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On the Modeling of Mobile Service Ecosystems

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Abstract

All ecosystem models are just rough approximations of reality. In the case of communications ecosystems, numerous actors interact with each other and create an incredibly complex process that tends to depress even the most diligent modeler. In recent decades, various methods have been used to solve this dilemma. This paper provides an account of some of the methods, including system dynamics, agent-based modeling, and value network analysis. In addition, an ecosystem model implemented in a spreadsheet format is discussed in more detail. An ecosystem model can be used to assess the relative importance of different factors, such as pricing and service quality on the profitability of service providers. Extensive ecosystem models are useful for enhancing our understanding of the complex processes occurring in ecosystems. In contrast, the models are hardly applicable for predicting how an ecosystem will evolve in the long term, because no ecosystem model can include all the influencing factors.

Keywords: Modeling, ecosystems, mobile services, quality of service

Introduction

The often-used maxim "All models are wrong, but some are useful" is devoted to George Box (1976).¹ The statement is also legitimate in the context of business analysis of mobile service providers that often are called Mobile Network Operators (MNO) in a technical context. A person responsible for designing a network operator's business strategy must build an economic model to make predictions about the effect of different business decisions. In the simplest case, the model can be the person's intuition based on her own experiences. From a certain perspective, the model is then a true neural network in the person's brain. The person is aware of the results of her intuitive analysis: one strategy thought by the person feels better than another does. The person may test her intuitive model by changing some limiting conditions and assessing the subsequent feelings, and thereby, she might be able to build a simple mathematical model that resembles her intuition. In contrast, it is impossible to find out the real (neural) model located in the person's brain, since the neural model is mixed with all other, hugely complex neural networks in the brain.²

¹ See also Sterman (2002).

² There are about 300 million adjustable parameters in each cubic millimeter of cerebral cortex, the outer layer of brain (Hasson et al. 2020).

In addition to pure intuition, an expert may use simple financial models to describe some aspects of the operator's business. For example, there may be one model to explain how price affects service demand (Munnukka 2005) and another model to explain how service quality affects the quality of experience (Fiedler et al., 2010). The result of a strategic analysis is based on an interaction between economic models and intuitive models. None of the models, economic or intuitive, would be correct or exact in any strict sense. The main method used by a group of researchers depends mostly on the tradition on their specific field of research. In a technical field, like communications networks, the tradition has been to use either closed-form mathematical expressions or network simulations. In the fields of economics and management, there have been different traditions usually applying top-down or system level approaches.

I spent the first half of my research career modeling communications networks and the other half combining technical and economic methods and models. This paper describes the most important insight gained during this research career. The paper is organized in the following way. First, I give a short account on my own experiences on modeling communications networks, services, and businesses. Then I outline other possible methods for analyzing and modeling of different processes occurring in the context of communications networks and services. Despite the numerous other options, I ended up using spreadsheets to build an extensive ecosystem model. The ecosystem model is explained in more detailed before the conclusive remarks at the end of the paper.

Background

The primary source for the thoughts presented in this paper is my personal experiences in modelling communications networks, services, and ecosystems. Therefore, I give a brief account on those parts of my professional career that are related to ecosystem modeling. My first serious attempt of modeling was to analyze the performance of switching structures used in Asynchronous Transfer Mode (ATM) networks. For this purpose, I started to build a traffic simulation tool from scratch in 1988 using Turbo Pascal and a personal computer with Intel 80386 processor. Compared to the current software development environments, the limitations in Turbo Pascal and in the computer capabilities essentially restricted the complexity of traffic models. The first version of the simulation tool consisted of a switching and queuing system fed by a large number of ATM simple traffic sources. In the later phase of the research, I concentrated on another closely related topic, connection admission control in ATM networks. Then the traffic model consisted of three layers: ATM cells, bursts of cells, and connections. The main outputs of the simulations were the average cell loss ratio and the average queuing delay.

The overall philosophy of ATM was that every connection through an ATM network has to comply with a pre-defined set of requirements, most notably, bit rate, cell loss probability and delay. If the network assumed that it could not satisfy all the requirements, then the network did not accept the new connection request. I studied this particular issue in my doctoral thesis (Kilikki 1994) by using the simulation tool as the main research method.

I began to be aware of some of the serious limitations in the model already when I wrote my thesis. First, it was assumed that traffic demand was independent of anything happening inside the network. There was no adjustment to any kind of changing condition. Network congestion or a change in price did not have any effect on the input traffic process. If there was not enough capacity to satisfy a connection request, the customer simply abandoned the request. Then if a connection request was accepted, it was assumed that the customer paid the bill based on the requested properties of the connection.³

When I was finalizing my thesis on ATM, the Internet emerged and changed everything. In the Internet, there were no real connections but loosely defined flows of packets that tried to adapt to the changing conditions in the network. In the Internet, pricing did not depend on any quality requirements on the level of connections. There were no quality guarantees, but only a best effort service based on an ad hoc solution called TCP/IP.

As to my modeling efforts, three changes happened in parallel. First, I changed by job from Tele (a service provider now part of Telia) to Nokia. At Tele, I wrote every line of the simulation code myself; at Nokia, there were more sophisticated simulation tools and many specialists in the field of network simulations. Second, I changed by topic from ATM to Internet and IP. Third, I took the issue of realistic human behavior much more seriously than during my ATM research. Consequently, I discontinued my coding effort and, instead, wrote a book about differentiated services or DiffServ (Kilki 1999). The book was not based on any extensive models or simulations but on my (limited) insight in realistic user needs and in how those needs could be satisfied with something better than best effort service, but without strict guarantees.

One of the main lessons from the ATM and DiffServ research was that what really happens in reality depends essentially on the business relationships between different actors. For me as a researcher, it meant that I had to widen the scope of my research. However, it is a big leap to move from ATM or IP traffic simulations to analyzing the complex behavioral patterns of users and business actors. Without an extensive understanding of the multi-level interactions between different actors, it is impossible to make a realistic evaluation of the demand for different kinds of communication service. That was the starting point for my next phase of research, ecosystem modeling.

At that point of time, 2002, I started to seriously ponder whether it could be possible to build a tool that integrates the separate models from IP traffic to operator business in a way that a person without any expertise in most of the topics included in the model could make reasonable operational, business, and strategic decisions. A long development process with the following five phases ensued:

³ Many researchers were aware of the problem of pricing in a situation where one application, video, consumed much more resources than the then most important application, phone call (Odlyzko 2001). The willingness to pay for entertaining video was smaller than the willingness to pay for phone calls. Nonetheless, the awareness of this dilemma did not lead to any change in the philosophy of ATM.

1. The first goal was to build a comprehensive scientific model used solely by the model developer (this phase took about 2 years).
2. The revised goal was to build a less intricate model for consultation purposes (4 years).
3. The third goal was to build a comprehensive ecosystem model for educational purposes (6 years).
4. Hibernation (6 years).
5. The last goal has been to write an article of ecosystem modeling in general (1 month).

With the funding and professional support from Nokia, I returned to coding, took Matlab and spent numerous months to design and code a model covering all the levels from IP packets to customers selecting between different services offered by mobile service providers. I succeeded to build the core of the model. Unfortunately, the model was too complicated and confusing and it had too many input parameters to be of any practical use. Nokia stopped the project because the project did not offer enough business potential for Nokia⁴; subsequently, our research team was moved to support consultation business.

As a result, I abandoned coding and moved to utilize spreadsheets, that is, Microsoft Excel®, as many consultants do. Of course, the spreadsheet format involves many hard constraints. From an ecosystem modeling viewpoint, the hardest problem was the implementation of feedback loops. At the same time, some restrictions are advantageous for a model builder of my type that tends to design as complex a model as the platform allows.

The first version of my ecosystem model implemented in Excel was aimed to support the consultation services offered by Nokia. In addition to the extensive ecosystem model, I used considerable efforts to model several phenomena related to communications services, including the network effect (Kilkki & Kalervo 2004), long tails (Kilkki 2007), value of time (Pohjola & Kilkki 2007), and quality of experience (Kilkki 2008). All of those models are incorporated in the ecosystem model.

Other methods for ecosystem analysis

The juncture from self-developed simulation tools to another method offered, in principle, an opportunity to compare the merits of different modeling approaches. No such a comparison was made then but now we can look back and assess what kinds of alternative ways for ecosystem modeling were available. The requirements for the methods and tools depend on the research questions. In my case, the most important questions were:

- 1) What is the demand for mobile services (voice, text messaging, mobile data, etc.) as a function of Quality of Service (QoS), price, marketing, and other relevant aspects?
- 2) How the differences between mobile operators influence customer churn and market shares within different customer segments?

⁴ In retrospect, the decision was well reasoned.

- 3) How the changes in services demand and market shares influence the business of service providers?

The context of the first question is a service monopoly while the other two questions consider the effect of real competition between service providers. One critical requirement is that the model must give *some* numeric estimates, not only qualitative insight. Instead of Excel, I could have used at least structural equation modeling (SEM), Bayesian networks, game theory, system dynamics, agent-based modeling, value network analysis, and value network configuration.⁵

Structural equation modeling is an extensively used method particularly in sociology and psychology (Anderson & Gerbing 1988). It has also been the dominant method in marketing and business analysis from the 1980s (Martínez-López et al. 2013). For instance, Baker & Crompton (2000) used SEM to analyze how much perceived quality affects the behavioral intentions of festival visitors. One of their conclusions was that “the total effect of performance quality on behavioral intentions was .79, of which .38 was indirect via satisfaction.” All of the three concepts were constructs based on questionnaire answers, not objective performance measures or real decisions. In the context of mobile service, SEM were rarely used before 2010. During the last ten years, some noteworthy articles have used SEM to study the use of mobile services. Zarpou et al. (2012) introduce constructs “perceived ease of use” and “perceived usefulness” to predict “behavioral intention” in the context of mobile services. Similarly, Kuo et al. (2009) used constructs “service quality,” “perceived value” and “customer satisfaction” to assess “post-purchase intention.” Park & Kim (2014) used constructs “perceived usefulness”, “service and system quality,” and “attitude” to predict “intention to use.” None of these articles used objective, measurable parameters in their analysis. Yamazaki et al. (2012) is a rare example using SEM to combine subjective quality of experience (QoE) measurements and objective QoS parameters to predict user satisfaction.

Many findings in SEM studies related user and customer behavior are relevant when building ecosystem models. On the contrary, SEM is hardly applicable on a technical level of IP packets or connections. In principle, SEM could be applicable on the level of business decisions, but in practice, it would be extremely difficult to gather a sufficient number of participants making similar business decisions to allow a reliable statistical analysis.

One potential method is Bayesian networks. In the mobile ecosystem context, Bayesian networks have been used for QoE modeling (Mitra et al. 2013 and Nourikhah & Akbari 2016) and for analyzing the features affecting the popularity of mobile phones (Kekolahti et al. 2016). The main obstacle to the successful application of Bayesian networks is that it requires considerable amount of relevant data. Even a huge amount of data is not helpful if the data does not include relevant information. Conversely,

⁵ I started my modeling career from packet (or more accurately, ATM cell) level simulations and then extended the models upwards to connections and users. It is hard to ignore models and tools you have used (more or less successfully) through a long research career and start from another direction. When that kind of decision is made, the real change takes considerable amount of time and effort.

if there is not enough data, no reliable analysis is possible even if all relevant aspects are, in principle, covered by the collected data. This requirement essentially limits the questions that can be answered by Bayesian networks.

Game theory could be used to model the decisions made in mobile networks when allocating limited resources, like spectrum, between users or between mobile operators (Charilas & Panagopoulos 2010). Moreover, game theory can be used to predict service providers' decisions about service pricing. However, game theory does not solve the problem of defining the starting point of the analyses. Many important questions remains, for instance: what is the level of pricing that is acceptable for customers or what is the additional cost of required infrastructure due to increased service demand? Game theory can provide helpful insight in the behavior of some actors in communications ecosystems but its scope is relatively limited.

A more versatile method is agent-based modeling (ABM) (Gilbert & Troitzsch 2005, Bonabeau 2002, and Twomey & Cadman 2002). Agent-based modeling can be used to evaluate systems in which actors make independent decisions based on the information available for them. In the context of mobile services, agent-based models are used to analyze the use of secondary spectrum (Tonmukayakul & Weiss 2005), network switching and multihoming (Finley & Basaure 2018) and customer churn in mobile markets (Hassouna et al. 2016). As these examples demonstrate, the most reasonable levels of analyses are users (when mobile services are used) and customers (selection between services and operators). Agent-based modeling is not reasonable on a purely technical level except in some special cases in which network equipment operates independently based on local information; adaptive routing is a potential example. Agent-based models may also include the decisions of mobile service providers while the customers of mobile services for the great majority of actors.

There also are several frameworks working on the level system understanding, see e.g., Forrester (1994). Different terms and frameworks are used to analyze mobile ecosystems, including system dynamics (Pagani & Fine 2008, Casey & Töyli 2012), network value analysis (Peppard & Rylander 2006), and value network configurations (Casey et al. 2010). The main strengths of these frameworks are in the illustration and visualization of the complex relationships between different actors. These frameworks also enable rough numerical analysis (see, e.g., Ruutu et al. 2017). In practice, they are not well suitable for detailed analysis, for instance, for evaluating how a certain change in pricing affects the profitability of the service provider.

Techno-economic modeling, in turn, concentrates on the analysis of the cost of building and operating mobile networks, while profit calculations are based on average revenues per user (ARPU) (Harno 2010). The ecosystem model presented in this paper could be classified as a techno-economic model with more detailed user and customer models than what are typically used in techno-economic models.

Table 1 provides a summary of the tools and methods at different levels of analysis. Typically, the inputs of a model on one level are based either on the measurements on the same level or on the results of the next lower level. Because a model or method seldom covers more than two levels, more complex integration of models must be performed through the mind of an expert. The ecosystem model is an attempt to integrate network, user, customer, and service provider models into one comprehensive model.

Table 1. Actors and methods on different levels

Actor	Objects	Decisions	Measure of success	Measurement tools & data	Analytical method
Legislator, regulator	Ecosystem	Laws, regulation	GDP, well-being	Macro-economics happiness studies	System dynamics, VNC, VNA
Service provider (executive team)	Services	Strategy, pricing, investments, contracts	Profit, market value	Financial statements, annual reports	Game theory, TEM
Customer	Subscriptions, products	Selection of products and services	Satisfaction with service (as a whole)	Surveys, sales data	ABM, BN, SEM
User	Calls, sessions	Start and end calls and sessions	Quality of experience	MOS	ABM, BN, TAM
Network element	IP packets	Accept or reject packets	Quality of Service	Traffic measuring tools	Network simulations

Abbreviations: ABM = Agent-based modeling, BN = Bayesian networks, GDP = Gross domestic product, MOS = Mean Opinion Score, TAM = Technology acceptance modeling, TEM = Techno-economic model, SEM = Structural equation modeling, VNA = Value network analysis, VNC = Value network configuration.

Ecosystem Model

The special property of the ecosystem model described in this section is its scope: the model covers all levels from IP packets to service providers. The most detailed parts are used to model the behavior of users and customers. The service provider level contains cost modeling whereas the actual pricing and quality decisions are made by the users of the tool (or by the players of the game). As to the IP level, the network operator is able to define some key quality parameters, including network coverage, service availability, and drop rate. The required amount of network devices and the required network capacity are calculated automatically based on the required quality parameters and service demand.

The ecosystem model is divided into six modules illustrated in Figure 1:

- **Applications** where average bit rate, relative benefit and usage and effort are calculated as a function of QoS. The models are, in principle, independent of the application, but in practice, many of the required conversion functions are application-specific.
- **User behavior** where monthly usage, net benefit and user satisfaction are calculated as a function of price, relative benefit, relative usage and effort. These calculations are done separately for each application, but the model itself is the same for all applications.
- **Customer behavior** where purchase decisions are calculated based on price, net benefit, user satisfaction, expected benefits, brand value, and network coverage.
- **Networks** where the required network resources (base stations, link capacities and RNCs) are calculated as a function of network load, network coverage, and QoS requirements.
- **Network operator** where CAPEX and OPEX are calculated as a function of required network resources. In addition, the module defines monthly decisions on QoS for each application and the access rate for mobile data services.
- **Service providers** where the share of customers in each service category and the profit per month are calculated. In addition, this module defines monthly decisions on prices per application and marketing efforts and focus of marketing.

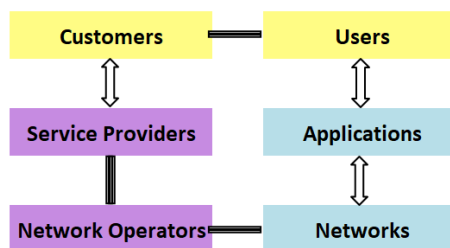


Figure 1. The main modules of the Ecosystem tool. Each module is implemented in a separate Excel file. Symbols: \equiv one-to-one mapping, \Leftrightarrow orthogonal mapping.

As to the dimensions, the ecosystem model contains four customer segments (early adopters, early majority, late majority, and laggards⁶), four service providers, three product categories (basic, advanced, and special), four applications (voice, text messaging, data, and video), and three types of region (urban, suburban, and rural). In theory, this would mean $4 \times 4 \times 3 \times 4 \times 3 = 576$ different combinations of user needs, prices, qualities, applications, and regions. However, regions do not form completely independent dimension in the implemented model but they are primarily used for cost calculations. Thus, there remain $4 \times 4 \times 3 \times 4 = 192$ combinations, which is a manageable complexity but somewhat arduous to handle in a spreadsheet format. A small set of input parameters are shown in Figure 2. The model includes about 100 common parameters and about 100 parameters for each service provider to define the starting point of the analysis.

⁶ The labels for customers segments and the shares of the segments are from Rogers (2010).

Some parts of the ecosystem model were relatively easy to build. In the case of voice, user satisfaction on a MOS scale could be estimated based on bit rate, drop rate, and packet loss ratio, because various studies about these relationships allow the development of a reliable model. Video was a more difficult object for modeling when the first version of the model was developed around 2008, because adaptive video coding was still under development. At that time, there were still strong opinions in favor of providing a special service for video streaming through the Internet.⁷ In the current version, the value of video connection is a logarithmic function of actual bit rate, which, in turn, depends on the available network capacity.

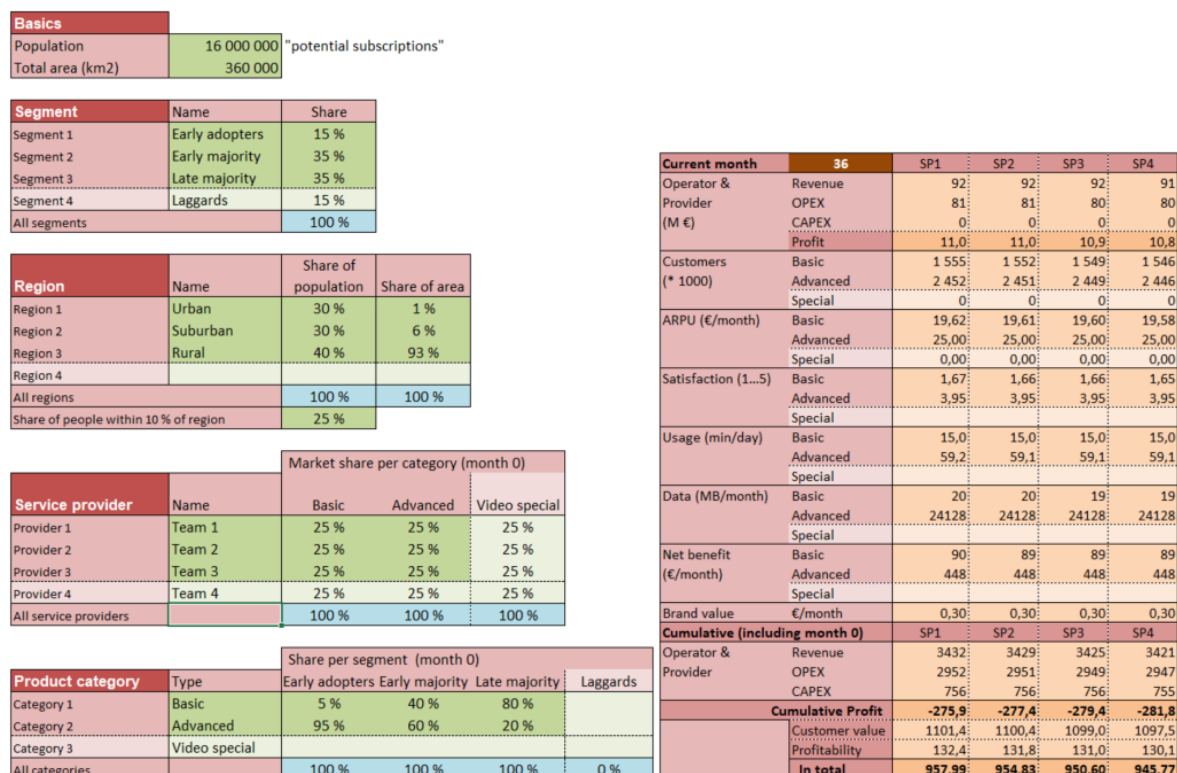


Figure 2. Examples of user interface in the ecosystem modeling tool, inputs on the left and outputs on the right.

The most challenging task in model development has been the integration of the effect of marketing on the generic customer model. The basic philosophy of the ecosystem model was that each service provider has a marketing budget proportional to the population, which is then directed to a specific aspect of the service. For instance, the service provider may use ten cents per inhabitant to advertise (low) price or (high) service quality.

Another possibility was to use the marketing budget for improving brand image, which, in turn, affected the choice between different service providers in addition to more objective criteria, like price, geographical coverage, and (measurable) service quality. In practice, the use of marketing for any other

⁷ The model included the possibility to offer special service for video streaming with own pricing and quality properties. However, that kind of video service did not provide any business advantage under the assumptions made in the model. Video streaming is offered nowadays through mobile data without any special arrangements.

purpose than the brand image was difficult to manage – we may just considered this as a weakness of the model, but it may also reflect real difficulties in creating effective marketing campaigns.

Ecosystem model as a game

The ecosystem tool was used on a course for master’s degree students at Aalto University from 2010 to 2015.⁸ Table 2 presents the main results of a game played by four groups of students in 2014. At the case presented here, the students were already familiar with the tool and they had played one round of the game. At this last stage of games, they were asked to plan in advance all their moves for the period of 36 months without knowing the moves of the other teams.

Table 2. The results of a game played by master level students in 2014. Basic (B) includes phone and text messaging (sms), Advanced (A) includes phone, sms, and data, Special (S) includes phone, sms, data, and video. Flat rate is monthly fee, voice price is per minute, sms price is per message, and data is per MB.

	Changes in pricing: Flat rate + phone + sms + data + video	Other changes	Later changes in prices	Total profit Value of customers ===== Game points
Team 1	B: 6 € A: 18 € S: 32 €	QoS improvements, better coverage, focus of marketing to price esteem 3 → 5	Gradually up to B: → 11 → 30 A: → 24 → 40 S: → 39 → 80	-132 3440 ===== 3308
Team 2	B: 15 € A: 7 € + 5c + 5c + 3€ S: 27 €		No changes	-502 3136 ===== 2634
Team 3	B: 9 € A: 11 € S: 19 €	Better coverage, additional marketing (A), focus of marketing to price, esteem 3 → 5	Gradually up to B: → 16 → 80 A: → 29 → 136 S: → 41 → 200	109 1187 ===== 1297
Team 4	B: 4.99 € + 6c + 6c A: 18 € + 6c + 6c + 4.50€ S: 12 €		S: First up to 15 € then down to 12 €	-505 1088 ===== 583

The teams applied two different strategies based on their earlier experiences of the game. Teams 1 and 3 started with relatively low flat rates to attract customers and later raised prices first with small steps and eventually more steeply. Teams 2 and 4 were more conservative with only moderate changes to parameters during the game. Team 3 increased the price too aggressively at the end of the game and,

⁸ The main reason for not using the tool on any later course was that the ecosystem course was combined with another course. The introduction of the tool required a considerable amount of teaching time and due to the wide scope of the new course, it was not reasonable to spend so much time for a specific topic of operator business.

consequently, lost most of the customers over the last two months; team 1 was more successful in implementing a similar strategy.

In a way, this game was a test how well the game worked against manipulative strategies. One of the problems with this type of game is that the length of the game is known in advance, which makes it possible to exploit strategies that do not take into account what would happen afterwards. There were also some problematic details in the model. In the previous year, one team noticed that negative prices could be used to manipulate customer behavior without crashing the game; the feature was removed in the next version of the game. It is very difficult to design a complex game that is both realistic and hard to manipulate.

Lessons

One of the main lessons during the development of the ecosystem tools was that the balancing between simplicity and accuracy is notoriously difficult. The first phase of model development ended when the Matlab simulation consisted of six nested loops from IP packet handling to the operator's profitability; the outcome was incomprehensible. The most reasonable solution to the complexity problem is first to divide the model into separate module and then to define the interactions between the modules as clearly and systematically as possible.

Real service providers are sometimes willing to discuss the challenges of their business development with an academic researcher but hardly ever are willing to share any sensitive information related to pricing and service design. This makes it very difficult for a researcher to verify any business model with real data except what is publicly available for instance in annual reports. Still, various model parameters can be adjusted in a way that the inputs (e.g., price) and outputs (e.g., usage of service) of the model correspond to the real figures. This was done with the ecosystem model for the Finnish mobile market in 2010 – 2014 in a way that if a service provider used the typical prices and access rates in Finland, the business of the service provider was modestly profitable and the average amount of mobile data was about 0.5 GB/month/user.

In terms of service design, the strongest conclusion from the student experiments was that the dominant strategy for pricing always was a common flat rate for all applications (voice, text messages, data, and video). If one service provider adopted flat rate, other service providers could not compete with it without moving to flat rate pricing. Usually, but not always, the urge to compete with each other led to fierce price competition. Since the game did not include anything resembling bankruptcy, an aggressive team with very low prices could ruin the business of other teams, too.

Ecosystem model version 2020

In the last phase of the development of my ecosystem models, I updated the ecosystem tool to reflect the 2020 situation. In practice, I checked what kinds of changes are needed to successfully simulate the current situation in the Finnish mobile market. The following updates were sufficient:

- Base station, RNC, and link capacities were multiplied by 15 without changing the price per network element.
- The expected daily usage of all applications was doubled from 20 to 40 minutes. Due to model properties, the actual daily usage was increased to about 60 minutes.
- The ability of video applications to satisfy basic user needs was increased from 6% to 30 %.
- The factor describing the elasticity of data usage as a function of the maximum bit rate was downgraded from 0.5 to 0.25. This means that the amount of downloaded data increases more slowly when the access rate is increased than in the 2014 version. Without this change in the parameter, the amount of downloaded data in the 2020 version would have been 58 GB/month instead to 24 GB/month.

The last change was the only change in the “internal” parameters of the model. All other changes could be justified by external reasons, particularly, by the rapid technical development of mobile devices and infrastructure and by the increase of the importance of video services. As a result of these changes, the optimal access rate was increased from 3 Mbit/s to 50 Mbit/s and the total data usage was increased from 900 MB/month to 24 GB/month. Thus, the ecosystem model produced a realistic picture about the current mobile operator business in Finland with relatively small updates. Of course, this success does not guarantee that the ecosystem model is correct in the sense that it could be used to make reliable predictions about the effects of different interventions or further development in general.

It seems, however, that we can make a trustworthy analysis about the *relative importance* of different issues on the service provider’s business. The method to study this issue to utilize ecosystem tool in a way that the four service providers compete against each other. A good strategy (related to pricing and service quality) is a strategy that leads to better business performance than what the competitors obtain. The criterion for the strength of provider’s business is the same as in the version played by the students: $\text{business result} = \text{“the cumulative profit over 36 months”} + 12 \times \text{“last month’s profit”} + 12 \times \text{“the number of customers”} \times \text{“the average revenue per user per month.”}$

Tables 3, 4, and 5 illustrate the sensitivity of this result to a change of three parameters: flat rate price (€/month), access rate (Mbit/s), and drop rate (average number of service interruptions per hour). Each service provider selects each of these parameters at the beginning of the game without changing any of them during the game lasting 36 months. The expected values for the parameters are: flat rate is 25 €/month, access rate is 50 Mbit/s and drop rate is 0.3 interruptions per hour. The middle column show the business result when all providers use the same values for all parameters. The left columns show the results when one provider decreases the value one of the parameters while other three providers keep all the parameters intact. Similarly, the right columns show the results when one provider increases the value one of the parameters while other three providers keep all the parameters intact.

For instance, the first row in Table 3 indicates that if one operator decreases price from 15 €/month to 14 €/month while other operators keep price at the level of 15 €/month, the operator’s result is -487

while other operators' result is -412. All these results are lower than the result (-374) when all operators use the price of 15 €/month. This means that no operator has an incentive to decrease the price.

Table 3. The effect of price on service providers' business results. In the left column, one service provider decreases price by 1 €/month. In the right column, one service provider increases price by 1 €/month. Access rate is 50 Mbit/s and drop rate is 0.3 per hour in all cases.

Price (P)	Result $3 \cdot P + 1 \cdot (P-1)$		$4 \cdot P$	Result $3 \cdot P + 1 \cdot (P+1)$	
	Result (P-1)	Result P	Result	Result P	Result (P+1)
15 €/month	-487	-412	-374	-357	-313
20 €/month	255	253	292	326	306
25 €/month	956	905	954	999	939
30 €/month	1644	1565	1614	1666	1578

Table 4. The effect of access rate on service providers' business results. In the left column, one service provider decreases access rate by 10 Mbit/s. In the right column, one service provider increases access rate by 10 Mbit/s. Price is 25 €/month and drop rate is 0.3 per hour in all cases.

Access rate (R)	Result $3 \cdot R + 1 \cdot (R-10)$		$4 \cdot R$	Result $3 \cdot R + 1 \cdot (R+10)$	
	Result (R-10)	Result R	Result	Result R	Result (R+10)
30 Mbit/s	1072	1180	1127	1089	1137
40 Mbit/s	1016	1065	1033	1007	1026
50 Mbit/s	955	978	954	935	937
60 Mbit/s	896	902	885	870	863

Table 5. The effect of drop rate on service providers' business results. In the left column, one service provider decreases the drop rate by 0.1 per hour. In the right column, one service provider increases the drop rate by 0.1 per hour. Access rate is 50 Mbit/s and price is 25 €/month in all cases.

Drop rate (D)	Result $3 \cdot D + 1 \cdot (D-0.1)$		$4 \cdot D$	Result $3 \cdot D + 1 \cdot (D+0.1)$	
	Result (D-0.1)	Result D	Result	Result D	Result (D+0.1)
0.2 per hour	913	934	938	942	943
0.3 per hour	950	951	954	958	951
0.4 per hour	966	959	963	967	955

The differences between the middle column and the left and right columns reveal the motivation of one service provider to change the value of each parameter, as illustrated by the color-coding. Green cells indicate that the change provides better result for one provider compared both to the original situation and to the result of the other providers. Conversely, red cells indicate that the change provides worse result for one provider compared both to the original situation and to the result of the other providers. Yellow and blue cells indicate mixed results.

Table 3 suggests that if the provider considers only its own result, the optimal flat rate is around 25 €/month. In contrast, if the provider is more concerned with its relative success compared to others, then the optimal flat rate would be around 20 €/month. Obviously, price is highly critical factor for the service provider's business. In particular, if all service providers could somehow harmonize their prices, the result would be much better for all of them than what any service provider can achieve through individual optimization.

The effect of access rate (maximum bit rate between the mobile phone and the base station) is noticeable but still essentially smaller than the effect of price. If price is doubled from 15 to 30 €/month, the result is improved by 1988 units; if the access rate is doubled from 30 to 60 Mbit/s, the result is reduced by 242 units. Moreover, the differences between the middle column and the right column is too small (about one percent of the result) to justify hardly any intervention related to access rate in the region between 30 and 60 Mbit/s.

As a common observation, the effect of other service quality parameter is smaller than the effect of access rate. For instance, Table 5 shows the effect of drop rate. The differences between results on each row are so small (mostly less than 1 percent) that it would be unreasonable to use the analysis as a basis for changing service quality, either up or down. The situation is the same with other quality parameters. If one service provider increases the packet loss ratio for voice calls from 0.1 to 1 percent, its result in the game would drop from 954 to 944.

It shall be stressed that the results in Tables 3, 4, and 5 are based on a model instead of reality. The overall results are, however, so clear and compelling that the following three observations can be made:

1. Pricing is by far the most important factor to determine the success of mobile service providers.
2. As to the technical performance, access rate is clearly the most important aspect.
3. As to other quality parameters (e.g., packet loss ratio or drop rate), there is a threshold after which any improvement has only a minor effect on the success of the service provider and, thus, provides no basis for creating competitive advantage.

These findings are in line with the results of a comprehensive study about the effect of network quality on user satisfaction (Finley et al. 2017): although access rate is the most important quality parameters, there is only a weak connection between measured access rates and user satisfaction. Similarly, the

results in Kekolahti et al. (2016) indicate that price and brand are more important aspects than any technical feature when selecting a new mobile phone.

In addition to the technical and pricing aspects, the service provider has one more critical activity, marketing. Although the model contains a relatively complex model to consider the effects of marketing, the model does not allow any realistic analysis of the effectiveness of marketing. The most obvious element of marketing is that without any marketing effort, the brand awareness and brand value decline and gradually diminish the attractiveness of the service provider and its services. In the ecosystem model, a service provider that does not spend money at all for marketing over a period of three years is usually a little bit more profitable than other providers but at the expense of a shrinking market share. This property of the model is not an emergent feature; rather, it is based on the insight of the model designer.

Conclusion

This paper gives an overview of efforts to model communications ecosystems at various levels, based on a brief literature review and a somewhat longer account of the development of one specific tool to analyze the key aspects of communications business. As a part of the literature study, a framework with five levels from IP packets to ecosystems is outlined. At each level, different actors make decisions and use different measures of success, tools for gathering data, and methods for analysis. The detailed discussion about the merits and problems with the available methods is left for further research.

Moreover, the paper explains an ecosystem modeling tool implemented in Microsoft Excel. The original aim of the tool was to utilize it in consultation services but in practice, it has been used mainly for educational purposes. As to the lessons learnt about the business of service providers, the most important factor defining the success of a provider is the price of services. Other relevant factors are type of pricing (usage-based pricing or flat rate), brand, and the access rate while other quality issues are of lesser importance. The models cannot be used to prove these kinds of claims; instead, the ecosystem model is able to demonstrate that it is possible to create a consistent and plausible model that supports many reasonable claims. In a way, the main use of an extensive ecosystem tool, like the ecosystem tool described above, is to verify the consistency of the opinions of the model developer. A model that is consistent and corresponds to reality can then be used to make predictions about the short-term effects of different interventions made by service providers and network operators.

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