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Era of Mobile Communications – European Systemic Success story

Timo Ali-Vehmas

Executive summary

The European Union is undertaking a concerted effort to revitalize its high-technology sector. Through a series of targeted political decisions, the EU aims to actively foster innovation in areas such as mobile communications, including the pivotal advances to 5G and 6G, artificial intelligence, silicon integration, and quantum computing. These forward-looking decisions are balanced by a comprehensive set of regulations and directives, establishing limitations and controls to ensure that growth is not only robust, but also sustainable and aligned with European values. At first glance, this model appears to strike an ideal equilibrium between driving innovation and safeguarding the public interest, but the true challenges emerge within the underlying details.

This study seeks to explore those critical details, first by examining how system boundaries, market structures, incentives, and policy decisions have shaped the trajectory of public mobile communications from its origins in the 1970s through to the present era of digital connectivity. Europe's early achievements in this field, particularly the success story of the 2G GSM system, reflected a unique alignment: a federated, collaborative operational model that echoed the structure of the European Community itself. This systemic harmony not only spurred rapid, continent-wide adoption but also enabled the system to serve as a global standard. Government regulators, the European Commission, and industry actors, universities and research institutes, all took full advantage of this initial alignment, far exceeding expectations in value creation and technological influence. The momentum was further increased by competition drivers such as a limited number of operating licences and spectrum auctions.

As the sector evolved, the dilution of the coherent systemic strategies gradually led to a fragmented environment. Efforts became scattered, old alliances dissolved, and the "walled garden" of early European leadership gave way to global competition in applications, platforms, and end-user products. This narrative examines that decline and the implications for today’s policy landscape.

Secondly, the evolving data economy presents new, untapped opportunities. In many respects, the data landscape now resembles the telecom monopolies of the 1970s, dominated by a small number of powerful actors. Within the European Union, stringent regulations, designed to protect personal

data, have unintentionally rendered data as scarce and valuable as spectrum once was. The key to unlocking future value will be the sustainable liberalization of this "high-risk" data, especially in applications linked to artificial intelligence and personal information. If managed carefully, this could unleash tremendous economic and social benefits while maintaining the foundational protections for civil rights that distinguish the European approach.

The experience of Europe's mobile communication sector affirms the effectiveness of the federated, regulatory oligopolistic model, where collaboration and competition are balanced under strong institutional guidance. The legal and regulatory foundations for the data economy are already in place, yet they may require targeted adjustments, as highlighted in recent policy reviews. Strategic initiatives should be launched to foster the emergence of data operators, similar to the GSM MoU era of telecommunications. Similar new licensed, federated entities could catalyze new business models in public services, transportation, health services, and education.

Today, most of the necessary technologies are mature or rapidly maturing. What remains is to incentivize commercial and social innovation, build mutual trust among stakeholders, and develop appropriate safety nets for all participants. It is critical to recognize that the loss of European leadership in mobile communications after the initial success could be repeated in the data economy if similar systemic alignment is not achieved and maintained. Prudent, sustained guidance should focus on structuring and defining boundaries, through technology-neutral regulations, without resorting to rigid taxonomies that might stifle innovation.

Furthermore, the policies such as operator licensing and spectrum auctions gave a very strong signal and motivation to market actors. Currently similar drivers have not been established.

Europe stands at the threshold of a renewed era of growth and social progress. However, this potential will only be realized through decisive, well-structured systemic decisions that align market opportunities, policy frameworks, and the evolving expectations of European society.

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This paper has been written in the context of a research project "Mobile is Global" to provide a systemic background knowledge for the project team and other related audience. The views expressed herein are the author's own personal opinions and do not represent earlier employers' views in any way. Nothing shared in this presentation should be considered an official statement or sanctioned by any organization I am or have been affiliated with.

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Era of Mobile Communications – European Systemic Success story

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Abstract

In the final decade of the last millennium, mobile communications became a powerful platform for European industry and consumers. It enabled Europe to create exceptional value and, for a time, to outperform other advanced regions such as the USA and Japan. Yet this wave of prosperity was short-lived, lasting only about 15 years. The next growth cycle took place higher in the system within services and applications, where European leadership quickly gave way to new global players.

This paper examines the systemic dynamics behind these developments. It shows how early choices created strong momentum, but how the failure to adjust systemic parameters in time opened opportunities for new entrants and substitutors. These actors built on Europe's achievements while replacing the original growth factors with their own rules, technologies, products, and services. The paper introduces a framework in which the mobile communications ecosystem is defined by a set of parameters that shape its structure, drive its dynamics, and trigger transitions between generations.

Looking ahead, the paper proposes ideas and models for how Europe might reclaim leadership. The aim is not direct confrontation or zero-sum rivalry ("red ocean"), but rather the reinvention of systemic success at key layers of the ICT architecture. By focusing on services, Europe could unlock new forms of value that remain untapped ("blue ocean"). Particular interest lies in services where labour productivity is lagging and where underused resources such as strongly regulated data could be made accessible in a sustainable way. These domains often align with the "high-risk" services and applications defined in the AI Act.

Such an approach would also affect the lower layers of the system, including the mobile communications platform itself. A winning strategy must therefore address all layers of the systemic architecture and define coherent parameters for each business or well-being domain. By applying a systemic parameter framework across six generations of mobile communications, the paper identifies how Europe can build a new leadership model for the service layer while revitalising the underlying layers.

The intended audience includes policymakers, business leaders, and researchers seeking strategies for sustainable value creation in resource-constrained, not fully harmonised markets.

1. Introduction

Mobile communications systems represent the largest network humanity has ever established, connecting over 5.8 billion unique subscribers[1] in real time across every country on the globe. This vast infrastructure provides a robust platform enabling an array of digital services utilized by individuals, businesses, and public organizations.

This paper aims to offer a systemic narrative that traces the evolution of mobile communication from seemingly isolated developments into a path-dependent process shaped by technological progress, policy decisions, business leadership, and the ingenuity of countless individuals. Adopting a systemic approach requires explicit definitions of the driving forces that set system boundaries as well as attentiveness to how these forces change over time. Internal structures, whether predetermined or emergent, significantly influence the system's dynamic behavior and evolution. Additionally, the distribution of critical and scarce resources, such as capital and spectrum, constrains the system's pace and shapes the competitive power of actors within it (Adner, 2017).

Technological innovation and ongoing development allow mobile communications to transcend previous barriers posed by limited boundaries, rigid structures, and scarce resources. Economic capital, in particular, serves both as the lubricant for system operations and as a measure of the value generated within the network. Human capital was in a significant role in facilitating the winners to take advantage of the systemic transition that required a fundamental mindset change.

Despite the technical nature of systemic modeling and analysis, the process remains inseparable from human action: individuals make decisions, enact changes, and experience the consequences throughout every stage of the system. The intent of this paper is descriptive, not evaluative, acknowledging that the strong path dependency observed in mobile communications typically links present conditions to prior decisions and events.

The origins of mobile communications in Europe were fragmented, with each nation adopting its own policies and technologies, and early services were thus limited in scope. Substantial progress occurred as automatic switching and limited international interoperability emerged in the 1980s and early 1990s, laying the foundation for the first generation (1G) and later the GSM standard (Haug, 2002).

This paper briefly reviews the historical context in which the core principles of modern mobile communications were defined. It then examines how the initiative evolved from vision-driven regional efforts to an internationally coordinated, strategic endeavor. This definition and coordination process took several years, only becoming fully apparent with hindsight, as discussed in Chapter 2. Chapter 3 investigates the systemic architecture of mobile communications, while Chapter 4 reviews generational transitions, highlighting changes in structure and boundary conditions that have shaped system dynamics. Finally, Chapter 5 synthesizes observations to explore how Europe might leverage its position to foster new value-creating ecosystems in the

1GSMA report, The Mobile Economy 2025
https://www.gsma.com/solutions-and-impact/connectivity-for-good/mobile-economy/wp-content/uploads/2025/04/030325-The-Mobile-Economy-2025.pdf

future as discussed in Chapter 6.

2. Vision and setting the scene

In the late 1970s, several advanced countries in Europe, the Far East, and the Americas, introduced early mobile communication services. These networks, often called **zero generation** (0G), essentially provided radio-based access to the fixed telephone network, offering voice calls usually with manual switching. The emergence of **first generation (1G) mobile systems** began with Japan's NTT launching a commercial network in 1979, followed by the Nordic Mobile Telephone (NMT) system in Sweden in 1981 and the Advanced Mobile Phone System (AMPS) in the United States in 1983[2]. The 1980s saw a rapid global expansion of 1G networks, though these systems remained isolated; there was little competition or collaboration across countries. The notable exception was the Nordic NMT system, which pioneered international roaming in the region (Hillebrand, 2013). In Europe, the UK introduced national competition by licensing two mobile operators already in the 1G era.

This period is characterized by the "separated" systemic state of 1G networks: each network was technically and administratively distinct. Meanwhile, in the European Community, growing enthusiasm for integration culminated in the Maastricht Treaty and the establishment of the European Union[3] in 1993. A critical precursor was the push toward a pan-European mobile communication system. There was no single defining event; rather, it was a series of enabling and facilitating developments such as CEPT[4]'s early service concept drafts of the Groupe Special Mobile (GSM) and spectrum allocation, governmental actions in major European countries, rapid technological progress in the Nordics, and fortuitous timing, “A slice of good luck and well judged timing” (Hillebrand, 2001) that collectively accelerated progress.

While Europe did not set out to enact a “Blue Ocean Strategy” (Kim & Mauborgne, 2005), the eventual creation of a unique federated market in the “federated” European Community was fundamentally more complicated than in other regions (Hillebrand, 2001) and in essence did create a completely new market opportunity for Europe. The U.S. telecom liberalization and technology developments served as reference points, yet the European model was designed for a semi-harmonized market, unlike the fully harmonized U.S. and Japanese markets. As a result, national governments in Europe retained significant influence over technical requirements, including roaming, billing, inter-network protocols, and spectrum coordination, distinguishing European **second generation (2G)** from other early adopters or digital cellular technology. This critical difference served the European system later well when the expansion of the 2G networks took place beyond the CEPT countries with their specific minor national deviations.

Both the U.S. and Europe aspired to develop universal mobile communication systems, but their

2Further reading see https://en.wikipedia.org/wiki/History_of_mobile_phones
3Maastrichtin Sopimus https://www.europarl.europa.eu/about-parliament/fi/in-the-past/the-parliament-and-the-treaties/maastricht-treaty
4CEPT, European Conference of Postal and Telecommunications Administrations, https://www.cept.org/

practical approaches diverged. In the U.S., the post-AT&T-breakup telecom market fostered competing, fully independent mobile operators, with the fixed-line network connecting systems but only for voice calls. This design precluded interoperability for advanced services like SMS, and lack of harmonized 2G radio technologies led to multiple incompatible standards, such as IS-54/136 (TDMA) and IS-95 (CDMA), which retained some backward compatibility with AMPS but did not prompt a major systemic transformation. The 2G market thus remained fragmented, with competition and collaboration patterns largely unchanged.

In contrast, Europe's introduction of competition was matched by a regulatory requirement for full interoperability among operators, culminating in the landmark Memorandum of Understanding (MoU) signed by 14 operators in 13 countries in September 1987 to launch GSM by 1991 based on shared standards. This collaboration required the creation of open standards and a unified radio interface, prompting the foundation of ETSI in 1988. Earlier CEPT initiatives had already allocated spectrum for 2G systems in 1982 and initiated the standardization work passed to established ETSI's Technical Committee GSM.

In essence, the U.S. introduction of 2G technology merely expanded the market's size, whereas in Europe, both the number and roles of market actors underwent substantial change. Europe's systemic shift toward collaboration and interoperability set the stage for wide-reaching and rapid mobile network success.

The development and deployment of the 2G mobile communications system in Europe spanned approximately a decade, from the early specification work in the 1980s to the commercial launch of the GSM network in Finland in 1991. This period witnessed a **profound systemic transformation**: the mobile communication landscape shifted from national monopolies operating isolated systems to a model featuring multiple interoperable and competing networks within every European country. This transition, illustrated in Figure 1, marked a radical departure from the previous order.

In 1G national fixed telephone operators also controlled the mobile operators while in 2G the multiple mobile operators in each country competed nationally and collaborated internationally based on the new regulation. In the USA only new radio technology was added to the existing market.

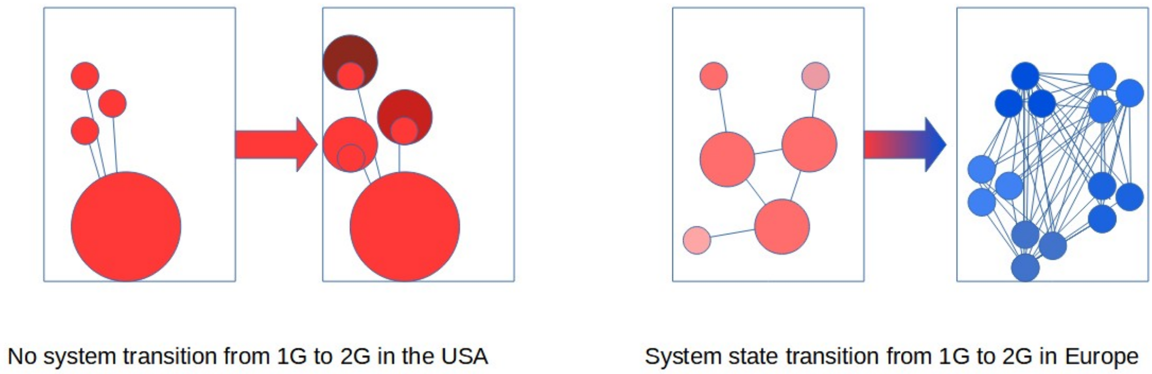


Figure 1: System states and transitions in the USA and in Europe

Equally significant was the liberalization of technology development and standardization, transitioning authority from national operators to broad industry collaboration in organizations such as ETSI. This move created an environment resembling a regulated oligopoly, while industry alliances, most notably the formation of the GSM Association (now GSMA) retained considerable influence over technological direction.

While it was recognized that future mobile systems and services would need to be competitive, this was only feasible after market and technology advancement through coordinated efforts. This process did not follow a singular, comprehensive master plan but rather evolved through incremental, collaborative decision-making among a diverse set of stakeholders. The resulting architecture and strategy can now be fully appreciated in retrospect, decades after its inception.

3. Coherent Systemic Architecture of the 2G

During the transition from fragmented, first-generation national markets to a more semi-harmonized, pan-European environment, both the old and new markets and systems coexisted but did not directly interoperate. This ambitious, vision-driven transition allowed for the definition and development of new systems and markets without significant compromises or backward compatibility constraints. To fully understand the depth of this change, a more detailed systemic analysis is required. The first step is to chronologically list the major development milestones encountered during the introduction of 2G systems.

In Table 1, the rows reflect the order in which these milestones emerged, presenting a rough historical sequence.

Table 1: Key system Dimensions of the 2G mobile communications in Europe in the order of first appearance

2G System dimensions	**National level**	**European level**	**Systemic implications (“Federated de jure”)**
Vision	New services using new technologies for the consumers	Pan European mobile service to enhance and speed up development of the European common market	Local national businesses extended to European common market
Political decision making	National governments	European Community/Union structures, CEPT, in line with global coordination bodies (ITU)	Federated and coordinated de-Jure national monopolies
Competition policies	Coverage requirements, Service obligations, Number of operators, National roaming, Service bundling policies	Pan-European coordination, national implementation, mandatory high level harmonization, with national exceptions. Global requirements for environmental and safety,	Federated coordinated set of de-Jure national oligopolies with global system boundaries.
Critical Resources (Radio Spectrum)	National radio spectrum plans, allocations and assignments. Local decisions on spectrum auctions	Pan-European coordination in CEPT/FM, in partial alignment with global rules.	Voluntary coordination based on national regulators' agreement in CEPT/FM
Standards	National authorities participated and controlled the European level	European coordination in CEPT and later in ETSI. Some ISO/IEC and ITU specifications acknowledged.	Mandated coordination based on national authorities’ agreement
Technical architecture	ISDN oriented, harmonized network architecture with additional key architecture such as Base station Controller and Home location register to	Visitor register based roaming based on the harmonised network architecture. Virtual Home Environment as an example how to solve local vs. global service conflicts *(Pseudo Harmonization)*	Harmonized technology allowing national variations on selected areas

	support mobility.		
Commercial architecture	National operators, with their unique services providers providing interoperable services with volume based charging and billing	Federated network of licensed operators, forming the GSM Association, addressing internetwork issues, such as roaming and clearing of roaming fees.	Voluntary coordination to support service interoperability between the networks
Technical development	Leading national technology companies running research, standards development, product and service development and business.	European collaboration in research (COST,..)	Voluntary coordination of private projects facilitated by European programs
Data, ID security	Operator specific SIM cards, Possibility to use national security measures, legal intercept etc.	European wide recognition of SIM card roaming, also Equipment ID register, Coordinated options for security algorithms	Coordinated many to many roaming agreements
Product approval	Fully under operators' control	Initially 3rd party test labs to run the for TA testing and making the decisions based on standardized requirements. Later any certified body to provide testing, including self-certification and market surveillance	Regulated but standards based market. Product approval became less important control point
Products and services	National implementation plans	Fully interoperable products and services launched based on national roadmaps	Full market compatibility, national configurations allowed. Oligopolistic and open market sales channels co-exist.
Intellectual Property	IP focusing on product innovation	IP Focusing on Standard Essential IP and separately for product innovations	Federated model for SEP between the technology developers. Traditional model for others

A key observation from Table 1 is that the structural shift affected all significant dimensions, notably leading to a coherent new 2G system. It should be noted that Table 1 is not entirely time-based; the sequence of technical and commercial architecture development often overlapped as they evolved in tandem. The table reflects this interplay, capturing the broadly sequential but non-linear nature of the changes.

All relevant layers of the system were organized and functioned under similar structures and boundary conditions, enabling consistent system dynamics across Europe, as described in detail in Table 2 below. This alignment simplified stakeholder engagement, clarifying optimal behavior, effective contribution, and value capture.

It is important to recognize that this regulated (de jure) oligopolistic model provided an effective framework for optimizing radio spectrum usage, the critical new resource, while through harmonised spectrum bands it enabled Pan-European interoperability. The approach effectively moderated strong network effects, preventing any single player from achieving a winner-takes-all position. However, certain national processes, such as spectrum auctions and MS-SIM bundling, were delegated to local authorities, allowing adaptation to national circumstances. The system was designed and standardized to accommodate these variations, with pragmatic flexibility also applied to standards development, supporting "pseudo-harmonization." For example, features like the Virtual Home Environment were initially developed to address the flexibility requirements on the market but later diminished in importance as the market evolved.

When defining the regulated oligopoly in mobile communications, it is essential to contextualize it. As mentioned, it is a de jure market structure established by law, contrasting with a de facto oligopoly that arises naturally. The main characteristic is the stability and resilience of the de jure model against disruptive market forces. This system is legally protected but more open and decentralized compared to a monopoly market. Furthermore, the regulated oligopoly in case of

GSM included an important feature based on the requirements for pan-European roaming of services. This created a specific market, a federated set of regulated oligopolies. The regulations also included a set specific service obligations that were embedded to the operating licences bundled with the radio spectrum assignments.

To emphasise the importance of this specific style of market competition, in this paper it is referenced as **federated de-jure oligopoly**. From the systemic perspective the federation element aligns with the similar federation element of the European Union during the time when the foundations of the 2G system were defined for Europe. Figure 2 illustrates the licensed and federated de-jure oligopoly as a network of blue actors. The global network of local oligopolies could also be called some kind of complicated meta-oligopoly market.

Prior to the policy-driven liberalization that ushered in the 2G era, the mobile sector operated as a **de jure monopoly**, represented in Figure 2 by a fully centralized model in red.

Another potential market configuration is **perfect competition**, known for high value capture by the end users as the upstream actors operate independently without coordination. This model can also be observed in wireless communication but is outside the scope of this paper due to its small total economic value. It is shown in Figure 2 with a brown color. Perfect competition often occurs when regulations are loose and there is little incentive for actors to collaborate.

In parallel, the fourth systemic model, monopolistic competition model, is characterized by modest regulative restrictions, which allows the market actors to seek better position by product differentiation and price competition. However, in mobile communications, the monopolistic competition has a special flavor due to the possibility to utilize network effects. Hence in this paper the fourth systemic model is defined as a **network driven monopolistic market**[5]. This inherently complex system model does not stay in the monopolistic state but it evolves easily towards true monopolies and may result in winner-takes-all behavior. It is depicted in Figure 2 as a green network.

Overall, Figure 2 aims to illustrate the structural differences among these four market models. This type of modeling is similar to other frameworks that discuss system dynamics. One particularly useful model is Cynefin[6], which addresses the challenges that arise when systems are implemented without clarity. A confusing situation, the state of disorder, occurs in the middle when a system incorporates elements from more than one archetype. Understanding these systemic factors allows for better interpretation of observations in mobile and wireless communications.

It is important to emphasise that the 2G mobile communications in Europe followed faithfully the vision of the federated de jure oligopoly systems thinking, initially. Later this systemic coherence was broken gradually.

5This happens especially when regulations encourage actors to collaborate. A prime example is how the regulative guidance was used to solve the tragedy of commons -situation in wireless communications. Regulators encouraged the fiercely competing product companies to develop a common specification for radio spectrum etiquette, listen before talk, for a specific spectrum slot they also assigned. This rather minor intervention made the monopolistic market dynamics become network driven.
6Cynefin https://en.wikipedia.org/wiki/Cynefin_framework

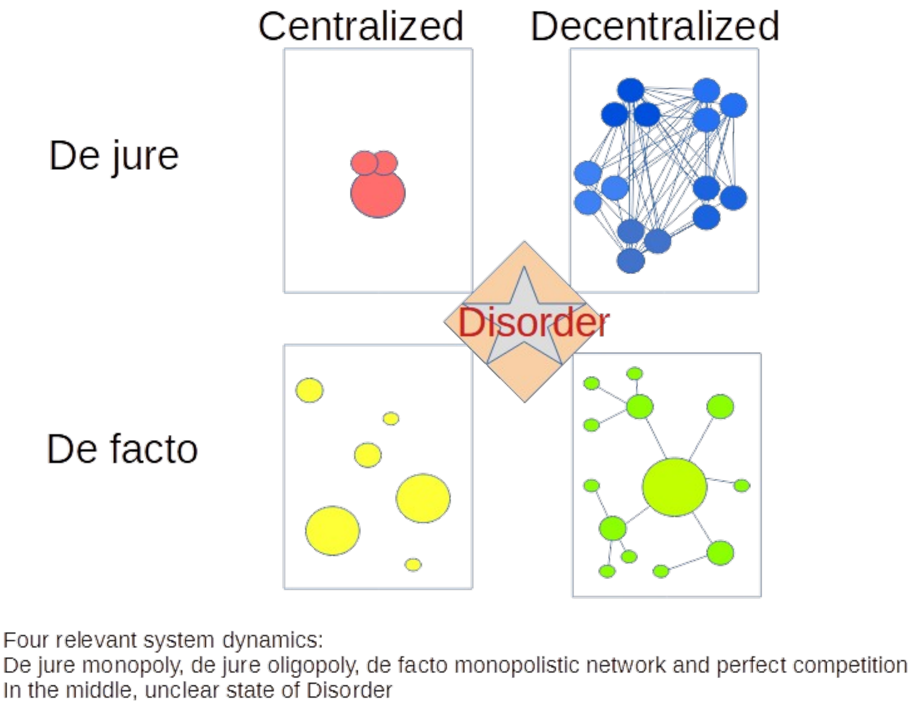


Figure 2: Illustration of four possible dynamics of competition and collaboration.

Although there are severe challenges in collaboration among these different market models, there are still needs, and even requirements, to facilitate such cooperation from time to time. Another model, the Quadruple Helix approach (Carayannis & Rakhmatullin, 2014), offers tools to manage system-of-systems-level collaboration without falling into the disorderly state. The Quadruple Helix model is described in Annex I.

3.1. Systemic view to 2G

To better understand systemic change, the historical developments can be reorganized to highlight the key elements of the system. In any system, important factors may be categorized in a similar way. The main elements include:

1. **Boundary Conditions and Resources:** These are the physical limitations that constrain the system, as well as the resources available that shape the system's growth.

2. **Competition Rules for Actors:** This set of rules defines how actors, specifically, mobile operators, must and must not operate their networks and deliver business offerings. It establishes the framework for competition within the system.

3. **Structural Dynamics:** These are the internal frameworks, including both voluntary and mandatory collaboration to define voluntary and mandatory interfaces, that enable different components of the system to interoperate at various levels. Together, these define how collaboration occurs within the system.

4. **Parameters for End Users:** This category includes the parameters and performance characteristics relevant to the final decision-makers, the end customers, who have the choice of services and products offered by operators and other providers. These factors govern the value created and how it can be captured.

These four fundamental systemic components will be discussed in further detail below and are summarized in Table 2.

3.1.1. Boundary conditions and resources

Clearly defined system boundaries play a pivotal role in analyzing the evolution of value systems, especially during transitions such as from GSM to UMTS (Hillebrand 2013), in addressing radio spectrum allocation (Basaure, Casey & Hämmäinen 2012), shaping mobile services (Vesa 2005), or understanding the unbundling of networks and services within national markets (Davies, Howell & Mabin 2008).

For 2G systems, physical boundaries were established on two levels. First, each country acted as a discrete entity responsible for regulating the proper operation of its network, requiring mobile operators to hold appropriate licenses. Second, the collective boundary of all participating countries defined the system's overall footprint. Operations could not extend beyond this external border, even as internal borders remained semi-transparent to support smooth operation both within each country and across the region.

Boundary conditions, together with available resources, shaped the system's dynamic behavior. Each country exercised control over its critical physical resources, resulting in some differences in system operation from one country to another. Among all resources, access to radio frequency spectrum was the most crucial for mobile communications, followed by the need for physical infrastructure elements such as numbering schemes, reliable power supply and real estate for radio equipment.

3.1.2 Rules for competition

The second set of system parameters consists of the rules that govern how each network should be operated in competition with other networks. These include service obligations, such as minimum network coverage requirements, and mandates for the openness of critical interfaces, for example, the radio interface and the interface between consumer devices (mobile phones) and subscriber identity modules (SIMs). Regulatory frameworks may also address issues such as tariff structures, special interfaces for authorities (such as legal intercept capabilities), and competition-related matters, including the bundling of SIMs with mobile devices.

A particularly important rule related to competition is the operator license, which effectively establishes a local monopoly for each mobile operator within their allocated radio spectrum. While this is a competition policy decision, it is practically implemented by restricting access to critical resources.

3.1.3 Rules and means for collaboration

A distinctive feature of the GSM system is that it is the only standalone 2G network supporting fully interoperable services between mobile operators. Unlike GSM, other 2G systems were interconnected via earlier fixed-line telephone networks, which limited advanced end-to-end services beyond basic voice communication. In Europe, this interoperability requirement was embedded within the EU regulatory framework and explicitly included in operator licenses. Although seemingly straightforward, this requirement compelled mobile operators to engage in deep technical and commercial collaboration, realized through a suite of standardized interfaces.

From a systemic perspective, this fostered a balanced dynamic between competition and cooperation unprecedented in the industry. Mobile operators extended their collaboration by establishing a Memorandum of Understanding (MoU) in 1987 and then forming the GSM Association (GSMA), initially to coordinate technical efforts inadequately addressed by formal standardization processes. Over time, GSMA evolved into a broader collaborative organization facilitating a wide range of joint activities. Similarly, GSM technology vendors created their own discussion forums in response to the operators' increasing coordination efforts. The aim in this collaboration was to speed up technology evolution and enhance standardization.

3.1.4. Rules for value creation and capture

The political determination to establish a pan-European mobile communication market through liberalization significantly influenced how value was generated and shared within the ecosystem. A particularly radical step was the introduction of spectrum auctions to allocate operating licenses. This approach locked operators into substantial upfront investments before commercially proven technology was available, while providing a major revenue source for governments. Most European countries adopted this model. The auction system was designed to maximize the auction fees, which led to some overestimations and evidently caused some difficulties to finance the network build-up.

Operators with semi-monopoly licenses were well-positioned to serve consumers in markets where competition was primarily technical, enabling them to capture value effectively once networks and mobile devices were deployed. Additionally, allowing SIM and mobile device bundling created subscriber lock-in that extended from spectrum licenses to consumer identity, a chain of exclusivity not present in countries that used non-auction license allocation methods such as beauty contests.

The introduction of competition also fundamentally altered value creation and capture upstream of mobile operators. Technology providers could supply any operator and sell consumer products directly, intensifying competition based on features and functions. Competition and collaboration in technology innovation and open standards and interfaces further stimulated vendor competition and downstream value capture, eventually differentiating the technology provider community into original developers and latecomer implementers. Fundamentally there were multiple, but not unlimited options for consumers to make choices.

Table 2 reorganizes the factors presented in Table 1 according to the systemic model. A glance at Table 2 reveals that the systemic change involved simultaneously adjusting nearly all levers of the value system, aligning them to the same systemic position. This alignment was critical in establishing the oligopolistic market structure characterized by a carefully balanced relationship between competition and collaboration.

It is fair to say that the level of systemic alignment was exceptionally strong, far more robust than seen in comparable system developments outside Europe. Almost all system dimensions were aligned with the federated de jure oligopoly model.

Table 2: System Dimensions of the 2G mobile communications as controllers for the system dynamics

2G System model	Aspects of Critical Resources	Aspects of Competition	Aspects of Collaboration	Aspects of value creation and capture
Vision	Radio spectrum, later also numbering space, real estate, power	Liberalization of the telecom market, national competition	End to end connectivity to all key services, Pan-European collaboration	Highly competitive market with some exclusive rights given to mobile operators.
Political decision making	National spectrum ownership. National spectrum licenses.	European Community/Union structures, CEPT, in line with global coordination bodies (ITU)	Strong coordination of EU policies by the European Commission and other EU bodies.	Federated and coordinated de-Jure national monopolies
Competition policies	Spectrum auctions, Coverage requirements and a number of service obligations	Multiple operators in each country, consolidation over national borders somewhat limited	Mandated interoperability and set of mandated open interfaces	Rules for bundling and unbundling of SIM/MS
Critical Resources (Radio Spectrum)	National plan to identify possible spectrum slots	Enough spectrum for realistic competition must be provided	Technically feasible spectrum masks	Auction fees and Value added taxes to national governments. Major risk was embedded in the auction mechanism, (Winner's curse)
Standards	Critical spectrum coordination done before technical standardization. Standardization focused on optimum of use of the resources	Standardization process in ETSI introduced strong technical competition and enforced competition elements between the mobile operators' services.	GSM standards initially in CEPT were defined in full collaboration. In ETSI aspects of competition were added while the collaboration on standardization focused pre- and pro- competition. Open access to all documents for the participants	The primary focus is new value for consumers by harmonized services. Value capture in the ecosystem is balanced based on contributions, material or immaterial.
Technical architecture	High dedication to optimum utilization of radio spectrum defined workload in the technical components of the architecture (e.g. voice coding vs. channel coding vs. implementation cost).	The number of open technical interfaces to enable competition is products and services. Competition in poorly interoperable value added services (failed to create new value)	All the interfaces were defined fully interoperable to enable collaboration throughout the implementation and deployment phase, in technical terms. Focus in basic services (Voice, messaging).	Value creation and value capture in balance. Value creation failed in all services beyond the basic services. Conflicts emerged later related to Internet paradigm
Commercial architecture	Radio spectrum was made available by national decisions, mainly spectrum auctions. Oligopolistic spectrum licensing effectively disables any attempts to aim "winner take all position.	National competition was enforced by disabling national roaming programmable SIM lock. International competition was not part of the system.	Collaboration internationally included roaming and clearing house functions as well as full interoperable basic services. Operators' and also manufactures' global voluntary organization built collaboration beyond standardization.	Volume based as well as flat rate tariffs were enabled. Operators were somewhat limited to build international networks, initially. Fundamental risks and uncertainties were relatively low. Flat rate for data became a significant disruptor later.
Technical developmen t	Leading technology companies running research, standards development to optimise the given goal to maximize the utilization of radio spectrum	Full competition to provide best technical solutions in research, standardisation and even more in the product development phase.	Early research phase especially EU research programs, COST, RACE, ACTS, FRAMES. Collaboration in the technology development on commercial basis	Value creation through technology and product development captured in commercial contracts to build networks and products. Role of IP important to balance the limitations set by commercial architecture.
Data, ID security	Security functions became critical due to emerging security threats enabled by novel technical solutions.	Technology competition in providing the best solutions for ciphering, authentication and security related registers in standardization. No real commercial competition.	Broad but well managed collaboration in standardization. Strong collaboration with authorities to provide additional features such as legal intercept. Also configurable security mechanisms to address non harmonised market needs.	Limited or no attempts to use data or security to direct value capture.

Product approval	Strongly standardized and regulated tests and approval process for all radio transmission.	No deviations in the product type approval requirements, hence no real competition.	Strong collaboration in test development.	Limited value creation/capture competition between product and test facility provides.
Products and services	High focus on radio performance to satisfy the stringent requirements of the efficient use of radio spectrum.	Fully competition in products and technologies globally as well as in services on national level.	Only vertically, between product and technology providers on commercial bases.	Value created by product and services was captured by vendors and services providers based on their competitiveness.
Intellectual Property	IP protected in case of novel enough inventions and solutions.	Competition in IP takes place later if relevant	IP rules of the standardization organization enabled novel ideas and contributions to be provided for the collaborative system development	Value creation takes place early while value capture only much later if at all. Regulation defined, limited market capture possibilities must be balanced by value capturing through IP.

The systemic alignment achieved in the 2G GSM system was so robust that it laid a foundation extending well beyond Europe, a foundation that has remained largely intact over time. This alignment created a powerful platform for growth within defined boundaries. However, it also resulted in a "walled garden" effect, which became a significant barrier to further expansion once the planned systemic growth opportunities were fully realized.

Technological development continuously drives new service possibilities, while the introduction of innovative services fuels the demand for new technologies. The distinctive characteristics of the licensed, federated regulation based oligopoly market model, first established in 2G, have periodically extended through succeeding generations including 3G and even projecting toward 6G, following patterns typical of limit cycle complex systems. The full coherence of the system dimensions started to slowly deteriorate, however, as early as the last years of 2G (GSM Phase 2 standards).

Adopting emerging technologies, business models, and strategies often requires complex, multifunctional transitions driving broad shifts from one policy regime and market logic to another (Zysman et al. 2010). These transitional phases encompass both periods of growth and challenges, which will be examined in the following chapter.

4. Periodic system evolution

The transition from a fragmented 1st generation system to the federated regulated oligopolistic 2nd generation system also initiated a new paradigm, periodic system evolution, better known as the evolution from 2G to 3G, 4G, 5G and finally to 6G. Time wise, the 1st generation systems emerged during the 1980's, 2G era spanned over 1990’s, whereas 3G dominated the leading markets during the first decade of 2000, 4G during 2010’s and 5G is the dominant now during 2020’s. The 6G is expected to enter the market by 2030.

There is a significant difference between leading and lagging markets in which technology generation is the dominant one. However, the lifetime of each generation is roughly a decade with heuristic observation that each even number generation completes the previous odd number generation in making the features and functions fulfilling the visionary expectations and furthermore, provide a platform for temporary novel innovations. This observation is not new, similar developments have been seen in several instances when a General Purpose Technology (GPT) has entered the market and later on shaped the market by enabling a new set of technologies to be built on the top of the GPT. The cycle not only enables the “spawning of applications” but guides the underlying platform development, i.e. the mobile communication to evolve to support the applications. This virtuous cycle has driven the development in a rather narrow framework set by the telecom regulations. In the following these cycles are analysed in more detail (Heikkilä et al, 2023).

4.1. Formation of the ecosystem

As the prelude, the era of 1st Generation systems was different from the following generations. There was no explicit periodicity observable yet in 1G. The regulations and other boundary conditions and structures were not set to form any solid larger framework and the limits of growth were not systemic, but rather technical, financial, and political.

4.2. The Era of 2G growth and expansion

In this study, the focus is on digital mobile communication, with the chronological inception marked by the deployment of the second-generation (2G) technology and services. In the European context, this milestone was achieved in Finland on July 1, 1991, aligning with the target established by the Memorandum of Understanding (MoU) signed in 1987.

Full commercial operation commenced approximately one year later, following extensive efforts to finalize market preparations and resolve technological intricacies. During this phase, the boundaries and internal structures of the technological ecosystem were rigorously tested and evaluated. These activities encompassed a broad spectrum of independent yet coordinated initiatives, including national radio spectrum auctions, testing and type approval procedures conducted in multiple laboratories, resolution of open issues within the standards in ETSI, and extensive hardware and software development by competing companies aimed at commercial deployment.

A significant milestone was the attainment of type approval for commercial devices, which led to GSM being colloquially nicknamed "God Send us Mobiles" due to its disruptive potential (Hillebrand 2001).

The foundational technological decisions for 2G systems were made in 1987, following an open comparative analysis of three different radio transmission concepts and speech coding technologies. The finalization and implementation of the selected system parameters into commercial products spanned approximately five years. Parallel to technological development, comprehensive commercial planning, offering strategies, and contractual negotiations unfolded across a dozen countries, where limited prior competition had characterized the telecom markets.

GSM network operations commenced once mobile handsets satisfying formal type approval standards were available, a milestone achieved in June 1992. Preliminary commercial services had been introduced earlier in select markets. In the same month, the first cross-border roaming agreement was signed between operators in the United Kingdom and Finland. By 1993, GSM subscriptions surpassed one million, underscoring the rapid acceptance of the technology.

By 1993, it was evident that GSM would dominate the mobile telephony landscape. Consequently, ETSI members initiated work on Phase 2 enhancements, emphasizing both technological evolution and supplementary services.. Key developments included the concept for packet data radio systems (GPRS) and enhanced voice coding schemes (EFR). The standardization process explicitly maintained the core architecture, as outlined in Table 2, with no intentions of fundamental restructuring. However, by the complicated introduction of data services, particularly support for “mobile internet” was the early indicator of the future challenges to use mobile networks as a data transportation platform. Service ambitions and systemic rules were in conflict, which became obvious only in the following generations.

Proposals to repurpose GSM as an access technology for fixed-line telephony were notably unsuccessful, often viewed as neglecting the systemic limitations of the technology. Additionally, a contentious debate emerged regarding the unbundling of the Subscriber Identity Module (SIM) and mobile device interface, popularly known as the SIM lock controversy. The resolution entailed standardizing this interface as a configurable feature, facilitating adaptation to diverse licensing models. SIM-lock is an example of a technology based solution in case of regional, national or ecosystem based unharmonized requirements. This incident is useful to consider as a solution for future needs where similar configurability in standards and technologies may be necessary (Conzales & Ali-Vehmas 2025).

Efforts to challenge GSM’s dominance included the adoption of Code Division Multiple Access (CDMA) technology in the United States and, to a lesser extent, PHS technology originating in Japan. While both systems enjoyed considerable success domestically, they failed to attain similar global market penetration as the GSM system. The competition was often perceived as a standards war over the radio interface; from a systemic perspective, however, it represented a contest over network features such as security, roaming capabilities, and supplementary services that were critical for operators seeking turnkey solutions. The robustness of the GSM architecture proved too formidable to be overcome by technological variations along only one or two dimensions.

Globally, the European model gained widespread acceptance due to its capacity to accommodate both international interoperability and slightly varying domestic requirements, facilitated by well-defined interfaces, configurability, and advanced performance features. During the 2G era, over 185 countries adopted the European GSM standard and by the advent of third-generation (3G) systems in 2004, subscriptions exceeded 1.3 billion.

The network effects generated by end-to-end service interoperability fostered a growth dynamic that primarily benefited the collective GSM community, rather than individual operators. Regulatory constraints on licensing effectively prevented a "winner-takes-all" scenario, maintaining a competitive equilibrium.

Finally, the initial perception of the European telecommunications landscape as comprising autonomous sovereign states lowered barriers for the rest of the world to subscribe to the same principles, one by one. The federated system model made it easy for non-European countries to adopt the same set of rules. The other early markets, USA and Japan, joined the GSM community only in the later generations.

4.3. Lack of systemic vision in the 3G struggle

Parallel to the evolution of 2G, the community also began focusing on the next generation of mobile communication. As early as 1991, dedicated efforts in ETSI standardization initiatives aimed at this next phase, culminating in the formation of the SMG5 group as a subcommittee under ETSI SMG TC. The European Union actively encouraged collaboration toward the development of the Universal Mobile Telecommunications System (UMTS), a European initiative designed to meet the requirements of the Future Public Land Mobile Telephony System (FPLMTS) established by the International Telecommunications Union (ITU).

In Europe, research into future radio and network technologies was broad-ranging. There were serious attempts to replace both the network and radio components with fundamentally new solutions. However, the rapid growth and established infrastructure of 2G systems created significant inertia, making drastic network overhauls impractical. Consequently, the 2G network with enhancements like GPRS served as the foundation for the next generation. While alternative options were considered, the band-wagon momentum behind the existing systems inevitably prevailed.

Regarding the air interface, the situation was different. Multiple candidate technologies for the air interface were available and already in commercial use. Therefore the technology competition focused on the question of the next dominating radio technology. This competition became particularly evident during the 2G era amid intense competition between European based TDMA/GSM and US-based CDMA technologies.

CDMA, developed within the TIA community under the IS-95 standard effort, was driven primarily by Qualcomm and supported by several other actors. Its hierarchical, systemic development model contrasted sharply with the broad, collaborative and federated approach employed by GSM within ETSI. This difference fueled intense rivalry, shaping global camps of technology advocates while in essence the it was all about different competition and collaboration (co-opetition) modes.

Research into third-generation (3G) radio systems in Europe began as early as 1988 and progressed through publicly funded programs such as RACE-1, RACE-2, and ACTS. These initiatives explored various technologies, including different variants of TDMA and CDMA, all assuming integration with the evolving GSM core network. The debate over which radio interface to adopt reached a climax during the SMG25 and SMG25bis meetings, where a specific wideband CDMA variant was selected. This decision aimed to pre-emptively reduce the competitiveness of US-based narrowband CDMA systems. Even if the chosen 3G WCDMA radio technology was inherently different from the 2G TDMA there were some key features defined to make it easier to make dual mode GSM/WCDMA devices, such as specification for system clock frequency and system time synchronization without any satellite component. Throughout the 3G era, these two camps remained in competition.

In an additional challenge to European leadership, China developed its own variant, TD-SCDMA, partially based on concepts and ideas emerging from European research programs that were not adopted in the SMG25bis decision. This development represented a strategic effort to establish an independent 3G standard. Even if this decision was an obvious commercial mistake in the global market, it created a momentum in China for their ambition for “indigenous innovation” which significantly pushed the science and technology capabilities forward in China.

European actors, including politicians, regulators, businesses, and universities, were deeply involved in this complicated network of competition and collaboration. The open standardization environment within ETSI allowed participants from around the globe to engage more or less on an equal footing. Part of this competition involved actively inviting key players from countries that had not yet committed to specific third-generation (3G) technologies. This invitation primarily targeted China and Japan, but also included the US and India. These countries either already used certain GSM variants or were deemed strategically important. This broad collaborative approach significantly influenced the key technical decisions, as the goal was to develop a concept and governance model capable of expanding the leading 2G system, i.e. GSM worldwide.

To strengthen this collaboration, an increasingly open approach to standardization was adopted. The efforts initially housed within ETSI transitioned to a new organization, the 3rd Generation Partnership Project (3GPP). This move allowed all formal standards development organizations in all regions to participate on equal terms. To ensure consistency and continuity, ETSI processes were adopted within 3GPP, preserving the operational model.

At this stage, there was little substantial debate about challenging the underlying system paradigm, even as one of the core features envisioned for 3G was to support emerging internet services. The consensus was that 3G would be a straightforward extension of the 2G as a technical and commercial paradigm. In most markets, this resulted in dual-mode devices and services supporting both 2G and 3G. The inertia of 2G was so entrenched that even the SIM card, a hallmark of GSM’s success, was carried over to 3G, despite questions about its benefits in markets where operators held monopoly control over the mobile device market. Systemic rules listed in Table 2 were maintained without serious questioning of their validity.

Therefore, a significant flaw in the 3G development was the lack of regulatory focus. The primary regulatory effort centered on allocating new spectrum for the next generation, often by extending existing 2G spectrum rules to include Time Division Duplex (TDD) support. The licensing model was inherited from 2G, favoring established operators and perpetuating existing market structures. However, regulators and much of the industry did not grasp the fundamental differences between the traditional telecom model and the internet paradigm.

The regulatory framework for 3G remained focused on voice services and SMS, maintaining relatively high tariff levels aimed at maximizing revenue from spectrum use. This approach led to operators charging exorbitant prices per bit and developing complicated GPRS charging systems, more complex, in fact, than the data transfer itself. Over time, it became clear that this model diverged significantly from the typical internet's flat-rate traffic model and its more efficient, cost-effective usage patterns. In countries where spectrum costs were low, either through beauty contests rather than auctions, the data tariffs eventually dropped to reasonable levels with flat-rate pricing while in most markets and especially while roaming the high volume based tariffs dominated. The beauty contests have facilitated the investments in network quality and coverage, which is clearly visible by comparing countries like Finland and Germany. High network investments have then facilitated flat rate tariffs creating a virtuous circle. High investment requirements in the very early stage will impact negatively to the performance of the services later in case of regulated markets.

This regulator gap fragmented 3G data usage and made data roaming particularly challenging, even for business users. Although 3G technology advanced rapidly, with higher and higher bit rates becoming available, ambiguous business models and regulatory inertia hindered the growth of the 3G data market. This had profound consequences as internet services grew increasingly important.

As a major side track the mobile community tried to define a specific "mobile internet" which should differentiate from the mainstream internet by maintaining the service and application development, at least its roadmap, under the control of the mobile operators. Almost all the functionalities developed for this purpose failed due to the "systemic disorder", the concept explaining the importance of systemic alignment (Snowden & Boone 2007). The mobile internet was developed intentionally to be somewhat different and hence not interoperable with the Internet but since there was no real power to make those concepts to operate as federated services either, the separated, single operator vertical implementations were not compatible to the traditional 2G systemic model either. This fundamental deviation of the two paradigms should have been reflected by reviewing the system dimensions, listed in Table 2, line by line to facilitate the early and systemic support for data based services over mobile networks in Europe.

In contrast, the US market saw only few operators with wide coverage across the continent. As these operators paid less attention to roaming, the environment was more conducive to internet service growth. Additionally, Wi-Fi played a crucial role in promoting wireless internet in the US, offering consumers alternative access options that weren't as prevalent in Europe's more fragmented landscape. This divergence became decisive when mobile applications emerged, shifting the competitive edge from hardware to software and from traditional telecom services to true internet-based applications. In practice, the systemic model in the USA was different in 1G, it did not follow the 2G transition in Europe as defined in Table 1 and Table 2. This local focus enabled mobile communications in the US to align with the internet paradigm and internet oriented mobile services much earlier and better than the strategy chosen in Europe.

In summary, European-led WCDMA/3G technology, including evolutionary advances such as HSPA, emerged as the dominant standard within a highly competitive environment. Nonetheless, its commercial success ultimately plateaued. Significant expansion beyond voice and messaging services primarily took place in the United States rather than in Europe. In 2012, European regulators recognized the need for affordable data roaming and amended policies to encourage operators to reduce prices. However, this policy shift occurred nearly a decade too late and chiefly benefitted internet oriented companies outside of Europe, enabling them to secure a dominant, or even winner-takes-all position on the top of a flat network layer of otherwise heavily regulated telecommunications infrastructure.

The 3G era can be characterized as a contest between two systemic models: federated mobile communications and a loosely regulated, network effects driven monopolistic internet paradigm. As a result, nearly all aspects of the 2G system model referenced in Table 2 were challenged by potential substitutors (if observed using Porter's strategic framework (Porter 2008)), particularly by entities that did not align with the vision or trajectory of 2G. For example, advocates of unlicensed radio spectrum opposed traditional licensing regimes; standards developed by organizations such as IEEE and IETF were promoted over ETSI and 3GPP; the role of the SIM card was questioned in the absence of viable alternatives; and both intellectual property management and the function of standard-essential patents (SEPs) faced significant scrutiny. In spite of these challenges, momentum of the 2G system paradigm has mainly prevailed. This Pyrrhic Victory could have been avoided by more solid systemic analysis and thinking when defining the basics of the 3G.

These disruptive efforts, however, can be rationalized with reference to the fundamental differences between the respective systemic models. Intentional efforts to prevent monopolies in mobile communications inherently limit the potential to achieve winner-takes-all outcomes. By contrast, in markets characterized by strong network effects and loose regulations, firms frequently support their strategies by offering early, unrestricted access to technologies, such as royalty-free patent licensing, open-source software development platforms, and financial incentives for developers to adopt specific tools (see Economides 1996).

This phenomenon is present in both domains: within mobile telecommunications, maximum early stakeholder contributions were achieved through mechanisms such as spectrum auctions, while in the internet sector, 'voluntary contributions' to potential winning entities served a similar function. In both contexts, initial substantial investments may be monetized subsequently, albeit in different quantities, through divergent mechanisms with distinct collateral implications. The resulting dispute has generated extensive debate, with the lack of systemic understanding frequently contributing to suboptimal outcomes.

For better understanding of the different types of platforms and their characteristics, Annex II visualizes the different levels of platforming. In this paper, the telecom platform follows the dynamics of the 2nd level of platforming, a commercial external single sided platform (Cusumano Gawer & Cusumano 2013). The data platforms in general, when meaningful network effects are present, utilize the higher order platforms, like the multi-sided or multiple multisided platforms to maximise the value created through super personalization and through network effects.

4.4. Focusing to create the Winning global system the 4G

Paradoxically, the 2G system, primarily designed for circuit-switched voice, was built using TDMA technology, whereas the data traffic which is more inherently packet-switched and focused on Internet data, was handled using CDMA technology. Consequently, for the mobile community, it was a natural progression to adopt a completely new radio technology, OFDMA for the next generation. The development of 4G originated as an backwards compatible extension of 3G, known as Long Term Evolution (LTE), which became the branding for the 4G standard.

From a systemic perspective, 4G marked the final transition from the "ISDN" style approach of the last millennium to a fully packet-oriented traffic model, both in the radio access network and the core network. Moreover, the network architecture was optimized by incorporating lessons from previous generations, using the frame of System architecture evolution (SAE). Essentially, 4G embodied the "big pipe" strategy, an approach heavily opposed by operators in earlier generations, focused on providing large, high-capacity data channels.

The LTE/SAE development in 3GPP proceeded rapidly, with minimal internal conflicts. However, actors dissatisfied with the traditional telecom paradigm, which limited their scope to connectivity and mobility, sought to develop alternative, fully internet-oriented technologies to challenge the telecom establishment. Two main systemic challengers emerged, both aiming to disrupt the market by a different radio technology: the Wi-Fi community, which adopted license-exempt spectrum and concentrated on indoor environments where spectrum rules favored high-performance local connectivity and WIMAX, driven by the silicon industry and companies seeking a role outside the standard 3GPP ecosystem to enable them to take leadership of the next generation mobile computing.

With fast progress in LTE development, Wi-Fi gradually diminished the strategic interest of telecom operators in providing the access, as 4G networks could deliver comparable or superior performance. Meanwhile, WIMAX aimed to provide broadband wireless access akin to LTE. Despite similarities with LTE, both WIMAX and LTE competed as equals, reminiscent of the earlier contest between WCDMA and CDMA2000. The interconnectedness between the radio access network and core network in LTE made it clear that adopting evolving LTE solutions represented a less risky, more reliable path forward, providing comparable performance. Systemic path dependency both in technology and commercially defined the direction of the periodic evolution.

By completing and consolidating the mobile services competition that had begun some 40 years earlier, 4G exemplified how collaboration within the community, coupled with timely technological development, contributed significantly to its success. The competition in LTE was in essence the last “battle” in the physical radio technology for mobile communications.

However, this systemic alignment with 3G addressed only the lower layers of the broader mobile ecosystem, the core network and radio access. When the mobile communication paradigm was initially drafted for 2G, it did not envisage the subsequent importance of other higher layers beyond voice and messaging, particularly applications and digital services. This initially valid but over time too narrow focus resulted in global success at the network layer but caused significant failures in other ecosystem layers, especially in enabling innovative applications and services.

As value creation moved upward toward applications and services, the technological framework within the 3GPP domain became increasingly restrictive and. This limitation was particularly evident in the barriers faced by mobile operators attempting to invest in new services. Conversely, the focus of the telecom community was reduced to ever higher performance of the networks. This strongly influenced the architectural designs and collaboration models, such as Open-RAN, which enabled software-based implementations of network infrastructure, similar to how smartphones became platforms for applications. This shift further reduced differentiation opportunities and drove business focus toward cost reduction.

The primary obstacle preventing data platforms and over-the-top (OTT) actors from dominating the entire ecosystem has been regulation, specifically, net neutrality policies. These regulations require equal treatment for all internet traffic, preventing data platforms from securing an uncontested "winner-takes-all" position. Without such regulatory boundaries, systemic pressure from OTT platforms could have resulted in a landscape dominated solely by data and application providers, marginalizing traditional connectivity and mobility providers. As a result, the connectivity and mobility layers have maintained the federated oligopolistic structure, but with a sharply narrowed focus on reducing costs and improving performance. This evolution separated the value creation and capture on the network layer and on the high layers to two totally separated businesses. The role of the network operators and their ecosystem was squeezed down while the over the top actors started to gain a much stronger role.

The 4th generation clarified that the telecom ecosystem revolves around two main entities: networks and services. Even when these seem to be integrated, for example, services running on the same mobile device, the fundamental boundaries between them remain. Networks and services each operate within their own virtual "sandboxes," with separate end-user identities, security mechanisms, charging, billing, and customer management functions. Services have their own virtual private data pipes and processing environments in mobile devices, almost completely isolated from the functionalities provided by network operators. This landscape was only truly set in motion during 4G, and the pursuit of a definitive winner in this competitive game may still be ongoing. So far the OTT actors have not been able to take full dominance of the overall ICT architecture (Fransman 2010) and ecosystem.

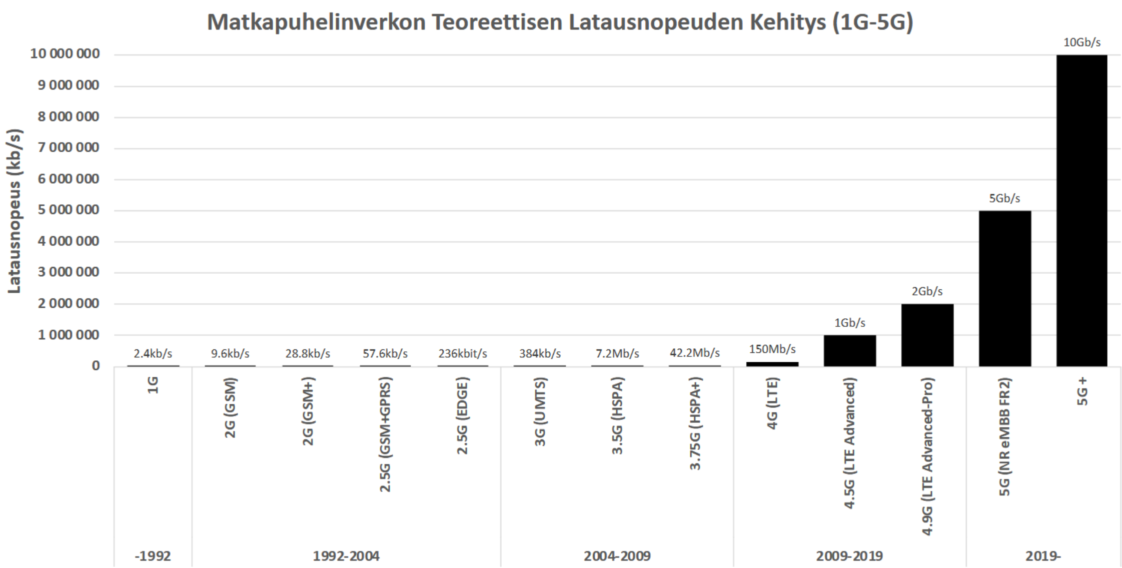
4.5. Enabling and facilitating the growth over the top of 5G

The extreme horizontalization in 4G has created a need for optimized support for vertical use cases that were not considered earlier. The goal for 5G is to provide optimized support for a wide range of system dynamics. Initially these included (1) uncoordinated narrowband radios such as those used in Internet of Things (IoT) applications, (2) focused but federated high-performance local systems like private enterprise networks, (3) special use cases such as military applications, and (4) continuing the evolution of 4G as a horizontal platform for telecom and over-the-top (OTT) services. The aim is to support all possible use cases with one flexible and configurable technology. From the systemic perspective, to support all the ecosystem dynamics illustrated in Figure 2 in chapter 3. However, the market adoption of narrow band and indoor applications has been significantly slower and weaker than originally anticipated.

5G is an exceptional system of systems, representing both a technological breakthrough and a significant standardization effort. However, geopolitical differences pose substantial challenges and obstacles to its optimal commercial deployment. Fragmentation and divergent national interests may restrict 5G’s ability to become a fully interoperable global network. Despite these challenges, 5G will continue to support the ongoing evolution of 4G and beyond, unlocking significant new business opportunities across various applications. By maintaining a clear separation between the services/applications and the network, the risk of fragmentation and network forks can be mitigated. Additionally, more harmonized global radio spectrum plans will facilitate coordinated 5G development worldwide, surpassing the fragmented landscape experienced with previous generations.

The 5G system offers a vast array of features and options, which can be summarized by its promise of an order of magnitude improvement over 4G in data rates, throughput, and latency. Heuristic Moore's law[7] is well known in the industry. It was noted by Gordon Moore as early as 1965 and it was later defined in more detail to say that the density of silicon technology seems to double every 18 months. Similar Edholm's law[8] has been observed in the late 1970s in transmission technology in telecommunications. It is convincing to see mobile communication at least until 5G to follow this very paradigm, indicating the state of the art status of the technologies developed over the decades. The interplay of Moore's law and Edholm's law is the fundamental force in the development, enabling very powerful silicon technologies to allow more demanding signal processing algorithms to be used to drive the fast performance evolution of the communications systems as seen in Figure 3.

Kuvio 1. Latausnopeuden kehitys



Kirjoittajien visualisointi, "downlink peak data rate".

Figure 3. Exponential growth of performance in mobile communications (Ali-Vehmas et al 2020).

This evidence of the leading edge technology development is one of the strongest arguments to see the 5G and the overall mobile communication technology paradigm to maintain its role as the harmonized global platform also in the future. The distinctive and timely enhancements like the 5G toolbox address the emerging challenges promptly. If there are regional or national mandatory requirements, those can be accommodated by flexibility and configurability in the 3GPP standards.

This makes 5G highly competitive against other technologies and deployment scenarios. In practice, public 5G deployments will include only a subset of the overall standard capabilities,

7https://en.wikipedia.org/wiki/Moore%27s_law
8https://en.wikipedia.org/wiki/Edholm's_law

while specific features are utilized to deliver optimized functionality for special use cases. While mainstream 5G is a mobile communication system operated by licensed mobile providers, certain aspects of 5G can also serve as direct competitors to traditional Wi-Fi applications, even using unlicensed radio spectrum. Within the 5G technology portfolio there are two parallel paths, one with backwards compatibility to 4G and another without this constraint, so called 5G new radio.

Over the past 40 years, licensed and unlicensed mobile technologies have competed without a definitive outcome. This ongoing competition has never been solely about the technologies themselves but about the ecosystems surrounding them. With 5G, for the first time, the potential exists for a clear winner in the radio access network to emerge. However, this will not end the ecosystem competition; instead, the four fundamental system dynamics described earlier will prevail and continue to influence business behaviors and strategies, driven by the business on higher layers of applications and services.

The 5G era is driven less by technology and more by human factors, including politics, particularly geopolitics, business models, and most importantly, the applications and services built on top of the communication platform. Unlike 4G, where applications and services were supported without specific adaptation at the communication layer, 5G envisions the creation of vertically optimized networks tailored for particular sectors such as traffic and transportation, industry, virtual reality, and more. The overall 5G domain represents a significant shift from the fully horizontal approach of 4G toward integrated, vertical business systems. Features like network slicing enable these specialized systems to leverage the scale and efficiencies of the underlying connectivity infrastructure. The emerging verticals may choose rather freely which of the 4 system dynamics is utilized.

A fundamentally new element in modern networks is artificial intelligence, which impacts all aspects of current technical systems. In mobile communications, AI plays two main roles. First, AI is used within the network itself to enhance performance, security, adaptability, and other capabilities. In this role, AI pushes network capabilities further along the exponential growth curve that has characterized telecommunications for years.

The other, more radical impact of AI is its role in applications and services that operate on top of the communication networks. These AI-driven applications are expected to deliver rapid development and significant value creation, which will, in turn, propel the evolution of the underlying network layers. It is likely that decision-making authority and financial influence will follow where the most innovative and impactful applications emerge.

Third option for AI based services at the edges of the network may grow and become a new important source of revenue also for the mobile network operators.

Consequently, the future of communication technology, beginning with 5G and reaching its full potential in 6G, will increasingly be shaped outside of the traditional group of actors. Developments within these higher layers of applications will take over strategic control of the domain, redefining the landscape of connectivity and communication. It is an important question which of the dimensions listed in Table 2 will prevail untouched in the 5G era and especially when introducing the 6G.

4.6. Completing the era of digital mobile comms with 6G

As with previous generations, even-numbered cycles have completed the developments initiated in the odd-numbered ones. The 6G era is no exception. During this final evolutionary step, the convergence of all communication technologies under the 6G umbrella is expected to reach the culmination point. This convergence applies primarily to technologies; however, divergence at the application and service layers above will continue. These layers will gradually build artificial vertical ecosystems, which will have a significant impact on the commercial deployment of the communication infrastructure itself.

The satellite component in the 5G and especially in the 6G timeframe is one possible breakthrough technology. Satellite communications can not compete with mobile communications in very dense areas but it is becoming mainstream in areas where the traditional networks are difficult to build, like sparsely populated areas, oceans, deserts or areas of military conflicts. Gradually the terrestrial and satellite components will find their optimum deployment scenarios with potentially rather broad areas of overlapping use cases.

It remains uncertain how the 6G technology community will ensure full interoperability across the entire system. Equally, it is an open question whether complete interoperability will even be necessary for end users. When ecosystem boundaries, particularly regulations, effectively separate actors and restrict collaboration and value creation, the need for technical interoperability diminishes.

The 6G will evolve to support diverse, large-scale vertical ecosystems, such as transportation or military communication systems, each building their core value on top of the communication layer. This development extends similar trends observed in 5G. These ecosystems may introduce some level of network fragmentation if network slicing becomes impractical due to high, ecosystem-specific requirements like ultra-low latency or enhanced security. Conversely, the fundamental technical components of 6G networks are likely to remain based on harmonized, standardized specifications, enabling the continued realization of economies of scale. The overall timeline and scope of 6G remain uncertain, with many potential growth avenues still largely untapped, even within the capabilities of 5G.

While 6G technologies are recognized globally through 3GPP-based standards, their commercial development will predominantly be driven by over-the-top (OTT) applications. Furthermore, geopolitical tensions could accelerate fragmentation, especially as higher-level applications and services become segmented along regional or national lines. AI-driven applications may be deployed within "ethical" or "value-based" sandboxes, as different regions and nations are likely to impose distinct ethical standards. Although these sandboxes might operate over a harmonized underlying network, consumers may experience reduced global interoperability (Conzales & Ali-Vehmas 2025). Significant new value must be created in the ICT space to justify the substantial investments necessary for 6G to fully materialize.

Sustainability will become increasingly central during the 6G era. Environmental, economic, and social considerations cannot be ignored by stakeholders in the mobile industry. With radio spectrum historically being the critical scarce resource driving technological optimization, new factors, such as energy consumption and the use of critical raw materials, will assume greater importance. The federated de jure oligopoly, which has proven effective in driving development and optimizing scarce resource use in case of radio spectrum efficiency, has significant merits to address these new bottle neck resources. It is desired to continue employing a similar model of competition and collaboration to address these new challenges. This systemic approach will influence not only the development of infrastructure but also connected devices and applications, including those utilizing AI.

Current world affairs are evolving rapidly, making it difficult to predict the exact path forward. Nevertheless, there is significant inertia in mobile communication systems, which tends to make them resistant to sudden disruptions. Development and standardization efforts for 5G, and now for 6G, continue along similar lines. This ongoing process is likely to guarantee at least partially global compatibility and interoperability of technologies, products, and services.

A plausible approach, based on historical lessons from mobile communications, has been to build configurability into systems and interfaces. In the 6G era, reusing these past solutions might help mitigate interoperability issues. One such concept is providing a Virtual Home Environment, enabling consumers to run their own applications on systems and networks that in principle are not compatible but let the configurable technologies make them implementable in one efficient, economy of scale network. Additionally the virtual incompatibility can be removed one day if the diverse forces are reduced.

Overall, the 6G system, encompassing both the network infrastructure and the applications layered on top, will embody the “dual helix” model[9] originally proposed by Charles Fine in (Fine 2000). This reflects an eternal ecosystem evolution that, instead of oscillating between decentralization and centralization, follows a continuous trajectory where evolution never needs to regress or reverse. See Figure 4 below.

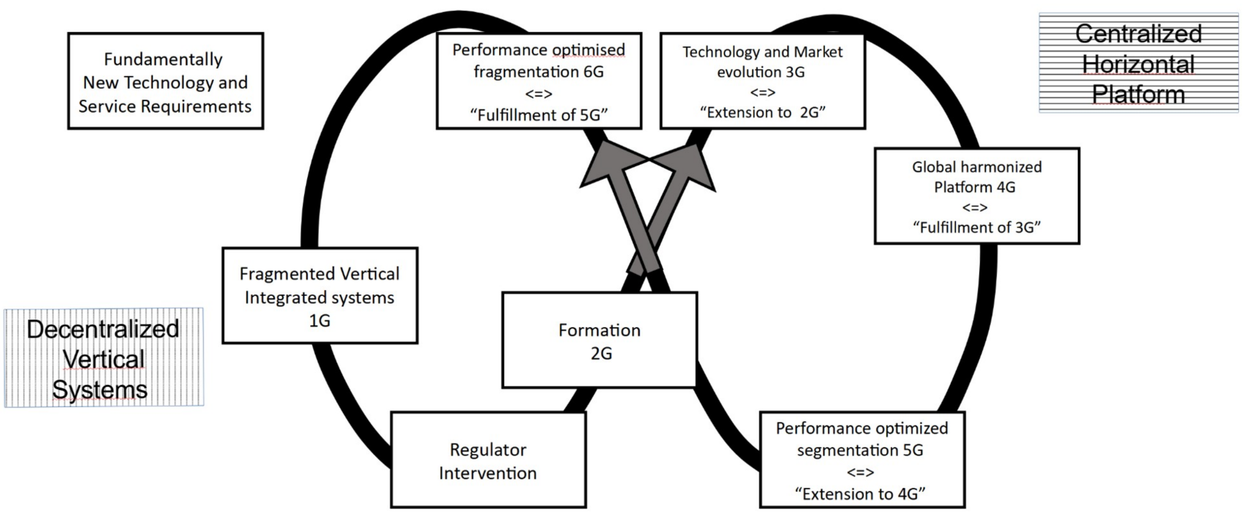


Figure 4. Systemic Double Helix evolution of Mobile Communication, adapted from Fine

9Not to be confused with the triple/quad helix models of Etzkowitz, Leydesdorf/ Carayannis, Rakhmatullis and others. The similarity in wording is accidental only.

4.7. The 7G is something completely different.

Periodic system evolution has concluded, and the focus has shifted upward to applications and services layers. In many ways, these higher layers, a.k.a. the layers of the Data economy are currently in a state similar to where mobile communications were during the first generation. This stage is characterized by significant fragmentation and the emergence of national and regional ecosystems driven by ethical and value based considerations, often with limited or no global interoperability.

The first observation is that mobile communications are no longer the primary driver of the digital economy, at least not without major breakthroughs in the foundational technologies of communication. However, there are several long term candidate technologies that could potentially reignite a new cycle within the double helix model also in the network layer.

Historically, each generation of mobile technology has spanned over a decade. The fifth generation has already defined the 2020s, and it is reasonable to expect that the sixth generation will dominate throughout the 2030s. The arrival of the seventh generation, often referred to as the next version of the first generation, is unlikely before the 2040s. This provides ample time for humanity to discover entirely new paradigms.

Among the most promising drivers for this transition are quantum technologies and general artificial intelligence. For example, concepts like spin communication could revolutionize the entire landscape. Similarly, geopolitical factors may accelerate the evolution of cybersecurity requirements and may require radical changes to the system architecture of communication networks.

Because these paths are highly speculative, this paper does not explore them in any detail. Nonetheless, much will depend on the interests of innovators and especially on the funding and support for deep technology research within universities and research institutes.

High value creation and both complicated and complex dynamics will continue to shape the digital ecosystems on the higher layers, new services and applications will emerge. Therefore, revitalizing the mobile communications, the network layer and its boundaries, structures and resources is fundamentally important, not only because Europe still has a good position in this domain.

5. Lessons learned

This paper examines the evolution of mobile communications, focusing on systemic transitions and the underlying drivers of its periodic advancement, rather than simply presenting a historical timeline. While history does not repeat itself precisely, the recurring patterns in systemic evolutions and ecosystem transitions offer valuable insights for scenario planning and potentially for charting future pathways. The following sections analyze these learnings, particularly the evolutions and transitions, on a generation-by-generation basis. Furthermore, the paper connects developments in mobile communications to the broader ICT ecosystem to identify relevant interlinkages and larger dynamics.

5.1. On the Mobile communication

The systemic history of mobile communication can be summarized, at a high level, using a dual helix model for the communication layer shown in Figure 4 above. A key observation is that the factors discussed in Section 3 shaped the digital mobile communications ecosystem from its inception, marked by the transition from 1G analog networks, through successive generations up to 6G. These factors initially enabled rapid network growth and value creation, provided the underlying paradigm remained consistent.

It is crucial to recognize both the advantages of this initially optimal setup and the limitations it imposed on growth, particularly concerning the utilization of alternative critical resources and the implementation of different models for competition and collaboration.

A comprehensive understanding emerges when connecting the systemic history of mobile communications to the evolutions and disruptions occurring above the connectivity layer. To clarify this picture, it's important to acknowledge that telecom services utilizing the mobile communication platform, especially voice, SMS, and certain value-added services, originally were strongly connected to the underlying transport network but over time their role became a more or less separated entity. This is evident in how internet and web applications have supplanted these traditional telecom services, offering similar functionalities, on the top of the transport layer, but operating outside the regulatory framework of mobile communications. A prime example is the near-complete substitution of traditional telephony and messaging by applications like WhatsUp. Traditional telecom services are still better integrated with the network but the growth in the value creation happens in areas where less restrictive regulations apply, the underlying network support is prioritized to support the internet and web applications. This development has separated the applications and services from the network both in business and in technology.

In practice, the systemic evolution illustrated by the double helix obscures the decline of telecom services, which clearly drove the paradigm in generations 1G, 2G, and 3G. These services were subsequently replaced by internet and web-based applications in generations 4G and beyond. It is also important to note that new value has consistently been generated in the higher layers, while the mobile communications layer has focused on cost reduction and performance optimization (maximizing value extraction from the critical resource, primarily radio spectrum). Even if this observation calls for consolidation on the network layer, it should be done in such a way which does not harm competition between the operators. Each market needs several actors to secure the federated oligopoly model to prevail instead of winner-take-all. Consolidation within the network operators facilitates consolidation also in the upstream. This has been visible over the decades where both the number of relevant system technology vendors as well as their component vendors has been decreasing significantly during the years and decades.

In summary, while the systemic history of mobile communication can be summarized using the dual helix model for the communication layer, it is essential to connect this development to related developments in higher layers, above the transport layer.

5.2. Developments on the other layers

To fully understand ICT ecosystems, it is crucial to look beyond the network layer, or "cluster." Annex III provides a visualization (Fransman, 2010) that illustrates this concept. While the different components of the overall ecosystem are often visualized as layers, it is more insightful to view the ICT ecosystem as a system of four equally important clusters.

The platformization of mobile communications reached its peak in 4G. The digital ecosystems that emerged on top of the communication layer were based on internet connectivity, particularly web technologies. These loosely connected ecosystems were able to leverage the communications platform as an optimal surface for growth. Initially, the communications industry welcomed these services due to their high data transport demands. However, the digital ecosystem layer operated under fundamentally different boundary conditions regarding critical aspects discussed in Section 3 for mobile communications, which had significant consequences.

While radio spectrum scarcity was a limiting factor for mobile communication, no equivalent limitation existed for digital ecosystems. Furthermore, competition rules, service obligations, and other regulatory requirements applicable to mobile communications did not extend to the layers above. There were no mandatory open interfaces specified. Although some interfaces were initially open, the introduction of application stores and proprietary device operating systems resulted in commercial control over critical embryonic interfaces, rather than standards-based openness.

Therefore, mobile communications and digital applications/services constituted intertwined but not aligned and therefore weakly connected sub-ecosystems in a systemic sense. This was also reflected in regulations, where for instance net neutrality requirements separated the network and services in the cloud.

The remaining two clusters consist of physical end-users, particularly their digitized data and identities (representing their invaluable assets), and their diverse devices and gadgets, including mobile devices and any other device capable of exchanging data and information with the ICT ecosystem. The influence of these two clusters has been limited by regulation and the actions of players within the other clusters. Consequently, the network and the "cloud" (a term encompassing the diverse services, applications, and data processing activities within today's digital data platforms) have been the most influential clusters.

In summary, the unrestricted growth and subsequent dominance of the "cloud" cluster comprising companies that have successfully led value creation above the communications platform, has resulted in a set of winner-take-all actors. Some are dominant in single service areas, while others hold leading positions across multiple value creation areas, leveraging their expertise and data assets to create horizontal and vertical dominance. The promise to provide early support for technology adopters in various forms, like royalty free patents, open source software, free software tools and more, are tools to gain unique position as a platform leader, which allows exceptional position to monetize these early investments through deep pocket strategy.

This success is attributable to a "substitutor" strategy, as described in classic strategic literature (e.g., Porter 2008), which involves changing the rules of the business rather than merely entering existing competitions.

In traditional mobile communications, value was created in the network cluster through connecting and transporting digital information, and in the device cluster through providing differentiated devices for information generation and consumption. However, growth in this model was constrained by resource scarcity (radio spectrum for the network, also controlled by national regulations) and physical differentiation limitations in portable devices.

Conversely, digital services and applications faced minimal limitations in acquiring, processing, and innovating with information, including end-user data and identities. This enabled a winning formula of differentiation to maximize value generation by maximal personalization of services and applications, even including potential price discrimination. Moore's Law drove down costs, while Metcalf's Law (and related network effects) provided increasing network value. There is no chance to compete with this value creation engine unless the set of rules are defined differently, to promote continuous competition, to avoid winner take all and to require openness in all embryonic interfaces of the ICT architecture.

The transition from a national mobile operator driven market to a new model driven by a small number of global cloud leaders was finalized by new value creation methods and optimal utilization of new technologies. These leaders are now expanding their influence to other parts of the ICT ecosystem, notably the device cluster, and increasingly the network cluster through initiatives like Open RAN. However, end-users' personal data and identities remain the cluster of multiple different operating models.

Recent regulatory actions, particularly in the European Union, aim to limit the power of cloud actors. This paper aims to provide perspectives on achieving this without confrontation or damaging value generation, while rather fostering the growth of new actors to challenge the status quo and bring new value to underserved areas. The discussed federated regulated oligopolistic model enables efficient utilisation of critical resources, not only radio spectrum, but also for instance road capacity or personal data while maintaining competition and avoiding the market to collapse to a winner-take-all monopoly situation.

When properly set, the oligopolistic competition and coordinated (federated) collaboration will speed up technology development as it has done in mobile communications. Such a model is also an easy systemic environment to set the systemic boundaries to the level that is secure, socially, economically and environmentally sustainable and still less complicated than the model we have today.

There are many underserved sectors of well being in Europe currently due to too complicated regulations that have hindered ecosystem growth. There is now an opportunity to enable sustainable growth, avoiding past negative consequences.

5.3. Other systemic evolutions (only for mental reference)

The evolution of mobile communications, and the broader ICT ecosystem, over the past four decades exhibits unique characteristics, yet parallels can be drawn to historical developments.

One such parallel can be found in the development of the Russian information society, as documented by Finnish researcher Ilmari Susiluoto (Susiluoto 2006). In the early years of the Russian Revolution, there was a strong belief that a scientific and mathematical systemic approach, often referred to as cybernetics, was well-suited for a centrally planned government. This conviction led to notable technological achievements, such as the launch of the first Earth-orbiting satellite. The ICT industry was organized in a highly vertical manner, with separate, isolated teams and technologies dedicated to spearhead applications, primarily in military and space domains. However, this approach was challenged by the Western model, which emphasized reusable hardware and software, and the gradual development of decentralized, platform-based architectures. This transition, though spanning half a century, mirrors the shift observed in mobile communication from 1G to 4G, where value creation migrated upwards. The rigid Soviet system, however, could not adapt due to fundamental differences in societal systemic thinking. Following the collapse of the Soviet Union, a platform economy did not emerge; instead, a feudalistic oligarchy was rapidly established.

More often the studies on system structures and their dynamics are much more focused and they lack the perspective of system state transition. However there is a large number of studies for instance on platforms which are useful, especially when their transformative power is considered. Horizontalization of technologies and the consequential emergence of platform economies are powerful forces because they liberate and democratize innovation and value creation, while the platform maintains predictability and provides the network. Often the best value capture position is with the platform owner rather than with the innovator on the top of the platform, unless the innovator is able to create the next level platform by himself. Ancient cities along the Silk Road also functioned as platforms for traders between East and West but more recent examples include web search, video game platforms, taxi services and more (Kretchmer et al 2020).

While many studies on system structures and dynamics tend to be narrowly focused, neglecting the perspective of system state transition, research on platforms offers valuable insights, particularly when considering their transformative power. The horizontalization of technologies and the subsequent emergence of platform economies are potent forces, liberating and democratizing innovation and value creation while the platform owner maintains predictability and provides the underlying network. The most advantageous position for value capture often lies with the platform owner, rather than the innovator building on the platform, unless the innovator can establish a subsequent platform of their own. Just as ancient cities along the Silk Road functioned as platforms for trade between East and West, contemporary examples include web search engines, video game platforms, and ride-hailing services and more (Kretchmer et al., 2020).

However, platforms also enable the growth of new verticals, and when such growth occurs without reasonable limitations, even idealistic movements like the internet and the development of blockchains and cryptocurrencies become susceptible to winner-take-all phenomena. The new services utilizing AI will include the same potential and therefore the systemic design and modelling of the future ecosystems is so fundamentally important.

5.4. Learnings

A fundamental question is how to balance growth and sustainability. While this is not a novel inquiry, a key point is that observing historical developments through systemic thinking, such as applying theories and models related to complex adaptive systems, can enhance our understanding of the broader picture and inform the development of relevant control mechanisms. The metaphor of business as an ecosystem, popularized by James Moore, provides a relevant framework for analysis (Moore 1993).

Societies, like businesses modeled as ecosystems, do not operate uniformly but rather exhibit a dynamic interplay of four distinct behaviors. Charles Fine's double helix model provides a framework for observing these behaviors, with particular attention to the dimensions of open vs. closed and centralized vs. decentralized.

Drawing on terminology from complex adaptive systems, these four behaviors can be described as states characterized by fixed, periodic, or strange attractors, while a fourth state lacks an attractor altogether. In natural ecosystems, these states might be represented by a zoo, farm, jungle, or cockfight, each involving biological entities but managed and controlled fundamentally differently. In the context of human systems, Harakka examines three of these systems, Kasarmi, Kasino, Kansankoti (Harakka 2022) and Homer in his epic story of Odyssey depicts this as a navigation challenge between Skylla and Charybris. The Narrow corridor (Acemoglu&Robinson 2020) also discusses the challenging and fragile state between the two dystopia but it does not address the main focus of this paper, i.e. how this ridge rather than a corridor has in essence two separate modes of operation: the complicated model: federated and regulated oligopoly system and a separate complex model: network effect driven monopolistic system.

Systemic states and transitions in societies and businesses are similar, where the rules of competition and collaboration define the structural elements. Boundary conditions, such as critical resource availability, fuel growth, while limitations on network effects, such as open critical interfaces and explicitly defined restrictions on power misuse, maintain a level playing field. Furthermore, the rules of competition, such as service obligations will shape the business dynamics. The role of open interfaces is critical, since they can be used to increase network effects or reduce the market power of closed systems while the freedom to make choices is the final lever for the consumers to become an active market actor.

These observations align with principles found in European political thought:

- *Liberté*: The extent to which individuals or companies can utilize available resources.
- *Égalité*: The power balance between actors, controlled and enforced to varying degrees.
- *Fraternité*: The capacity of actors to interact and cooperate effectively, akin to using a common language, facilitated for instance by standards.
- *Freedom of Choice*: The capacity for consumers and citizens to exercise their will and make choices, which is critical for the effectiveness of both democracy and market economies.

Mobile communications and the broader ICT ecosystem offer a unique context for understanding historical developments, not merely as a sequence of events but as a systemic structure where a limited set of boundary conditions and structures can manifest in diverse behaviors that cannot be fully understood by observing the behaviors alone. The initial transition from 1G to 2G mobile communications was a great success story, systemic change was implemented in a coherent manner.

The next systemic change that should have been done in the 3G when the digitalization and internet started to overtake the value creation of basic telecommunication would have required much more profound analysis and decisions to create a next version of Table 2, to rethink all the principal factors and this way to maintain the momentum. This never took place but rather there has been continuous debate, challenges and difficulties to make the technology to support the two paradigms simultaneously.

Thanks to the novel engineering and persistent standardization the later generations of mobile networks have been able to respond to these conflicting requirements surprisingly well. However, this evolution path could have been far more straightforward, efficient and even better in value creation if these systemic factors would have been taken into account already in 3G.

Assuming even partial relevance of these learnings, the question arises: can these levers be used to develop new businesses with well-defined evolution paths, including paths that allow for short term unpredictability? This challenge is analogous to predicting climate change despite the inability to forecast weather beyond a few days.

While a comprehensive answer is beyond the scope of this study, the aim is to stimulate interest and curiosity in systemic modeling and thinking

6. For new opportunities

A practical question is how to leverage the learnings of mobile communications in the context of the slowly developing European data economy. A specific opportunity may emerge in the context of the AI Act[10], particularly its requirements related to high-risk AI-driven services and applications, in conjunction with other EU legislation, to foster new business models for Europe. By following the development path observable in mobile communications it may be possible to create "blue ocean" markets instead of red ocean competition in selective domains of well being (as defined by Stiglitz et al. 2009). This is not only an issue of data economy but the evolving regulatory landscape for communication networks is also relevant.

The success of mobile communications serves as a valuable model for Europe, as it is aligned with the political landscape of the nascent European Union: a semi federalistic framework of independent member states seems to prevail. The competition and collaboration among telecommunications operators were structured through a licensing model. While this model in

10EU AI Act https://www.europarl.europa.eu/topics/en/article/20230601STO93804/eu-ai-act-first-regulation-on-artificial-intelligence mobile communications has matured, it established a globally leading business that remains a significant technological force. There is still a significant growth potential within the globally harmonized 5G and 6G technology platform. The driving force is however on the higher layers of network independent applications and services. The expected growth of the data traffic requires doubling of the capacity every 5 years.

With more proactive regulatory intervention, the long-term evolution might be even more attractive. The focal point of the new regulative activities must naturally be the services and applications, i.e. the data economy. The current approach in the data economy regulations, however, is mainly prohibiting and limiting, only. During the early days of mobile communications this was balanced by very well defined, proactive, even mandated actions, such as spectrum auctions and federated oligopoly market definitions. Currently this side of the regulatory tool box is completely missing. It is possible that right today, there is an exceptional opportunity to create blue ocean markets through regulations. This is quite a rare situation and therefore may not be such an obvious idea.

The four levers defined in the previous chapter will influence the market opportunities through their impact on the innovation possibilities (Bauer Bohlin 2022). By using those measures regulators can preset the market to function in one of the systemic market models, discussed in chapter 3. It is also possible and in general also desirable to utilise different market models for different use cases (or domain of well being). It may also be useful to note that these different models have clearly different benefits and disadvantages. For instance the de jure monopoly maximises the control while minimises the choice for the end users. De jure oligopolistic markets seem to be more effective in utilising the critical resources and encourages the innovation focus to address the bottle necks rather than consumer value. Obviously loosely controlled markets maximise the innovation opportunities and often provide highest value through differentiation to the consumers. Under strong network effects this market dynamics leads very easily to winner take all monopoly positions. Therefore it is quite important to pay attention to the problem that is supposed to be solved by the planned market model.

To visualize this opportunity four options may be proposed to be developed on the top of the 5G/6G platform. The option based on the federated and regulated oligopoly system model is the **identified blue ocean opportunity** for federated, regulated set of member states a.k.a. for the European Union. All the other systemic options may be built on the top of the same configurable platform but those options do not promise any specific competitive advantage for Europe.

The evolving mobile network will support any and all of the value creating options, the services and applications running on the top of the mobile network. However, the priorities in defining the details of the communications layer, will be driven by the service layer promising the highest value creation opportunity. Figure 5 aims to illustrate the part of the high level architecture, services and applications on the top of the network with optimised slicing. The systemic coherence (or alignment) between the network and application layers is a meaningful consideration to facilitate fast and credible innovation diffusion and service adoption for both the services and applications themselves as well as the enhancements for the network.

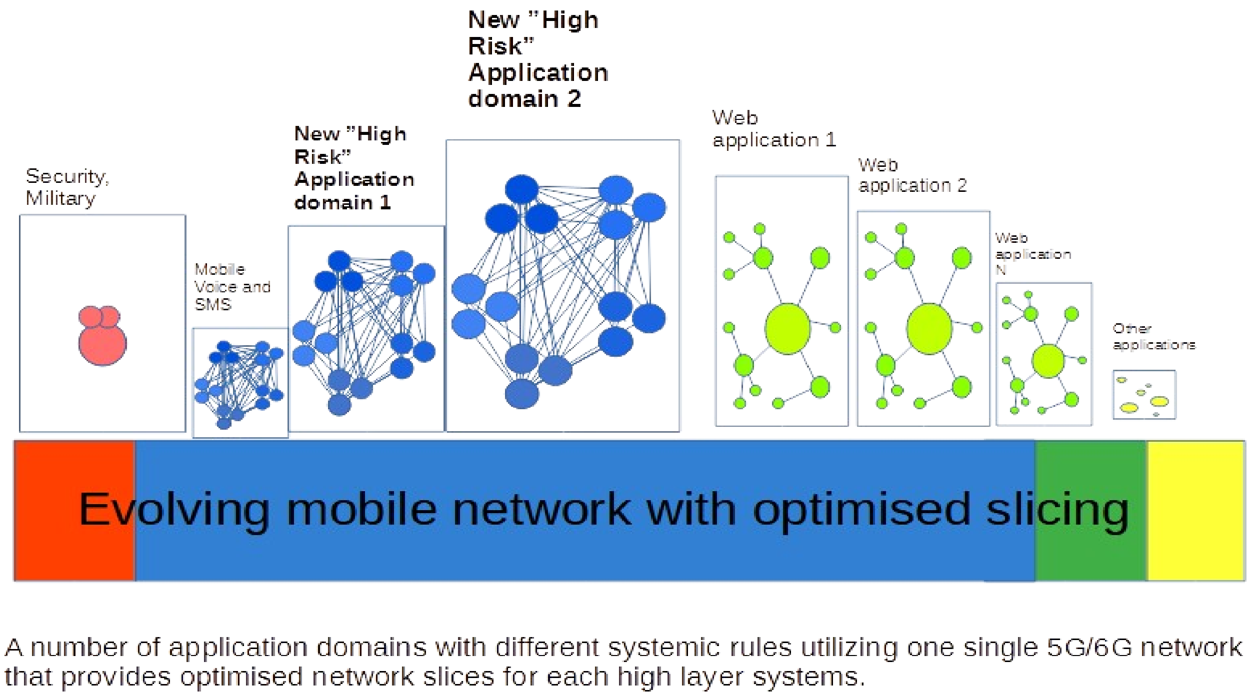


Figure 5. Four systemic options on the top of the evolving 5G/6G network

The emerging AI based applications in the “High risk” category provides this exceptional opportunity for such a systemic alignment. It aligns itself to the critical resource driven de jure oligopoly system of the critical resource driven mobile communications. The critical resources are different but the system model to maximise the sustainable utilization of the critical resource calls for the same or similar market mode. The other categories defined in the AI ACT fall easily in alignment for other market models, monopoly for prohibited use cases (if some of this still needs to be allowed), low risk category aligns with the network driven monopolistic market and no risk category aligns from systemic perspective in some sense to perfect competition.

For the success of future systems and services, active systemic thinking is important not only in the beginning but there has to be continuous monitoring and further interventions when necessary to maintain the momentum. This observation is very valid also for the next two examples, both falling into the category of "High Risk” services as defined in the AI ACT.

Identifying new opportunities can begin by examining the European Union and the world through a similar lens that was used in the early days of mobile communications. Although the world has changed, some pockets of well-being still exist, where similar boundary conditions and structures prevail as in the 1G era of mobile communications.

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Example 1 Ground Traffic

Ground traffic offers an example. Competition and collaboration are often rather limited on rails, while road traffic approaches perfect competition. Collaboration among automobile drivers is minimal, and competition and value generation are constrained by strict policies, taxes, and also law enforcement. Although limited information technology tools have been introduced to reduce costs, no new value has been created within the ecosystem (Ali-Vehmas&Casey 2015).

Given the need to modernize road traffic due to new energy sources and their impact on current fuel taxes, as well as congestion and limited road capacity, the critical resource scarcity presents an opportunity for systemic intervention.

Introducing pan-European mobility operators, licensed to manage traffic on the road system, could mirror the introduction of mobile telecom operators, licensed to operate radio systems on scarce spectrum within a partially federated union.

This new mobility operator model should incorporate similar boundary conditions and structural elements to the telecom model, including open interfaces, licensed access to scarce resources, service obligations (extending coverage to commercially unprofitable areas), legal intercept capabilities, and elements from the 5G toolbox. This would naturally be in alignment with the 5G telecommunication system dynamics, which would facilitate the fast adoption and motivate faster deployment of 5G.

To illustrate the necessary proactive actions a question arises: What would be the necessary actions to make for instance the firms operating the parking garage payment services to make them manage the mobility service also in the case when the automobile is moving from one garage to another ? Charging and managing the driving on the streets and roads! Additionally a large range of personalised services could be offered ranging from discount prices outside of peak hours to extra fees for by-passing the traffic jams, and many other opportunities. Personalised driving experience would make the end users prefer new ways of operating similarly as they learned to prefer mobile phones over fixed telephony.

The paradigm shift is significant. It will require redefining all road traffic related specific fees and taxes to be managed and collected through these mobility fees instead. This would enable a totally new way to make the users pay volume based charges in a transparent way facilitating a major shift towards sustainable traffic and transportation. Furthermore, since the road traffic is not limited to national borders, using the federated regulatory oligopoly model would be the natural way forward in Europe and later beyond.

To maintain the trust and privacy, it is important to offer these services on a commercial basis whereas legal intercepting is a functionality requiring a similar process as in the telecoms.

This new mobility ecosystem constitutes a radical restructuring of the business. It will require sustained political support but offers the potential for a blue ocean growth strategy, addressing the key aspects in green transition using digital technologies and building upon a paradigm of systematically regulated domain of well-being.

It may be useful to note that almost all of the necessary technologies are already available even in use on a small scale. The proposed example is a rather low hanging fruit if compared to the massive 10 year development of the 2G network 40 years ago.

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Example 2: Health care services

Another potential area for a similar systemic change is in healthcare. The fragmented European market lacks competitiveness, and significant obstacles hinder growth and prosperity. The healthcare sector operates on a century-old systemic model, initially adopted by factories and later replicated across various sectors. This conveyor-line model has been abandoned in data-driven businesses, where data has become the new source of value.

While establishing new licensed operators may not be necessary in healthcare, the market dynamics resemble those of 1G in mobile communications, necessitating a transition to 2G. However, the tools and steps differ, with the main bottleneck being the "tragedy of the anticommons": complicated and unclear rules governing consumer data utilization. The focus should shift to value creation through primary use of data (providing new value for primary data owners), beyond secondary uses.

In health care the information management should therefore be separated to operate on the top of the physical traditional health care. These already existing organizations could become those 2G health care information operators if their operating rules were defined proactively to follow the 2G mobile communications federated de jure oligopoly setup. In essence these health data information operators should be allowed to provide their services beyond their initial physical service provider to other service providers, too. Furthermore, the consumers should have the possibility to choose the information operator based on the value the operator is able to provide using the primary date of the consumer. And this model could be extended beyond national limits, too, to cover the whole EU.

By the information operator licensing the use of many other health related personal data sources could be connected to the service. For instance data from the social networks could reveal significant additional information for the health care specialists to gain a more holistic view on the situation. All use of personal data, any data must always be authorised by the person him/herself.

Example 3: AI Agent based Virtual me.

As a third example a novel new service based on the AI Agent approach is discussed.

The dynamic team of AI Agents running on a mixture of hardware and software platforms is building a network of digital servants. These servants are imitating the knowledge bases, awareness and actions of the person who in this way is virtualizing his or her presence in multiple places and roles into one holistic entity, Virtual me based on a dynamic set of AI Agents.

In the context of this paper it is important to consider the structure and communications needs of these AI Agents. They will physically run as a software in not just one cloud but in reality in several different clouds and most likely in different data centers all over the globe.
Furthermore, some of them may also run in smaller computers, in automobiles and other vehicles and also in mobile phones, laptops etc. the person is using in his or her daily life. Edge cloud processing is necessary due to delay and other similar constraints while large data centers take care of other computing intensive parts.

All in all there is a significant new value created in such a system from the personal perspective, which is the primary interest of the person him or herself.

These AI Agents will generate order or magnitude higher data traffic and the human users can generate. This sets clearly higher demands to the network capacity and also requirements for a variable set of network qualities.

Depending what kind of AI applications these agents are running, the network will have to follow the different regulatory requirements of different risk levels as defined in the AI ACT. If the system follows the current model of the mobile telecom, there will be a number of different regulatory sandboxes in different parts of the system, which requires rather complicated management of identities, trust and security elements.

As illustrated in the Figure 5 above, the underlying network may or may not be sliced and aligned with the higher layer risk level driven categorization. It may be useful to note that the applications creating the highest new value to the user will also drive the optimization of the system, including the underlying network functionalities. Hence, it is important to pay attention which of the over the top ecosystems will create more value than others and how those ecosystems are aligned with the structures and dynamics of the mobile communications network.

AI Agents is a new paradigm to add significant new value but this paradigm shift can be used also to limit the power of network effects and avoid winner take all situations and liberalise the market in a similar way as the telecom monopolies were broken, i.e. market was liberalised 40 years ago. This is now possible if the requirements of AI ACT are implemented in an innovative way.

The use cases of an AI Agent Virtual me are not discussed exhaustedly here. This is an opportunity for the reader to look towards the future with optimistic lenses.

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These brief examples illustrate the potential for similar systemic changes in other domains governed by the AI Act. The so-called high-risk AI application and service domains are subject to the same dynamics. Reorganizing the pan-European job market (including immigration management), improving the pan-European education system, and enhancing financing (especially with the increasing use of cryptocurrencies) represent additional opportunities. The common general observation is that a public service is public service also in case it is operated by private actors. This liberal model has turned out to be an exceptional success story for Europe in the case of mobile communications. There is no reason to believe it can be implemented in several other domains of well being and carefully taking the necessary systemic dimensions into account, in good mutual alignment.

This paper does not aim to exhaust all necessary discussions and new thinking in Europe. Instead, it encourages readers to step back and analyze the underlying factors that influence competition and collaboration, and their implications for value generation and capture. Further detailed effort is needed for instance to analyse the proposed examples 1 and 2 using the systemic modelling drafted in Chapter 3 especially in Table 1 and Table 2. This analysis could provide multiple considerations for a number of policy recommendations both for new regulations for network cluster as well as for other clusters and the interfaces between all of these entities.

7. Conclusions

Systemic modeling of business ecosystems offers a unique perspective for understanding systems through their fundamental constraints and path-dependent behaviors, rather than solely relying on visual observation at a single point in time.

This approach facilitates learning and the development of disruptive businesses, whether driven by regulations and policies, market actions, or a combination thereof.

Europe successfully introduced 2G mobile communications but gradually lost its leadership as value creation shifted to higher layers of the overall ICT architecture. Wherever the centers of value creation locate is critical to the emphasis on how features and functions are further developed in other parts of the architecture.

The strengths and unique characteristics of the European Union persist, albeit with limited recognition. Europe is largely attempting to emulate the value creation models of applications and platform services originating primarily in the USA. Instead, Europe should identify untapped well-being domains and reconstruct sustainable, federated, licensed de jure ecosystems, as implicitly already suggested by various acts and directives. Decisive explicit decisions that would propel the European data economy onto a rapid growth trajectory remain outstanding. Such decisions should incorporate elements akin to those implemented in mobile communications 40 years ago. Current regulations and policies impose numerous restrictions and boundary conditions but do not foster the emergence of European and national "operators." Further work is needed to establish rules governing competition and, particularly, collaboration, while safeguarding consumer choice.

Harmonizing the fragmented data market in the EU is challenging. A technology and standards-based approach, akin to that used in GSM, should be pursued concurrently. "The best is the worst enemy of good." Configurable standards would facilitate service adoption within the EU and enhance the acceptance and adoption of European systems outside the Union.

There is no need to concede in the technology-based global competition. Rather, we must carefully select our battles and strategies.

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TO BE CONTINUED

Annex I Systemic states and collaboration

The four systemic states in the systemic modeling is a rather broadly used concept. Partially this has been recognised for many years for instance in Public-Private Partnership literature. In a modern society there are however more actors and actor groups. Beyond Private (large scale enterprise) and Public (Government) it is crucial to also consider how groups like the 3rd sectors and universities (People) and even single human beings (Persons) can participate, basically on an equal basis.

The original PP Partnership model utilizes the Triple Helix concept (Etzkowitz & Leydesdorf 2000) while there is an extension developed later, the Quadruple Helix (Carayannis & Rahkmatullis 2014) to provide the full picture.

Therefore, when considering the potential collaboration between any and all of these four different system dynamics it is important to note their different drivers and expectations, systemic sets of rules. It is easy to fall into a state of disorder instead of value increasing and sharing dialogue.

Therefore the systemic thinking should consider beyond PP partnership to include Private and Public but also People and Person as an actor archetype, hence PPPP -Partnership.

Figure AII.1 illustrates the three out of total 12 different collaboration modes between different types of parties.

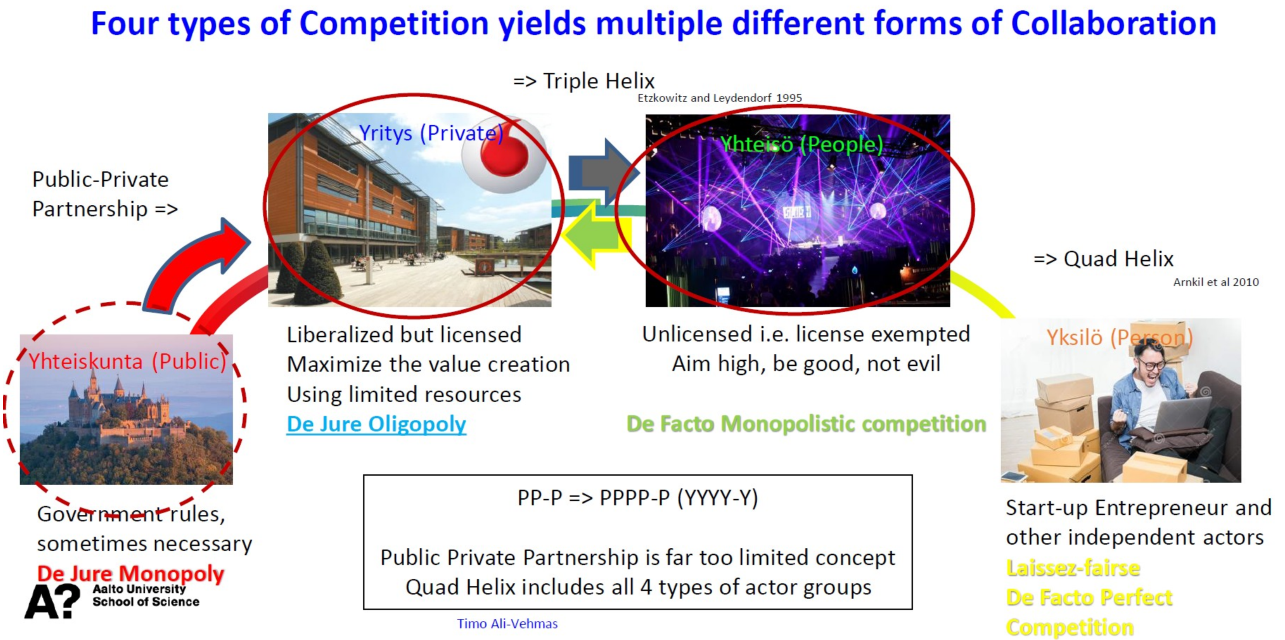

Figure AII.1. Four types of competition models and some of their PP Partnership relations

Annex II Different levels of platforming

Platform is a tool to standardize and optimise operations with the aim to reduce all cost factors, development costs, investments and operating costs. The simplest type of platform, Internal platforms have been used since the dawn of the industrial era. More recently platforms have been provided also to the external users (customers of the platform provider) to allow them to benefit also (Gawer 2000). These both types of platforms are single sided, the platform owner provides and the platform to their customer only.

The digitalization has enabled a third level of platforming to emerge, the two-sided platform initially provided by Google in the search engine, connects more “sides” to the same platform and separates the sides from each other. More generally, *“Many if not most markets with network externalities are two-sided. To succeed, platforms in industries such as software, portals and media, payment systems and the Internet, must “get both sides of the market on board.” Accordingly, platforms devote much attention to their business model, that is, to how they court each side while making money overall.”* (Rochet Tirole 2003).

When more independent and separated parties are connected to the same platform the system becomes a multisided platform (Hagiu, Wright 2015). More recently when more than one multisided platforms utilizing the same primary data are connected together, the ever growing network effects and new possibilities to create new value multiply the power of such platforms on the marketplace.

FIgure AII.1 illustrates the evolution of the platforming

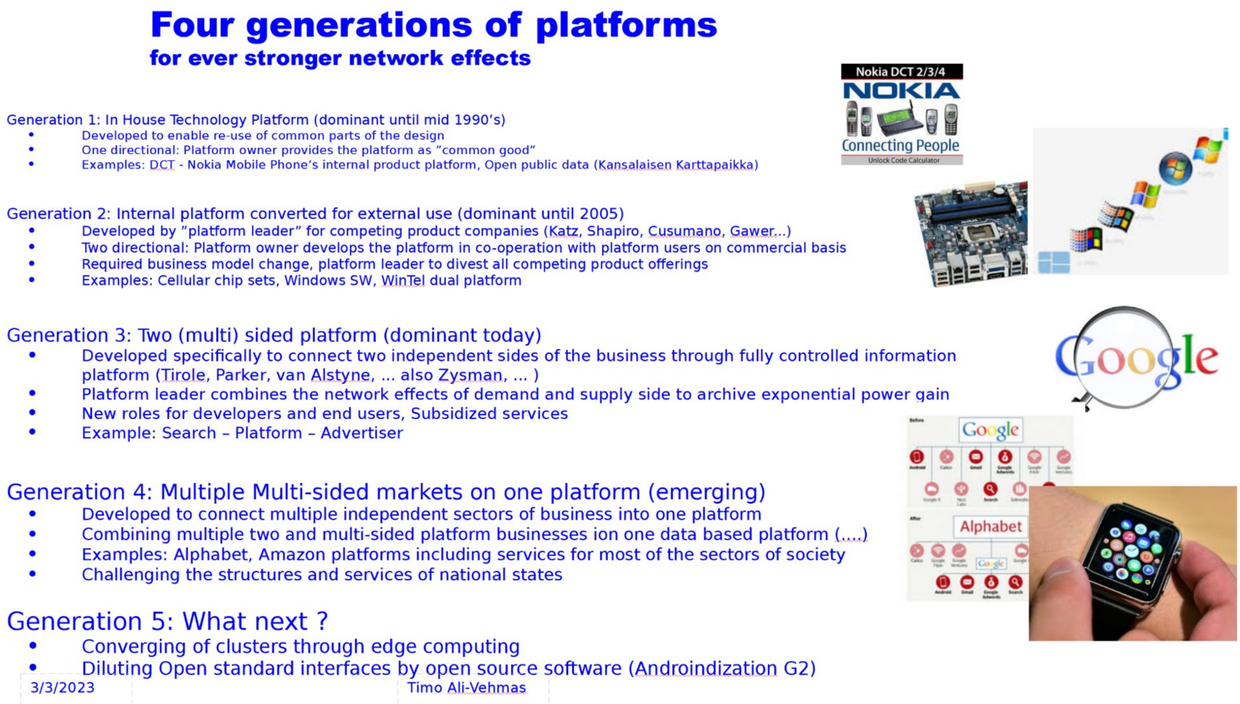

Figure AII.1 Four generations of platforms

Annex III Systemic Clustering of the ICT

In analyzing ICT-driven value system boundaries, this paper adopts Martin Fransman's (2010) framework, which identifies four key layers or clusters within the 'ICT ecosystem': networked element providers, network operators, content and application providers, and consumers. To ensure long-term strategic relevance, this analysis employs a multi-dimensional approach to define sustainable boundaries for these actor groups, recognizing that value creation-based structures alone may lead to transient conclusions.

This paper uses the term 'cluster' to neutrally refer to these layers, avoiding any inherent prioritization between layers, actors, or actor groups, while still indicating commonalities within each grouping. Clusters are identified by their core technical asset (e.g., 'network') rather than the legal entity controlling the asset (e.g., 'network operator'). Adapting Fransman's (2010) framework with these clarifications, the recognized clusters and their interfaces form the high-level structure for ICT-driven value systems.

The clusters of the ICT-driven value system are defined as follows:

Cluster 1: (Content) This cluster encompasses all forms of aggregated digital content, including music and movie libraries from major content brands. Increasingly, public and private databases (big data) in sectors such as healthcare and education are becoming integral parts of this cluster. Content and application providers manage this cluster. From the implementation perspective the Content is assumed to be located mostly in the cloud.

Cluster 2: (Network) This cluster includes all infrastructure for transporting digital content and connecting stakeholders. Key components include global mobile and fixed communication networks. Network control functions are typically embedded, while implementation technologies are increasingly cloud-based. Both licensed network operators and other actors may operate the network entities and systems.

Cluster 3: (Device) This cluster comprises all consumer products and gadgets connected via Cluster 2 that enable the consumption, control, and augmentation of content from Cluster 1. These devices provide the physical user interface for accessing the capabilities of the value system. Examples include smartphones, automobiles, televisions, home appliances, and medical equipment, often interconnected locally.

Cluster 4: (Personal Data) This cluster recognizes that consumers own their personal data. While historically underdeveloped, the role of personal data is rapidly evolving due to the growth of the Internet of Things and related data-driven phenomena. Control rights and ownership of personal data are subjects of ongoing regulatory debate. This cluster includes data stored on SIM cards and similar data, irrespective of the physical storage medium, as well as any personally identifiable data, such as user-generated content on social networks. Separating personal data from the person is analogous to separating the network from the network operator

These clusters have been identified using generic degrees of freedom in knowledge generation (Fransman, 2010); conversely, a lack of such freedom yields a similar structure. Control mechanisms imposed by regulation have been extensively studied, as exemplified by research on network neutrality (Wu, 2003; Bauer, 2010) and mobility for roaming subscribers in the Universal Mobile Telecommunications System (UMTS), using either Mobile Station (MS) or Subscriber Identity Module (SIM) roaming (Rapeli, 1995), all of which demonstrate consistent results.

From a system dynamics perspective, such regulation aims to manage the intensity of positive and negative feedback loops within the system. Holistic analyses of value systems necessitate consideration of both cluster-level factors and inter-cluster dynamics. This includes the impact of actors (companies) operating across multiple clusters, thereby influencing the strength of system-level feedback loops. While all ICT-driven value systems incorporate elements from each cluster, their specific implementations vary on a case-by-case basis.

The four clusters define (4 – 1)! = 6 interfaces, representing symbiotic relationships (Fransman, 2010), between the clusters. From a system dynamics perspective, the role of these interfaces is as critical as that of the clusters themselves. The key interfaces between the ICT clusters are defined as follows:

- **Interface 1: Content and Network:** This interface defines the boundaries and limits bundling between content and network services, such as the provision of quality of service for specific content (e.g., Net neutrality).
- **Interface 2: Network and Device:** This interface supports device interoperability and restricts technology-based lock-in possibilities (e.g., open-air interface standards).
- **Interface 3: Device and Personal Data:** This interface separates device identities from end-user identities, limiting the bundling of mobile devices and subscriptions (e.g., compliance with the General Data Protection Regulation (GDPR)).
- **Interface 4: Content and Device:** This interface is weakly defined, with various bundling models existing without consistently promoting openness and competition.
- **Interface 5: Content and Personal Data:** This interface is also weakly defined, with various bundling models existing without consistently promoting openness and competition.
- **Interface 6: Network and Personal Data:** This interface focuses on end-user personal data (e.g., number portability and related regulations).

Of these six interfaces, four (1, 2, 3, and 6) are systematically recognized, meaning that the rules governing openness and bundling are defined through institutional elements such as laws, regulations, and standards. Interfaces 1 and 2 are particularly widely adopted. Each key interface plays a significant role when market actors seek new opportunities, such as bundling functionalities from different clusters to enhance value creation and capture. Interfaces with weak regulatory requirements are often diluted by highly competitive service, product, and technology bundles.

The clusters are often presented as a logical vertical stack of layers separated by horizontal interfaces (shown as pairs of arrows pointing at the interfacing clusters, with de jure unbundling shown as solid lines, and possibilities for de facto bundling as dotted lines), as illustrated in Figure AIII.1."

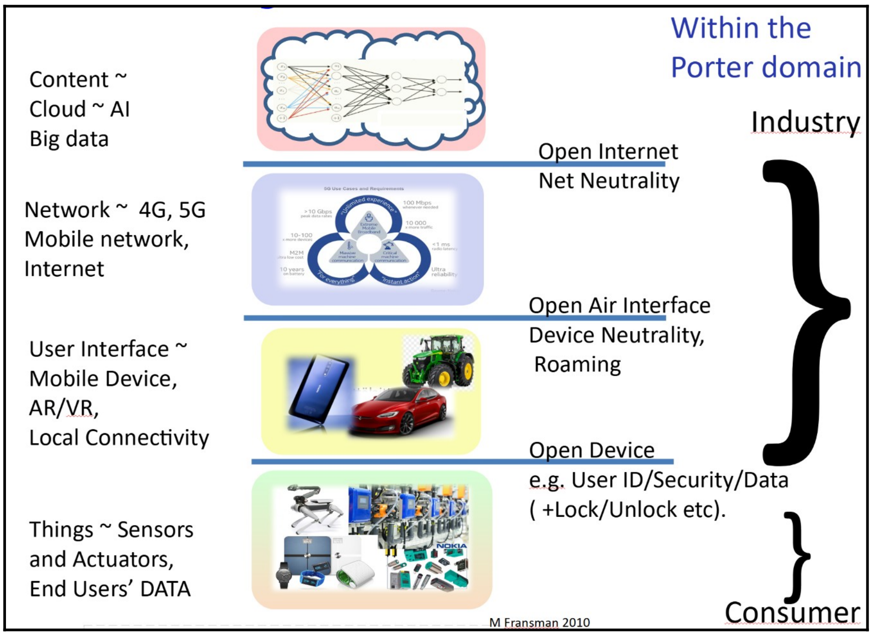

Figure AIII.1. ICT architecture as a stack

In the future, weakly recognized and managed interfaces will require comparable attention to other key inter-cluster interfaces, particularly given the increasing influence of network effects across interrelated industries (Heinrich, 2014). The conventional vertical stack model with horizontal interfaces has fostered a conceptual framework where regulations and standards address the market horizontally, while companies often pursue vertically integrated business models. This notion is partially misleading, as it can inadvertently diminish the importance of Interfaces 4-6, which are not explicitly represented as "horizontal" in such diagrams. Therefore, it is beneficial to re-conceptualize the stack, representing all clusters as equally important. This approach provides a more balanced perspective on the functional division of labor within ICT clusters (Fransman, 2010) and their high-level boundary interactions (represented as arrows), as illustrated in Figure AIII.2

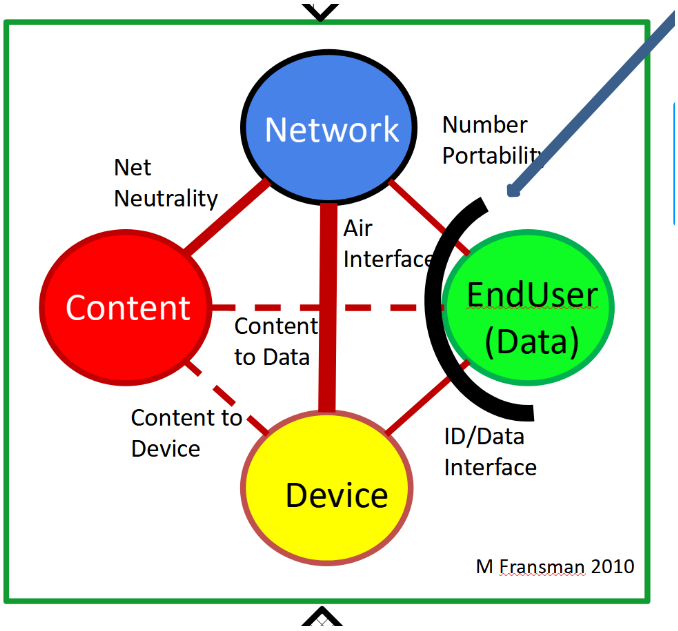

Figure AIII.2. ICT architecture is symmetrical position with all 6 embryonic interfaces visible

In this representation, well-defined interfaces are depicted with solid lines, while weakly recognized interfaces are indicated with dotted lines. This allows for flexible application of both vertical and horizontal conceptual models. The symmetrical presentation of the clusters facilitates adaptable analysis, enabling each interface to be examined in a "horizontal" position and related to potential "vertical" bundling strategies. While each ICT cluster comprises numerous actors offering competing products and services, the systemic nature of the ICT landscape necessitates collaboration between competitors and partners both within their respective clusters and across different clusters. The interface designed to protect end-users and their data is highlighted with a black arch, emphasizing its critical role in contemporary data economy considerations.