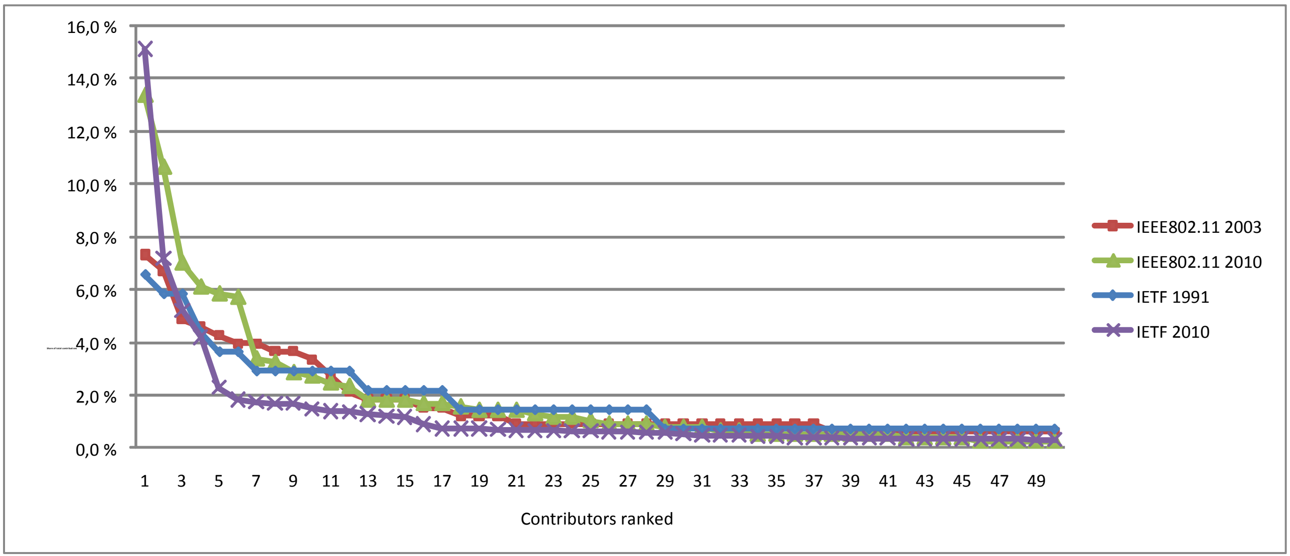
[20] Unencrypted Wi-Fi access points have led to many legal disputes and national legislations regarding the issue is unclear.

the two value systems is, however, gradually starting to occur and is driven mostly by dual model capabilities of devices. For example laptops, which have traditionally used only Wi-Fi access points to wirelessly access the Internet, are gradually starting to use mobile networks and vice versa mobile devices, which have traditionally used only mobile networks for wireless connectivity, are gradually starting to use Wi-Fi access points. Furthermore, mobile operators are increasingly trying to off-load traffic from mobile networks to Wi-Fi access points and on the other hand end-users are increasingly turning their devices into Wi-Fi access points and backhauling the aggregate traffic through the mobile networks.

Furthermore, as shown in Figure 9, a collision can also be observed on the level of technology creation where Internet standardization, by IEEE 802.11 and also IETF, that has thus far followed the strange attractor dynamics, has shown minor signs of consolidation and a possible transition towards limit cycle dynamics (as opposed to the diversification happening in 3GPP as shown in Figure 5).

Figure 9. Share of total annual contributions of top 50 contributors in IEEE 802.11 in 2003 and 2010, and in IETF in 1991 and 2010. Source: computed based on data from IEEE and IETF



Thus, a collision of the network of limit cycle subsystems driving mobile communications and the network of strange attractor subsystems driving the Internet is ongoing. As these value systems, which follow distinctly different dynamics, collide, it is unclear if, how, to what degree and in what part of the technical architecture Wi-Fi and cellular network services will convergence. It is also possible that one of the value systems gains a significantly large role leading to a situation where the other value system becomes a subsystem of the larger one and full synchronization happens. For example recently, GSMA, Wi-Fi Alliance and Wireless Broadband Alliance have started collaboration in order to create a SIM-based solution for Wi-Fi roaming which will be based on Wi-Fi Alliance's Passpoint certification technology which could in turn lead to such convergence and synchronization.

As Internet access seems to be the driving force also in mobile communications, a potential evolution path is one where the decentralization of radio intelligence to the devices continues and the dynamics of the strange attractor node network extend to the level of wireless access provisioning. In such a paradigm the wireless devices would become so called cognitive radios (Lemstra, Anker et al., 2012) and form a complex adaptive system on the level of wireless access provisioning as well as cloud based services on the top of the converging wireless networks.

5 Discussion and Conclusions

In this article we have modeled the evolution and diffusion of GSM and Wi-Fi as a result of the collaboration, alignment and synchronization of a large set of different business actors and technologies. Although the modeling approach has been qualitative we have been able to highlight relevant transitions, alignments and synchronizations in both value systems using concepts from value system modeling and systems thinking literature. What is interesting to note is that the value systems have followed distinctively different evolution paths and underlying dynamics. The value system around mobile communications has gone through a stepwise transition from a centralized national monopoly model characterized by a network of fixed attractor subsystems to a globally harmonized GSM value system characterized by a synchronized network of limit cycle subsystems. The value system around wireless local area access provisioning is, in turn, evolving from a set of fragmented technologies and isolated venue owners characterized by a network of no attractor subsystems to a global value system of IEEE 802.11 based Wi-Fi certified equipment (possibly enhanced by public roaming in the future) characterized by a synchronized network of strange attractor subsystems.

Overall, our analysis highlights the importance of value system alignment, internal structural fit and synchronization. Fast and successful introduction of services is more likely to happen when as many as possible of the relevant factors (depicted in Table 1) and subsystems of the value system are aligned with the same fundamental system behavior (e.g. in the case of GSM, aligning them with limit cycle dynamics). Transitions do happen naturally, but they typically also require external orchestration from policy makers, i.e. change of rules (intervention of the regulator) or introduction of new type of collaboration (e.g. standardization). When orchestrating the overall value system, looking at only one or two of these factors or subsystems is not sufficient.

The introduced framework combines and builds on many concepts from prior research and can for example be seen as extending the concepts introduced by Lemstra et al. (2011) who identified a trade-off between design driven co-ordination where governments play a large role (which would correspond more to fixed and limit cycle type of dynamics) and spontaneous market driven industry co-ordination where entrepreneurial efforts are more important (which would correspond more to strange and no attractor type of dynamics). Overall, the introduced framework can be used by policy makers to model different levels and stages of value systems and to examine the corresponding alignment and internal structural fit. In the future the framework could be developed further especially with quantitative methods that would enable more formal modeling and testing such as agent based modeling, system dynamics, mathematical network theory or statistical analysis.

Finally, as indicated by the analysis, the value systems around GSM based mobile communications and Internet are on a colliding course especially on the level of wireless access provisioning. Thus the framework could be applied to study the future evolution path of wireless access provisioning especially as it relates to the emergence of cognitive radio technologies that reside at the heart of this collision point. This could be realized by studying and modeling both historical and future evolution of the value system in an example market, such as Finland. Furthermore, on a broader level it could be interesting to study how wireless access provisioning intersects with application development and cloud based services.

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