Vesselkov, Alexandr; Hämmäinen, Heikki; Töyli, Juuso

Multihoming with Dynamic Mobile Network Selection

Published in:
International Journal of Business Data Communications and Networking

DOI:
10.4018/IJBDCN.2018070102

Published: 16/04/2018

Document Version
Publisher's PDF, also known as Version of record

Please cite the original version:
Vesselkov, A., Hämmäinen, H., & Töyli, J. (2018). Multihoming with Dynamic Mobile Network Selection: Possible Scenarios and Impact on Competition. *International Journal of Business Data Communications and Networking*, *14*(2), Article 2. https://doi.org/10.4018/IJBDCN.2018070102

Table of Contents

International Journal of Business Data Communications and Networking

Volume 14 • Issue 2 • July-December-2018 • ISSN: 1548-0631 • eISSN: 1548-064X

An official publication of the Information Resources Management Association

Research Articles

The *International Journal of Business Data Communications and Networking* is indexed or listed in the following: ABI/Inform; ACM Digital Library; Bacon's Media Directory; Burrelle's Media Directory; Cabell's Directories; CSA Illumina; DBLP; DEST Register of Refereed Journals; Gale Directory of Publications & Broadcast Media; GetCited; Google Scholar; INSPEC; JournalTOCs; MediaFinder; Norwegian Social Science Data Services (NSD); SCOPUS; The Index of Information Systems Journals; The Standard Periodical Directory; Ulrich's Periodicals Directory; Web of Science; Web of Science Emerging Sources Citation Index (ESCI)

International Journal of Business Data Communications and Networking
Volume 14 • Issue 2 • July-December 2018

Multihoming with Dynamic Mobile Network Selection:
Possible Scenarios and Impact on Competition

Alexandr Vesselkov, Aalto University, Espoo, Finland
Heikki Hämmäinen, Aalto University, Espoo, Finland
Juuso Töyli, Aalto University, Espoo, Finland & University of Turku, Turku, Finland

ABSTRACT

This article describes how mobile operators occasionally fail to provide adequate service quality due to network overload, blackouts, or coverage white spots. Customers can increase the quality of connections by multihoming, i.e. using subscriptions of several operators. Multihoming is facilitated by an innovative reprogrammable embedded SIM (eSIM) that can enable dynamic switching between networks. Although eSIM multihoming is advantageous, its future is not definite, as it is affected by multiple factors and actors with conflicting business interests. This paper defines scenarios for the evolution of eSIM multihoming and its possible impact on competition by constructing qualitative system dynamics models based on expert interviews. The results show that depending on market conditions and actions of stakeholders, multihoming may reach high diffusion, find application in special use cases, or fail to take off. With high diffusion, competition between operators will become more dynamic, and market share will be defined by the number of served sessions.

KEYWORDS

Always Best Connected, Embedded SIM, Embedded UICC, GSMA, Mobile Telecommunications, Qualitative Model, SIM, Subscription Management, System Dynamics

1. INTRODUCTION

Mobile data traffic has grown remarkably fast, with an increase of 18-fold within the previous five years (Cisco, 2017). This growth in traffic is one of the main challenges of mobile network operators (MNOs), which are constantly building new infrastructure to meet increasing consumer demands. Despite these measures, customers occasionally find themselves unable to use mobile services because of congestion, network blackouts, or coverage white spots. Researchers and practitioners are actively seeking ways of addressing these problems. Thus, some operators have exploited unlicensed spectrum bands by deploying Wi-Fi hotspots in public areas, while some others have used small cells operating in licensed bands to address both coverage and congestion problems. Apart from these measures taken by individual operators, cooperation between MNOs could potentially help to mitigate congestion by jointly optimizing network utilization. Different models of dynamic spectrum access have been proposed, varying in the extent of spectrum openness and collaboration between operators (Zhao & Sadler, 2007). However, despite the promising potential of spectrum sharing (Basaure, Suomi, & Hämmäinen, 2016), mobile operators have not been active in its implementation.

DOI: 10.4018/IJBDCN.2018070102

Problems due to congestion, network blackouts, or coverage white spots can also be addressed by customers by using several mobile subscriptions from different operators, which is referred to as end-user multihoming. Multihoming is particularly popular in developing and emerging markets. Multihomed customers typically use handsets with multiple Subscriber Identity Modules (SIM cards) that enable them to access the services of several operators with a single device. A recently developed reprogrammable embedded SIM (eSIM), which can become a new standard for SIM cards, can significantly advance end-user multihoming by enabling its smooth functioning in all eSIM devices. Embedded SIM can contain several operator profiles, corresponding to different subscriptions, which can be downloaded over the air. After profiles have been stored in a SIM, a user can swap between them locally. Therefore, embedded SIM may eventually help to implement the "always best connected" concept (Gustafsson & Jonsson, 2003) by enabling the dynamic selection of a network that provides the best combination of service price and quality.

However, the implications of embedded SIM on the business of mobile operators remain unclear. Since eSIM is reprogrammable and may contain several operators' profiles, it will reduce the customers' switching cost incurred when changing from one operator to another. The switching cost will be essentially zero if eSIM-based multihoming is widely supported and operator selection is fully automated and dynamic. This would likely significantly change the dynamics of market competition. On the other hand, the change in competition will be minor if eSIM-based multihoming does not penetrate the market or operator switching is strictly controlled by MNOs. Moreover, although eSIM-based multihoming with dynamic network selection may considerably affect the market, it remains unclear whether it will promote healthy competition, or lead to devastating price wars and a decline in investments. Therefore, this research aims to determine drivers and possible scenarios for the diffusion of eSIM-based multihoming, as well as the potential changes that it can bring to market competition.

The study utilizes causal loop diagrams for creating qualitative system dynamics models for the diffusion of eSIM and eSIM-based multihoming with dynamic network selection, as well as market competition under the conditions of eSIM-based multihoming. Potential outcomes of eSIM multihoming diffusion and its possible impacts on competition dynamics were further studied based on the constructed models. The models were created iteratively through extensive desk research and interviews with 13 experts. The results of this study can be relevant to policy makers in assessing embedded SIM as a tool for increasing market competition and for mobile operators in developing their eSIM and multihoming strategies.

The rest of the paper is structured as follows. Section 2 provides background information on the embedded SIM and reviews the related work. Section 3 presents the utilized method and information on the interviewed experts. Section 4 introduces the qualitative system dynamics models for the diffusion of eSIM and eSIM-based multihoming, as well as for the market competition with multihoming widely adopted. Possible scenarios for eSIM-based multihoming diffusion and the competition dynamics are presented in Section 5. The discussion of stakeholders' interest in eSIM-based multihoming is given in Section 6. Section 7 ends the paper with the conclusions of the study.

2. BACKGROUND

2.1. Embedded SIM

Machine-to-machine (M2M) devices constitute a growing share of mobile subscriptions. Just like smartphones, such devices use a SIM card for identification and authentication to the cellular network. To increase reliability and save space, SIM cards are often soldered to the surface of M2M devices. Typically, SIM cards contain pre-provisioned unchangeable credentials of a single Mobile Network Operator (MNO), meaning that in a home country, the device can access only the network of the operator that has provided the SIM card, and switching between operators is only possible by physically changing the SIM card. With soldered SIMs, this implies that M2M service providers become locked-in to an initially selected MNO. Solving this problem facilitated the development of Embedded SIM - a standard for reprogrammable SIM cards enabling remote and local management of subscriptions.

GSM Association (GSMA) started the development of Embedded SIM (eSIM) specification in 2011 (GSM Association, 2011). Embedded SIM was originally promoted as a standard for M2M devices. The usage of eSIM-based remote and local subscription management for consumer devices was initially ignored by mobile operators, likely because of business concerns (EY, 2015). However, as no technical limitations existed for applying eSIM in non-M2M devices, and as the value of such application was recognized, GSMA published an initial specification for consumer devices in 2016 (GSM Association, 2016). This specification, however, provides certain restrictions that limit the functionality of eSIM. For example, the specification limits the device to a single enabled (active) profile, which means that customers cannot access several networks simultaneously. Moreover, the specification states that local profile management, that is, switching between profiles already downloaded to the eSIM, must require explicit user intent and cannot be automated (GSM Association, 2017). Overall, these limitations seem to be set up artificially for decreasing the risks of losing customers.

2.2. Current Implementations of eSIM and Alternative Solutions

Multiple mobile operators, SIM manufacturers, and device vendors have piloted or committed to deploy products and services compliant to GSMA Embedded SIM specifications for M2M devices (GSM Association, 2015). However, little indication of commercial eSIM implementation can be found. The deployment of eSIM by carmakers, expected to be pioneers, is still in an initial stage. Likewise, eSIM-based consumer devices are nearly non-existent, with Samsung's smartwatch Gear being a rare example (Samsung, 2016).

Apart from eSIM, there are other solutions providing similar functionality. For example, many M2M devices use foreign SIM cards and operate in a permanent roaming mode to be able to access the networks of several local partner operators (Machina Research, 2016). However, roaming usage typically implies additional charges, and permanent roaming may be prohibited in some cases. Furthermore, traveling customers can use a Multi-IMSI SIM offered by some mobile virtual network operators (MVNO). These SIM cards contain several IMSIs (International Mobile Subscriber Identity), which allow subscribers to avoid high roaming charges by selecting and using a suitable identifier in each country. Unlike eSIM, the technology of multi-IMSI SIM often does not provide the capability for remote management or uses proprietary mechanisms. While a multi-IMSI SIM is intended for travelers, Google's MVNO Project FI[1] enables subscribers within the USA to change between three local cellular networks and Wi-Fi based on the signal strength and quality. This can be viewed as an early example of the "always best connected" approach.

Furthermore, devices with multiple SIM card slots (most often, two) enable end-user multihoming. Typically, both SIM cards are active at standby, but only one can be actively used at a time. However, recently device models with dual active SIM cards started to appear (e.g., Asus ZenFone 2 ZE550ML). Such devices include an additional radio transceiver and thus allow users to use both SIM cards simultaneously for circuit-switched communication. However, typically only one SIM is usable for mobile data access. Another disadvantage of multi-SIM phones is that fitting several SIM slots to a handset is problematic from the device design point of view.

2.3. Switching Costs

In a simple case, switching costs may induce so-called "bargain-then-ripoff" pricing (Farrell & Klemperer, 2007), when a supplier reduces the prices in the initial period to gain a customer base, and increases in a later period to "harvest" the locked-in customers. Therefore, in mature markets, which are in a later period, switching costs reduce competition and social welfare (Klemperer, 1987), which suggests the need for regulatory bodies to use policy to lower switching costs. One example of such policy is mobile number portability (Buehler & Haucap, 2004). At the same time, regulators should also consider the relationship between competition and innovation that was found to have an inverted-U shape (Aghion, Bloom, Blundell, Griffith, & Howitt, 2005), meaning that excessive competition may harm innovation and lead to a loss in social welfare.

In mobile telecommunications, switching costs manifest in financial costs, including a contract termination penalty, as well as in procedural costs, including the efforts required for the arrangement of a new subscription, change of a SIM card, and uncertainty about the quality of a new MNO. Although multihoming removes some of the switching costs, for realizing its full potential customers need to be able to compare the services of available networks to choose one of them for a communication session. Such a mechanism is necessary to ensure that customers receive the highest quality of service by using the best available network.

2.4. Multihoming and Dynamic Network Selection

While the "always best connected" concept is relatively well-researched in the context of heterogeneous cellular - Wi-Fi networks (e.g., Kassar et al., 2008), only few works consider combining several cellular networks for improving the service quality. Deb, Nagaraj, & Srinivasan (2011) developed a model, in which users holding devices with several simultaneously active radio interfaces (e.g. LTE and 3G) may associate applications and choose an operator at fine timescale for each radio interface. Their model showed 4-times capacity gains in comparison with using a single network. According to the authors, users' devices cannot independently collect sufficient information for efficient selection of a mobile network, and therefore they propose the operators to broadcast certain information for enabling appropriate network choices. However, as the authors acknowledged, there is a little incentive for MNOs to collaborate.

To facilitate the selection of the best available network, Evensen et al. (2011) suggested a method for bandwidth estimation through the lookup of a crowdsourced database that contains information on the service quality of available networks at a certain location and time. The main challenges of this method are database information gathering and its maintenance (Sonntag, 2016). In turn, Yuanjie et al. (2016) created a client-side service called iCellular, which enables mobile devices to select the best available operator based on low-level cellular information, such as QoS and radio profile of each available network, which is collected without attaching to the network and interrupting an ongoing connection. Since real network performance is hard to measure without the network registration, iCellular predicts the performance of each operator based on the collected cellular information.

Better seamlessness of dynamic network switching can be further achieved by using multipath protocols, such as Multipath Transmission Control Protocol (MPTCP). This protocol can increase the quality of service by enabling the use of multiple link-level channels (Sonntag, 2016). Moreover, MPTCP can automatically change a connection from one network to another even in the middle of a session. The development of MPTCP is ongoing, but so far MPTCP has not been widely used (Suomi, 2014).

3. METHODS

3.1. Qualitative System Dynamics

System dynamics method is widely used by researchers and practitioners for learning the structure and dynamics of complex systems and designing the policies for bringing these systems to desirable outcomes (Sterman, 2000). System dynamics focuses on the internal feedback structure of a system that generates dynamics through the interaction of variables presented in a model. A modeling process starts from a conceptualization phase, where a qualitative model is constructed. After that, modeling typically proceeds to a quantification stage, where numerical inputs are defined and causal relationships between the variables are quantified, so that the model can be simulated. However, sometimes the quantification of a model involves so many uncertainties that produced numerical outputs could be misleading. This is especially true when the problem under investigation is futuristic. In this case, a qualitative model provides valuable insights into the research questions without the danger of producing unrealistic numerical results (Coyle, 2000). In our research, the qualitative system dynamics modeling is used.

System dynamics models present key variables and causal relationships between them. These relationships can be of a positive (+) or negative (-) polarity. A positive (negative) polarity implies that the variables are changing in the same (opposite) direction(s). For example, with metered pricing, there is a negative polarity connection between a service price and consumption: the less the price, the more the consumption (ceteris paribus). On the other hand, the relationship between service consumption and average revenue per user (ARPU) is positive: the more the consumption, the more the ARPU (ceteris paribus).

The relationships between variables form feedback loops when a change in one variable alters other variables that eventually cause the initial one to change again. Feedback loops can be reinforcing (marked with R) or balancing (marked with B). Reinforcing loops include an even number of negative polarity links and result in an exponential increase or decrease of the variables in the loop, whereas balancing loops have an odd number of negative links and lead to a goal seeking and balancing behavior. The idea of system dynamics is to capture the interaction between different feedback loops that determine the evolution of a system.

3.2. Interviews

The models were created iteratively through extensive desk research and two rounds of expert interviews. During the first round, four experts were interviewed for determining preliminary model inputs, whereas during the second round the constructed models were checked through additional nine interviews. Table 1 presents background information on the participated experts and the codes assigned to them. The codes are used to refer to the interviewees in the rest of the paper.

4. CONCEPTUAL MODELS

First, we assume both the availability of technical components required for eSIM support, and tools for automated, transparent profile (operator) selection (since although currently prohibited by GSMA such selection is technically feasible). Furthermore, since mobile data is an increasingly important mobile service that is growing rapidly in terms of traffic (Möller et al., 2017) and revenue (Lopes, 2014), we assume mobile data as the primary service that handset algorithms try to improve and optimize through the operator selection.

The diffusion of end-user multihoming with dynamic network selection (Figure 2) is modelled as a two-stage process, which starts from the diffusion of eSIM among the end users (Figure 1). The models present the diffusion on the level of a separate national market.

4.1. Diffusion of eSIM

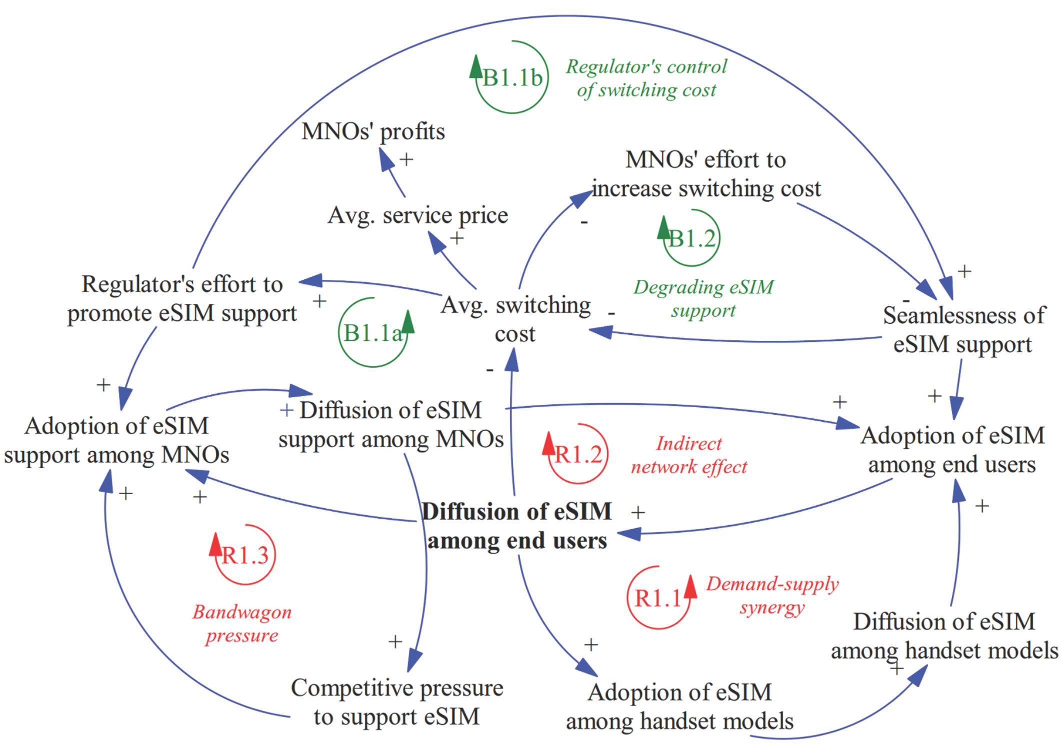
The *Diffusion of eSIM among end users*[2] (Figure 1) is the sum of eSIM adoption events divided by the number of handsets in use. eSIM can be implemented in a soldered or traditional removable form factor that can be retrofitted to existing handsets (MNO1, MNO2). The *Adoption of eSIM among end users* increases as the supply of handset models with soldered eSIM grows (*Diffusion of eSIM among handset models)*. Device manufacturers, in turn, start to produce more handset models with eSIM as they see the demand for such a feature, indicated by the growth in the diffusion of eSIM (soldered and removable), as reinforcing loop R1.1[3] "Demand-supply synergy" shows.

In the initial stages, handsets may be equipped with dual SIM cards, one of which could be a soldered eSIM. Thus, Apple iPad Pro comes with an empty SIM slot as well as soldered Apple SIM, which could be viewed as a proprietary version of a reprogrammable SIM[4]. This illustrates

Table 1. The background information on the interviewed experts

	Interviewee code	Organization	Position and field of expertise
Round 1	SV	SIM card vendor	Solution sales manager, SIM expert
	MNO1	Mobile network operator	Project manager, eSIM expert
	MNO2	Mobile network operator	SIM specialist
	EDU1	Research institution	Chief research scientist, Telecommunications
Round 2	EDU2	Research institution	Professor, Telecommunications
	MINTC	Ministry of transport and communications	Senior advisor
	REG1	Communications regulatory authority	Senior specialist, cyber security
	REG2	Communications regulatory authority	Head specialist, technical operability
	REG3	Communications regulatory authority	Chief specialist, spectrum management
	REG4	Communications regulatory authority	Chief specialist, stakeholders
	BC1	Broadcaster	Technology development manager
	BC2	Broadcaster	Strategy manager, technical systems
	DM	Device manufacturer	CTO, R&D director

Figure 1. Conceptual model for the diffusion of eSIM



the interest of device manufacturers in eSIM. In fact, some experts noted that the threat of Apple making own proprietary SIM that could become a de facto standard was one of the main drivers of eSIM standardization activities (SV, MNO2). Device vendors can be interested in promoting soldered embedded SIM because of the opportunity to improve the design of the devices (MNO1, MINTC). Moreover, with soldered eSIM, device vendors become new SIM owners, which allows them to utilize it as a secure element and take the lead in, for example, SIM-based NFC mobile payment solutions (MNO1, MNO2).

Some experts have noted that MNOs deliberately slow down the standardization and adoption of eSIM. This process was described as "driving with a handbrake on" (SV). Thus, loop R1.2 "Indirect network effect" shows that operators' unwillingness to support eSIM for handsets (*Adoption of eSIM support among MNOs*) may become one of the main potential barriers for the *Diffusion of eSIM among end users* (BC1, BC2, DM). Without operators' consent and technical support, remote and local management of subscription profiles may not be possible since MNOs may, for example, prohibit the provision of their credentials over the air. In this case, eSIM can be either unusable or used only as a traditional non-reprogrammable SIM if it comes from a factory with a subscription loaded. However, the growing *Diffusion of eSIM among end users* can put pressure on operators to introduce the support for eSIM. Furthermore, the *Adoption of eSIM support among MNOs* can be driven by the bandwagon effect, as loop R1.3 suggests (MNO2, REG1).

Finally, policy makers may use the support for eSIM as a tool for decreasing switching costs and promoting competition. Thus, if the *Average switching cost* is too high, a policy maker may mandate the support for eSIM to prompt its adoption and diffusion, which would lead to the reduction of the switching cost (loop B1.1a "Regulator's control of switching cost"). However, for taking such active steps, a regulator must be confident that customers and the market will benefit from the adoption of eSIM (REG2). Further, even if eSIM for handsets is supported, operators may try to offset the decrease in the switching cost by reducing the *Seamlessness of eSIM support,* as shown by loop B1.2 "Degrading eSIM support". This is because the switching cost affects the intensity of competition, decreases the price level, and ultimately affects *MNOs' profits*. Thus, operators may restrict subscription contract conditions, charge a fee for a subscription profile change (MNO1), or require their profiles to be deleted when a subscription of another MNO gets enabled, which would make eSIM multihoming infeasible. However, if too restrictive rules on remote or local subscription management are set, a regulator is likely to intervene and prohibit such practices (EDU2), as loop B1.1b illustrates.

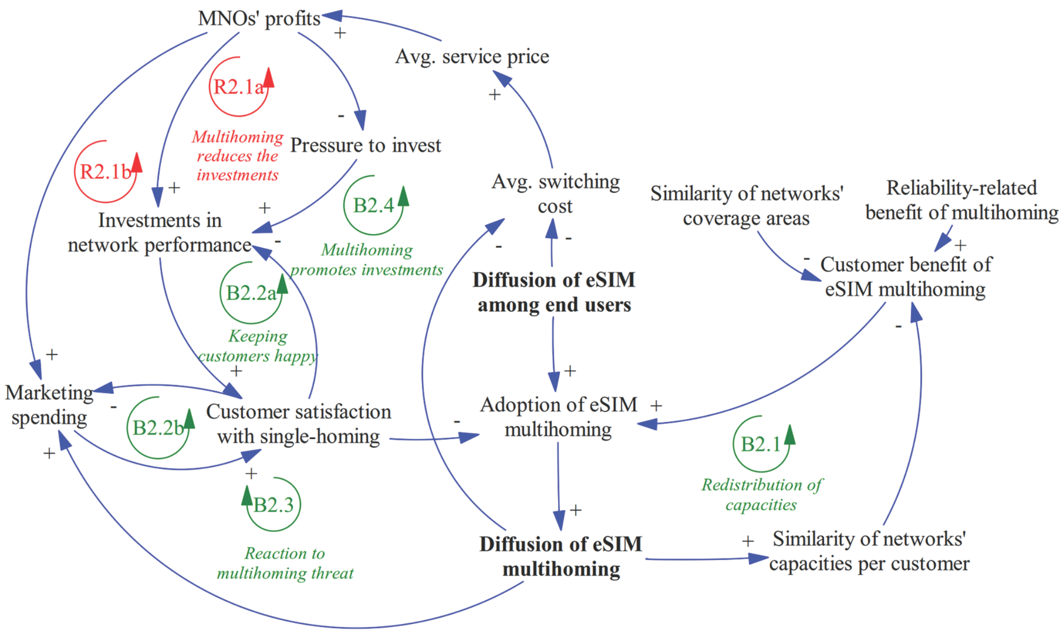
4.2. Diffusion of eSIM Multihoming

The *Diffusion of eSIM multihoming* (with dynamic network selection - hereinafter left out for brevity) is affected by benefits that it can bring to the customers, which can be divided into capacity, coverage, and reliability-related. However, capacity and coverage-related benefits can be only realized if the networks of operators are different in the mentioned quality metrics. For example, if the operators' networks completely overlap in coverage, multihoming does not bring a coverage advantage (REG3). Therefore, as shown in Figure 2, there are negative links from the *Similarity of networks' capacities per customer* and *Similarity of networks' coverage areas* to the *Customer benefit of eSIM multihoming*.

As eSIM multihoming penetrates the market, competing networks become more similar in terms of capacity that they provide to customers. This decreases users' intention to adopt multihoming, as loop B2.1 "Redistribution of capacities" suggests. This relationship occurs due to the load and congestion balancing capability of eSIM multihoming. In fact, the last single-homed customers have little capacity-related benefit to gain by adopting multihoming because earlier adopters prevent the overload in a standalone network by dynamically switching to other networks with available spare capacity.

In reality, there is always a certain disparity between the networks of competing operators. However, the adoption of multihoming may be limited by the necessity of maintaining several concurrent subscriptions, which implies some additional inconvenience for customers (EDU2, REG1,

Figure 2. Conceptual model for the diffusion of eSIM multihoming



REG2). Furthermore, depending on pricing models, the monetary cost of multihoming may be high, although with metered or block data pricing there would not be much price difference between single-homing and multihoming approaches (EDU2, DM). Although flat rate pricing with unlimited data would not be feasible for many multihomed customers, since the examples of true unlimited mobile data tariffs are rare (tefficient AB, 2016), it is reasonable to assume that block and metered pricing will continue to dominate in future. However, a more important reason for possible limited uptake of multihoming is a sufficiently good performance of the individual networks (REG2, REG3, MINTC). As Figure 2 shows, if customers are satisfied with the service quality of singe-homing, they will not adopt multihoming. Therefore, MNOs will try to ensure *Customer satisfaction with single-homing* by increasing the *Investments in network performance* and *Marketing spending* (loops B2.2a and B2.2b "Keeping customers happy"). In case if the *Diffusion of eSIM multihoming* starts to grow, operators can respond to this by increasing *Marketing spending* that can strengthen the customers' loyalty (EDU1). This is shown by loop B2.3 "Reaction to multihoming threat". Nevertheless, if the *Diffusion of eSIM multihoming* grows to a high level and multihoming becomes a de facto standard, the operators will likely stop the promotion of single-homing and put their efforts into getting a larger share of the traffic of the multihomed customers.

Loops R2.1a and R2.1b show the competition between single-homing and multihoming, as well as the negative impact of multihoming on investments. They suggest that if customers are satisfied with their providers, they will not adopt multihoming, which will keep the *Average switching cost* along with *Average service price* unchanged and enable the operators to use their non-decreased profits to further increase *Investments in network performance* and *Marketing spending*, which will strengthen customer satisfaction. However, if customers are not satisfied with their separate operators, they will adopt multihoming, which will result in a reduction of the switching cost, higher competition, and less operators' profits to invest in marketing and network improvement that will further decrease *Customer satisfaction with single-homing*. However, on the other hand, decreased *Average switching cost* and *MNOs' profits* will increase operators' *Pressure to invest* to retain their incomes (EDU2). This is shown by loop B2.4 "Multihoming promotes investments".

4.3. Competition under Conditions of eSIM Multihoming

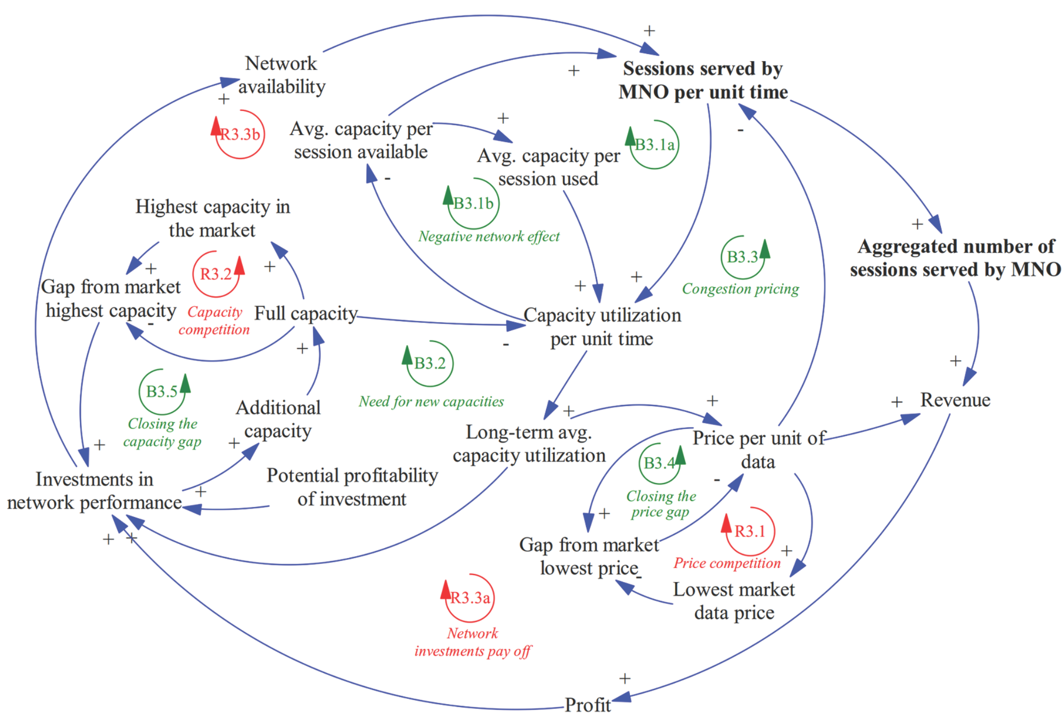
Here we assume high *Diffusion of eSIM multihoming*. Network selection is assumed to be seamless and transparent to end users; however, only one network can be used at a time for a data session. Furthermore, operators are assumed to use a metered or block pricing model, so that users' handsets can define the price for every transmitted megabyte of data.

Figure 3 presents the model of the operations of an individual MNO in a competitive local market. The focus variables of the model are the number of *Sessions served by MNO per unit time* and *Aggregated number sessions served by MNO*. In a multihoming scenario, operators are not anymore competing for a market share traditionally defined as the share of subscriptions. Instead, the share of sessions served by an MNO and the amount of traffic carried by the network become relevant metrics of the operator's performance and success.

Customers select a network for their data sessions based on the *Network availability*, *Average capacity per session available* and *Price per unit of data*. *Network availability* only provides a competitive advantage for an operator in the areas not covered by other networks (typically rural or indoor areas) or if the availability of competing networks is temporarily interrupted by some technical problems (BC1).

Due to a negative network effect, the number of *Sessions served by MNO per unit time* increases the *Capacity utilization per unit time*, which reduces the *Average capacity per session available* and correspondingly the number of sessions allocated to the MNO (loop B3.1a). Furthermore, as loop B3.1b suggests, the congestion effect becomes stronger if the allocated sessions require high data rates (*Average capacity per session used*). Depending on the *Long-term average capacity utilization*, an operator decides whether investments are required for growing the *Full capacity* to decrease the capacity utilization and attract new sessions, as loop B3.2 "Need for new capacities" shows. Although investments are typically made if the *Potential profitability of investment* is positive, sometimes

Figure 3. MNO's operations in eSIM multihoming scenario



operators are forced to build network coverage in certain unprofitable areas because of the regulator's requirement and competition (EDU2, REG2). However, in a multihoming scenario, the motivation for covering sparsely populated areas can become lower, since unlike in single-homing, in multihoming not getting a service in one area does not affect the operator's reputation and does not prevent customers (or their devices) from selecting that operator in other areas (REG2).

Apart from building new infrastructure, capacity utilization can be affected by the deployment of congestion pricing. As loop B3.3 shows, an operator can balance *Long-term average capacity utilization* by adjusting the *Price per unit of data* that will change the number of *Sessions served by MNO per unit time*.

Similar to a traditional single-homing model, with multihoming mobile operators compete in price and quality. However, the competition becomes more dynamic. Thus, a decrease in price or increase in quality instantly results in a growing number of allocated sessions (given that competitors did not make any changes). "Price competition" loop R3-1 and "Closing the price gap" loop B3.4 show that if MNOs have underutilized network capacity, they will try to attract more data sessions by reducing the *Price per unit of data* to the *Lowest market data price*. If different MNOs provide similar or sufficiently good quality of service, customers select the operator based on their price. In this situation, a price war between MNOs may decrease the price to a marginal cost. This may lead to the reduction of operators' *Revenues, Profits,* and *Investments in network performance*.

Quality competition is illustrated by loops R3.2 ("Capacity competition") and B3.5 ("Closing the capacity gap"). Operators will try to match the *Highest capacity in the market* to attract more sessions. This type of dynamics can occur since the deployment of additional capacity instantly increases the number of allocated sessions (loops R3.3a and R3.3b "Network investments pay off"), given the competitors' prices are equal. However, matching the highest market capacity is only feasible if the investment is expected to pay off within a reasonable time.

5. POTENTIAL SCENARIOS

The models presented in Section 4 can result in different dynamics and produce different outcomes, depending on the strength of feedback loops. This section uses the presented models for identifying potential end states of the diffusion of eSIM and eSIM multihoming, as well as market dynamics under the conditions of eSIM multihoming. Figure 4 shows a connection between diffusion of eSIM, eSIM multihoming, and new competition dynamics.

5.1. Diffusion of eSIM

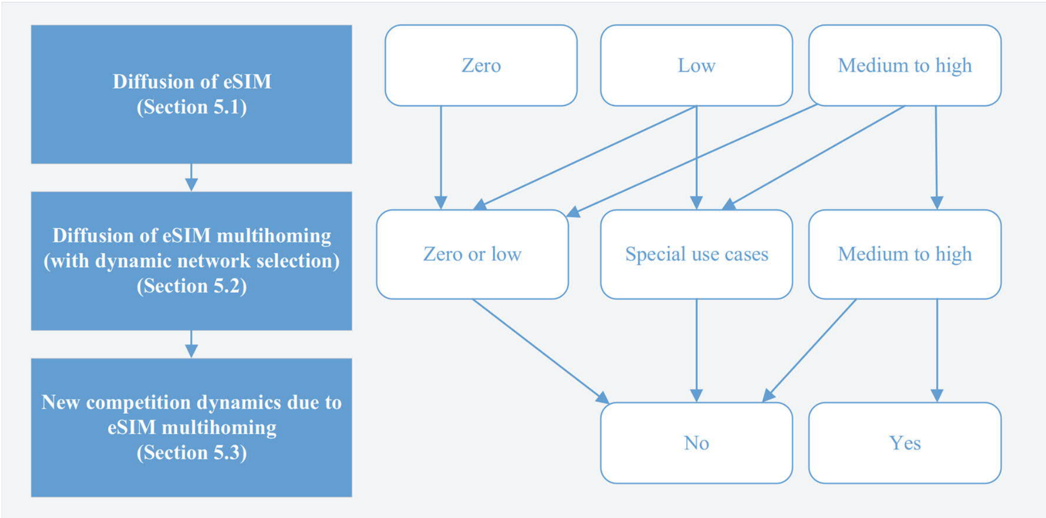
5.1.1. Scenario 1: Zero Diffusion

The diffusion of eSIM among end users may fail to take off if mobile operators refuse to support eSIM for handsets (loop R1.2, Figure 1) and device manufacturers do not produce handsets equipped with eSIM (loop R1.1). Such situation may be caused by a "chicken and egg" problem. Thus, device producers that are in a position to drive eSIM adoption may refuse to invest in the development of eSIM handsets unless they see operators' commitment to deploy the corresponding infrastructure and readiness to support eSIM. In turn, operators can decide to wait for a sufficient number of handsets with eSIM to appear on the market before making their commitments. Furthermore, customers may also refuse to buy an eSIM handset if the device model selection is not wide and operators' support is limited.

5.1.2. Scenario 2: Low Diffusion

Diffusion of eSIM among end users may remain low if a limited number of corresponding handset models is available, and a few MNOs support remote and local subscription management. Even if small operators adopt eSIM for handsets, the indirect network effect (loop R1.2) will not be sufficiently

Figure 4. Connection between diffusion of eSIM, eSIM multihoming and new competition dynamics



strong to motivate customers to adopt eSIM. Moreover, the number of handset models with eSIM will remain low in this case (loop R1.1). Furthermore, even if a service support and device models are available, the diffusion of eSIM may stay low if the process of remote or local subscription management is limited (i.e. operator change is slow, expensive, or otherwise restricted), which makes eSIM multihoming infeasible. These imperfections of switching operators may be due to some technical or legal issues, and resolution of these issues might be not in MNOs' interest (loop B1.2).

5.1.3. Scenario 3: Medium to High Diffusion

The introduction of eSIM handsets by major device manufacturers and its support by large MNOs can ensure the high diffusion of eSIM. The inclusion of eSIM to a new generation of Apple and Samsung flagship smartphones would likely induce fast user adoption and create a strong indirect network effect, which would motivate operators to support eSIM for handsets (loops R1.1 and R1.2). Similarly, if, for instance, Vodafone starts offering remote and local subscription management for handsets by supplying removable eSIM, the adoption of eSIM would grow, and device makers would willingly produce compatible products. Naturally, for eliminating the risks of lacking a supplementary product or service, handset manufacturers and MNOs should coordinate the launch of the first eSIM handset models and eSIM (remote and local subscription management) service. The bandwagon pressure will likely result in other operators following the market leaders in the adoption of eSIM (loop R1.3).

The scenario for the medium to high diffusion of eSIM is more likely to occur if there is demand for multihoming that such SIM may enable. Furthermore, regulators' promotion or mandate for the introduction of remote and local subscription management for handsets (loops B1.1a, B1.1b) may be required for this scenario to happen.

5.2. Diffusion of eSIM Multihoming

5.2.1. Scenario 1: Zero or Low Diffusion

Diffusion of eSIM may further lead to the spread of eSIM multihoming, given that the technology for the latter is mature (Figure 2). However, multihoming may fail to become widespread if there is a limited benefit of combining the services of several individual operators. This is true if the networks have similar capacities per customer and coverage footprints. Moreover, customers that are satisfied with the service of their separate operators are less likely to switch to multihoming. The uptake of eSIM multihoming can further be limited if MNOs succeed in putting extra efforts for the development of customer loyalty (loop B2.3). Moreover, MNOs can increase their network investments to sustain in a competition intensified by eSIM (loop B2.4), which can increase customer satisfaction with single-homing.

5.2.2. Scenario 2: Adoption for Special Use Cases Only

eSIM multihoming can potentially be used only for some special applications, for instance, to provide reliable connectivity to mission-critical public safety and military applications. In some cases, multihoming can be a cost-efficient substitute for redundant multi-channel transmission systems that are used nowadays. Therefore, a regulator may be interested in promoting the use of eSIM multihoming as a mechanism for maintaining high reliability of public safety services. Furthermore, some business customers may decide to adopt eSIM multihoming for ensuring that they are always best connected, even though maintaining several subscriptions can cause extra costs. This scenario can happen if ordinal users are satisfied with the quality of service that they receive with single-homing, or perceive benefits that multihoming provides as insufficient for its adoption.

5.2.3. Scenario 3: Medium to High Diffusion

Multihoming can widely substitute single-homing if the operators fail to ensure that the quality of individual networks is good enough to keep customers satisfied (loops B2.2a, B2.2b). This can be either because of low profits limiting investments in network development and marketing or because of the poor network management and distribution of profits. Diffusion of eSIM multihoming may impose additional budget constraints, which can lead to less investment and a further decrease in the attractiveness of singe-homing (loops R2.1a, R2.1b). Furthermore, the disparity in the coverage and capacity of different networks drive the adoption of multihoming. However, potential capacity benefit decreases as the number of multi-homers increases, which slows down the adoption of eSIM multihoming (loop B2.1).

5.3. Competition under Conditions of eSIM Multihoming

5.3.1. Scenario 1: Over-Provisioning

The model in Figure 3 can result in different market dynamics. Operators can invest in building new network capacity to attract a larger share of data sessions (loops R3.2, B3.5). However, if competing MNOs deploy capacity simultaneously, it may lead to capacity over-provisioning. Taking into account a relatively low incremental cost of carrying each megabyte of data traffic, operators can decide to increase the number of served sessions by decreasing the price, which can lead to severe price competition (loops R3.1, B3.4). This can ultimately increase the utilization, but because of decreased profits, operators may not be able to invest in new capacity in a timely manner (loop R3.3a), which combined with traffic growth can lead to network congestion (loops B3.1a, B3.1b). Congestion-based pricing can be used to mitigate the problem (loop B3.3), but the construction of new capacity is required in the long term (loop B3.2). Thanks to increased prices, profits will grow, and MNOs will likely be able to react to the congestion by building new capacity. Eventually, the market can reach an equilibrium, in which sufficient amount of capacity is available to provide a good service at a competitive price. However, if one of the operators dominates the market and has more resources that allow a greater price reduction, it can displace a smaller MNO from the market if the regulator does not intervene.

5.3.2. Scenario 2: Under-Provisioning

Since eSIM multihoming complicates the network planning and dimensioning, MNOs may postpone investing in network capacity expansion. If other MNOs do the same, congestion can occur, even though dynamic network selection can initially help to reduce the effect of the overload spreading it equally between competing networks. When the MNOs realize a need for new investments, they will invest to increase the full capacity (loop B3.2), which may in some cases lead to over-provisioning, as described in Scenario 1. However, the operators may also be unwilling to invest in building the infrastructure in sparsely populated areas with little traffic, especially if the area is already covered by another MNO. This can lead to the situation in which an operator becomes a local monopoly and can set a higher monopoly price if the regulator does not intervene.

In general, forces determining competition between mobile operators are not much different in single-homing and multihoming scenarios. However, eSIM multihoming makes competition much more dynamic. Thus, operators can see an immediate effect of new capacity deployment or service price change. However, network quality improvement is ultimately limited by technological advances and spectrum availability. Moreover, mechanisms for dynamic congestion pricing are not yet available. Therefore, it is possible that in this supposedly dynamic scenario operators' market shares (in terms of sessions and traffic carried) will be rather stable.

6. DISCUSSION

There are no technical limitations restricting the implementation of the "always best connected" concept through eSIM multihoming with dynamic network selection. Therefore, its future will be determined by the extent it can serve stakeholders' interests. Device manufacturers seem to be interested in eSIM, since it will allow them to improve the design of handsets and take control of the SIM. As an example, Apple is already experimenting with a proprietary Apple SIM in some of its tablets.

End users can always benefit from the eSIM multihoming; however, the pricing models deployed by operators should make it sensible to maintain several concurrent subscriptions. Metered usage-based or block pricing would be the easiest and most suitable methods for multihoming. However, some user groups, such as mission-critical public safety, military, and business customers may adopt multihoming even despite significant extra costs.

Mobile operators seem to be concerned about the potential business consequences of eSIM multihoming. However, the best performing MNOs should benefit from the implementation of a multihoming approach. Operators will be able to attract new customers more easily by offering them good service quality and prices. Therefore, the MNO with the best service quality and price should get the highest market share. Operators can also win by being able to share congestion with competitors. Moreover, multihoming lessens the impact of technical interruptions on the customer. Finally, eSIM saves the operators physical SIM-related costs, such as retail cost.

Regulators can also be interested in eSIM handsets and multihoming. However, the regulators' role would likely be passive unless MNOs try to abandon or restrict the functionality of eSIM handsets. Furthermore, a regulator should ensure that eSIM-based multihoming does not result in MNOs significantly decreasing network investment. Especially in sparsely populated areas, MNOs may be motivated to coordinate the construction of new network infrastructure, so that the operators' networks do not overlap in these areas letting one of the operators be a local monopoly and potentially make some profits in these areas.

The diffusion of eSIM and availability of the mechanisms for dynamic network selection may attract new players to enter a mobile telecommunications market. For example, there may be a place for multi-operator MVNO that, similar to Google's Project FI would collaborate with several local MNOs and enable its customers to use the best partner network. This approach would remove users' inconvenience of maintaining several concurrent subscriptions.

7. CONCLUSION

Embedded SIM and eSIM multihoming are promising directions in the evolution of mobile telecommunications. However, in countries with well-developed mobile networks and well-functioning market competition, multihoming may not receive wide adoption, if the coverage and capacity benefits of combining several networks are limited, and customers are satisfied with the service of a single operator. Therefore, eSIM multihoming may first start diffusing in developing and emerging countries, where mobile traffic is increasing rapidly, but network development fails to keep pace with the traffic growth.

If eSIM multihoming penetrates the market, the switching cost will become essentially zero and competition between operators will become more intense and dynamic. Operators will compete for each data session, and the share of sessions carried by an MNO will become a new indication of the operator's success, instead of conventional market share defined based on the number of mobile subscriptions. The timescale of operator switching is significantly different in multihoming and traditional single-homing approaches: minutes or seconds in the former case and years or months in the latter. Thus, in a single-homing scenario, customers can tolerate some imperfections in service quality and change an operator only when dissatisfaction has accumulated to a certain level. With multihoming, the device switches the network after it has detected a better alternative and can switch back when the first network becomes the best again. This should encourage quality competition and fast deployment of new capacity in densely populated areas with a stable traffic growth. On the other hand, this may have a negative impact on infrastructure investments in sparsely populated areas, where service usage is low. Therefore, regulators should impose minimum coverage requirements to guarantee the accessibility of mobile services and benefits of multihoming to the entire population.

When operators cannot differentiate in quality and have excess capacity, increased emphasis is put on price competition, which can become severe because of high fixed and low marginal cost. This price competition may have a devastating effect on network investments, and although under some circumstances the market can recover and reach an equilibrium, in which the network utilization and service price are reasonable, in some other cases severe price competition can result in the displacement of a weaker operator from the market. In any case, the regulator should monitor competition to prevent an excessive increase.

This study analyzed the forces driving the diffusion of eSIM and eSIM multihoming with dynamic network selection. Furthermore, potential impacts of eSIM multihoming on market competition were researched. The study further contributed to building the understanding of possible future scenarios for the diffusion of eSIM and eSIM multihoming. Finally, it shed some light on new market dynamics that can arise with wide diffusion of eSIM multihoming. The study results are relevant for regulators, mobile operators, and device vendors in structuring their eSIM strategy. The study has some limitations, including a lack of quantitative estimates from the system dynamics models. However, future research can address this issue by building on the study as more eSIM data becomes available.

ACKNOWLEDGMENT

This work was supported by Digital Disruption of Industry (DDI) project, funded by the Strategic Research Council of the Academy of Finland; and the Internet of Things program of DIGILE (Finnish Strategic Centre for Science, Technology and Innovation in the field of ICT and digital business). Authors want to thank all the interviewed experts for the valuable input to this work and Dr. Benjamin Finley for valuable comments.

REFERENCES

Aghion, P., Bloom, N., Blundell, R., Griffith, R., & Howitt, P. (2005). Competition and innovation: An inverted-u relationship. *The Quarterly Journal of Economics*, *120*(2), 701–728. doi:10.1093/qje/120.2.701

Basaure, A., Suomi, H., & Hämmäinen, H. (2016). Transaction vs. switching costs—Comparison of three core mechanisms for mobile markets. *Telecommunications Policy*, *40*(6), 545–566. doi:10.1016/j.telpol.2016.02.004

Buehler, S., & Haucap, J. (2004). Mobile Number Portability. *Journal of Industry, Competition and Trade*, *4*(3), 223–238. doi:10.1023/B:JICT.0000047299.13443.5a

Cisco. (2017). *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016–2021 (white paper)*. Retrieved from http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.html

Coyle, G. (2000). Qualitative and quantitative modelling in system dynamics: Some research questions. *System Dynamics Review*, *16*(3), 225–244. doi:10.1002/1099-1727(200023)16:3<225:AID-SDR195>3.0.CO;2-D

Deb, S., Nagaraj, K., & Srinivasan, V. (2011). MOTA: engineering an operator agnostic mobile service. In *Proceedings of the 17th annual international conference on Mobile computing and networking - MobiCom '11* (pp. 133–144). New York, NY: ACM Press. doi:10.1145/2030613.2030629

Evensen, K., Petlund, A., Riiser, H., Vigmostad, P., Kaspar, D., Griwodz, C., & Halvorsen, P. (2011). Mobile video streaming using location-based network prediction and transparent handover. In *Proceedings of the 21st international workshop on Network and operating systems support for digital audio and video - NOSSDAV '11* (p. 21). New York, NY: ACM Press. doi:10.1145/1989240.1989248

EY. (2015). *Mobile network operator on-demand subscription management study*. Retrieved from http://www.ey.com/Publication/vwLUAssets/EY-mobile-network-operator-on-demand-subscription-management/$FILE/EY-mobile-network-operator-on-demand-subscription-management.pdf

Farrell, J., & Klemperer, P. (2007). Coordination and Lock-In: Competition with Switching Costs and Network Effects. In M. Armstrong & R. Porter (Eds.), *Handbook of Industrial Organization* (Vol. 3, pp. 1967–2072)., doi:10.1016/S1573-448X(06)03031-7

Association, G. S. M. (2011). GSMA-Led Task Force Defines Market Requirements for a Standardised Embedded SIM [Press release]. Retrieved July 3, 2017, from https://www.gsma.com/newsroom/press-release/gsma-led-task-force-defines-market-requirements-for-a-standardised-embedded-sim/

Association, G. S. M. (2015). Leading M2M alliances back the GSMA Embedded SIM specification to accelerate the Internet of Things [Press release]. Retrieved July 3, 2017, from http://www.gsma.com/newsroom/press-release/leading-m2m-alliances-back-the-gsma-embedded-sim/

Association, G. S. M. (2016). *RSP Architecture Version 1.0*. Retrieved from http://www.gsma.com/rsp/wp-content/uploads/docs/SGP.21 Architecture v1.0.pdf

Association, G. S. M. (2017). *RSP Architecture. Version 2.1*. Retrieved from https://www.gsma.com/newsroom/wp-content/uploads//SGP.21_v2.1.pdf

Gustafsson, E., & Jonsson, A. (2003). Always best connected. *IEEE Wireless Communications*, *10*(1), 49–55. doi:10.1109/MWC.2003.1182111

Kassar, M., Kervella, B., & Pujolle, G. (2008). An overview of vertical handover decision strategies in heterogeneous wireless networks. *Computer Communications*, *31*(10), 2607–2620. doi:10.1016/j.comcom.2008.01.044

Klemperer, P. (1987). Markets with Consumer Switching Costs. *The Quarterly Journal of Economics*, *102*(2), 375. doi:10.2307/1885068

Li, Y., Deng, H., Peng, C., Yuan, Z., Tu, G.-H., Li, J., & Lu, S. (2016). iCellular: Device-Customized Cellular Network Access on Commodity Smartphones. In *Proceedings of the 13th USENIX Symposium on Networked Systems Design and Implementation* (pp. 643–656). Santa Clara, CA: USENIX. Retrieved from https://www.usenix.org/node/194983

Lopes, M. (2014, March 13). U.S. mobile data revenue surpasses voice call revenue: analyst. *Reuters*. Retrieved from http://www.reuters.com/article/us-usa-mobilephone-data-idUSBREA2C24J20140313

Machina Research. (2016). The inexorable rise of M2M roaming [Press release]. Retrieved July 3, 2017, from https://machinaresearch.com/news/press-release-the-inexorable-rise-of-m2m-roaming/

Möller, R., Barboutov, K., Furuskär, A., Inam, R., Lindberg, P., & Öhman, K. … Wallstedt, K. (2017). *Ericsson Mobility Report*. Retrieved from https://www.ericsson.com/assets/local/mobility-report/documents/2017/ericsson-mobility-report-june-2017.pdf

Samsung. (2016). Samsung to Release Gear S2 classic 3G with GSMA Compliant eSIM [Press release]. Retrieved July 3, 2017, from https://news.samsung.com/global/samsung-to-release-gear-s2-classic-3g-with-gsma-compliant-esim

Sonntag, S. (2016). *No Link Left Behind*. Aalto University.

Sterman, J. (2000). *Business dynamics : systems thinking and modeling for a complex world*. Irwin/McGraw-Hill.

Suomi, H. (2014). *Techno-economic feasibility analysis of multipath protocols in the Internet*. Aalto University.

Tefficient. (2016). *Mobile data usage 1H 2015. 5 GB per any SIM and month no longer a utopia - if price is right*. Retrieved from http://media.tefficient.com/2016/01/tefficient-industry-analysis-1-2016-mobile-data-usage-and-pricing-1H-2015.pdf

Yap, K.-K., Huang, T.-Y., Kobayashi, M., Yiakoumis, Y., McKeown, N., Katti, S., & Parulkar, G. (2012). Making use of all the networks around us. In *Proceedings of the 2012 ACM SIGCOMM workshop on Cellular networks: operations, challenges, and future design - CellNet '12* (p. 19). New York, NY: ACM Press. doi:10.1145/2342468.2342474

Zhao, Q., & Sadler, B. M. (2007). A Survey of Dynamic Spectrum Access. *IEEE Signal Processing Magazine*, *24*(3), 79–89. doi:10.1109/MSP.2007.361604

ENDNOTES

1 https://fi.google.com/about/faq/
2 The variable names are highlighted in *italics*
3 "B" or "R" in the name of the loop correspond to balancing and reinforcing loops, respectively. The direction of an arrow in the loop notation matches the directions of relationships between the variables in the loop.
4 https://www.apple.com/ipad/apple-sim/

Alexandr Vesselkov, M.Sc. (Tech.), is a doctoral candidate in Network Economics research group at Department of Communications and Networking, Aalto University, Finland. His research interests include diffusion of mobile devices and services, business models and business ecosystem analysis of the Internet of things.

Heikki Hämmäinen is professor of Network Economics at Department of Communications and Networking, Aalto University, Finland. He has MSc (1984) and PhD (1991) in Computer Science from Helsinki University of Technology. His main research interests are in techno-economics and regulation of mobile services and networks. Special topics recently include measurement and analysis of mobile usage, value networks of flexible Internet access, and diffusion of Internet protocols in mobile. He is active in several journal and conference duties.

Juuso Töyli, D.Sc. (Econ. & Bus. Adm.), D.Sc. (Tech.), is Professor at Turku School of Economics at University of Turku and adjunct professor of Network Economics at Aalto University, Finland. His research areas include logistics performance, management of services and technology, complex social systems, networking business, and business simulation games.