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DIFFUSION OF INTERNET PROTOCOLS – MEASUREMENT FRAMEWORK AND EMPIRICAL ANALYSIS OF THE FINNISH MOBILE MARKET

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Internet protocols spread to potential adopters through several successive phases, including implementation, acquisition, and adoption of the protocol. This process, called as protocol deployment, involves several stakeholders and varies depending on the deployment environment and the protocol in question. This paper develops a framework for measuring the diffusion of protocols during the different steps of protocol deployment. The framework is then applied to measure how a set of 11 protocols has gradually spread into mobile handset models on sale, handsets in use, and into actual usage in the Finnish mobile market. The results reveal that the protocol deployment is driven by applications, such as web browsing, email and real-time communications. The handset vendors' decisions on which devices the protocols are pre-installed have impact on the diffusion of protocols into handsets in use. However, the identified gap between the capability to use and the actual use of the protocols indicates that the handset acquisitions are largely driven by other factors than the protocols and that the acquisition of the protocol capable products is a poor proxy for adoption. These results are relevant especially for protocol developers that are interested in improving the success rate and adoption speed of their protocols.

Diffusion of Internet protocols standardized by the Internet Engineering Task Force (IETF) is a relevant and special example of standards diffusion because the IETF operates a bottom-up marketplace for individual protocol standards. The Internet constitutes a unique environment for innovation diffusion due to its global, distributed and unregulated nature where control over resources is spread among a multitude of stakeholders with diverse economic goals (Marcus, 2004). Moreover, the Internet protocols are networked innovations, which exhibit significant network externalities (Katz & Shapiro, 1986). As a result, the diffusion of IETF protocols is a market-based process where the successful alignment of economic incentives is a key to success (Clark, Wroclawski, Sollins, & Braden, 2005).

From the technical perspective, a protocol can be understood as a software component or feature, which enables products such as applications and services (Jorstad, Dustdar, & Do, 2005). The evolution of these components and products is interlinked (Adomavicius, Bockstedt, Gupta, & Kauffman, 2007). Similarly, the protocol adoption decision often depends heavily on the product containing the protocol, such as an application, operating system (OS) or device – thus diminishing the direct impact of protocol on the end users' adoption decision (Warma, Levä, Tripp, Ford, & Kostopoulos, 2011) and increasing the impact of supply-side decisions to include the protocol in products (Kivi, Smura, & Töyli, 2012). This is an example of demand-pull vs. technology-push (Ende & Dolfsma, 2005). Consequently, protocols and other software features may not become available to the potential end users due to the decisions of software and hardware vendors (Levä, Komu, Keränen, & Luukkainen, 2013). For example, the decision of Apple to not support Flash in their mobile devices prevents end users from adopting (services based on) it. Moreover, services, protocols, and the products containing them are communication technology platforms that engage into standards wars (Stango, 2004; Church & Gandall, 2005), which impact their success in the market.

The traditional diffusion of innovation theories (Rogers, 2003) and the case studies on protocol diffusion (e.g., Hovav, Patnayakuni, & Schuff, 2004; Ozment & Schechter, 2006; Joseph, Shetty, Chuang, & Stoica, 2007) often focus on measuring or modeling the end user adoption. As Lyytinen and Klein (2001) conclude, this is insufficient for explaining the diffusion of complex, networked technologies, and the focus needs to be widened to cover the critical process features and all key players. To overcome too narrow, end user adoption centric perspective, Levä and Suomi (2013) define *protocol deployment as a process, during which a protocol is advanced from the first specification into actual use on the Internet through steps such as implementation, acquisition and adoption of the protocol*. Measuring and analyzing diffusion during all these different steps is important to understand the dynamics of protocol deployment and to identify the critical factors affecting the success of Internet protocols.

The purpose of this article is two-fold. First, the article develops a framework for measuring the diffusion of Internet protocols during the different steps of protocol deployment. This is achieved by identifying the deployment steps, models, and measures of Internet protocols. Second, the developed framework is applied to quantify and visualize how a set of 11 protocols has gradually spread into mobile handset models on sale, handsets in use, and actual usage by end users, using an extensive longitudinal and cross-sectional data collected from Finland in 2003-2012. The focus is on the client-side deployment for individual end users (consumers). Diffusion on the server-side is excluded from the analysis, even though the developed framework is applicable also for measuring deployment on the server-side. Finally, diffusion patterns and delays between the different deployment steps are identified from the diffusion data, and the explaining factors for them are discussed.

The article makes a methodological contribution by identifying alternative deployment models of Internet protocols and developing a framework for measuring protocol diffusion in different steps of protocol deployment. The article makes a practical contribution by applying the developed framework for measuring the diffusion of protocols into mobile handset models on sale, handsets in use and actual usage of the protocol in an example national market, and analyzing the identified diffusion patterns.

The rest of the paper is structured as follows. Section A develops a framework for measuring protocol deployment by identifying the deployment steps, models and measures. Then Section B describes the research process and the data that are used in Section C to measure the diffusion of the selected protocols by analyzing the data from the identified deployment steps. Finally, Section D concludes the paper.

A. Framework for measuring protocol deployment

After a protocol has been developed, it spreads gradually into use. Levä and Suomi (2013) define protocol deployment as a process, during which a protocol is advanced from the first specification into actual use in the Internet. This covers the commercialization and diffusion phases of the well-known innovation-development process of Rogers (2003). In this paper, protocol deployment is divided into three steps. First, in the implementation step the protocol is made available to the end users. Second, in the acquisition step, the potential end users acquire capability to use the protocol. Finally, in the adoption step, the users start using the protocol.

The involved stakeholders and the detailed deployment actions vary depending on the deployment environment and the protocol in question – resulting in different deployment models. This paper recognizes three models, namely pre-installation, update installation, and post-installation. The models differ from each other mainly in where the protocol is implemented and what is the product or product bundle the end users acquire to get the protocol (Warma et al., 2011). The models are not mutually exclusive and can co-exist depending on the protocol.

The diffusion of a protocol can be measured in each of the deployment steps and for all the models. The identified three high-level deployment measures are availability level, capability level, and usage level. What is actually measured depends on the deployment model and the objectives of the study. In order to manage the complexity of protocol deployment, this paper combines the deployment steps, models and measures into a framework for measuring protocol deployment. The framework is illustrated in Figure 1 and introduced in more detail in the following subsections.

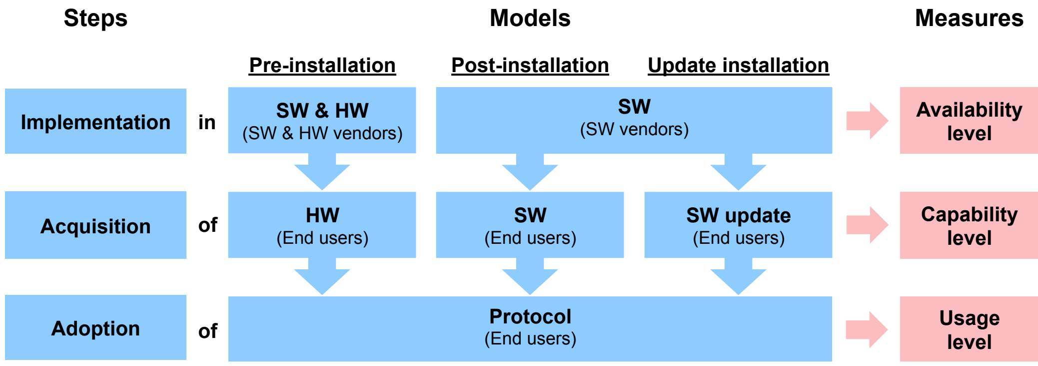

Figure 1. Framework for measuring protocol deployment, including the identified deployment steps, deployment models, and deployment measures.

1. Deployment models

After the development of a protocol, it needs to be first implemented and made available to the end users for the acquisition to take place. From the deployment perspective, protocols are software components implemented in software products (SW) that run on hardware products (HW), i.e., devices. At least three different implementation locations in SW can be identified: i) the kernel of an operating system, ii) middleware (e.g., Java library), and iii) an application. The modular nature of software complicates the picture because software products are often implemented inside other software products acting as SW platforms (e.g., application for OS). Understanding of this modularity is relevant since the protocol deployment follows the deployment of the SW and HW products they are implemented in.

Consequently, the three deployment models differ from each other in how the SW containing the protocol is packaged. In the pre-installation model, the end user acquires both HW and SW as a bundle without the need to install anything. This model is used heavily with mobile phones where the hardware and software are tightly bundled and provided by the same stakeholder – the HW vendor. In the post-installation model the end user already possesses the HW (and possibly the SW platform) and acquires only the SW product in which the protocol is implemented. This is the predominant model for providing applications to smart phones through the app stores. In the update installation model, new protocols are pushed to the end users with updates to the SW. This requires that the end user already possesses the necessary SW that has been originally deployed along the pre- or post-installation models. For example, desktop browsers, smart phone applications, and operating systems are updated regularly. The update process may be manual necessitating separate adoption decision for each update, or automated so that the end user accepts the installation of all the future updates at once.

After the end user possesses the HW and SW equipped with the protocol, he or she has the capability to use it. However, the adoption of the protocol occurs only after the end user starts to use the networked services enabled by the protocol (i.e., when the user starts to generate protocol traffic).

2. Deployment measures

The diffusion of the protocol can be measured during each of the deployment steps. The three deployment measures are availability level, capability level and usage level.

Availability level is a measure for the implementation step. From the supply viewpoint, availability defines how widely a protocol is included in the different HW and SW products the end user can acquire, i.e., *the number of protocol implementations.* From the market viewpoint, availability defines the potential end user population that could acquire the offered HW and SW product, i.e., *the number of potential buyers*. In the pre-installation model, market availability is simply the number of potential buyers of HW, whereas in the post- and update-installation models the population is limited to the end users that possess the HW and SW, in which the protocol can be installed. Understanding both sides of availability is relevant especially for protocol developers that decide in which products they implement their protocols, as they are interested in estimating the population they can achieve with specific implementations.

Capability level is a measure for the acquisition step. It defines the share of end users that could use a protocol, i.e., *the number of potential adopters*, which is a subset of the potential buyers. Data on cumulative sales of the HW and SW products containing the protocol provides one approximation of the capability level. However, by using cumulative sales data it is difficult to take the replacement acquisitions and discards into account. Consequently, data on the products in use provides more accurate information on the capability level. Mobile operators' charging data is one potential source for this data. The capability level is relevant especially for application and content service providers that decide upon which protocols they build their services.

Usage level is a measure for the adoption step. It defines the share of end users that have taken the protocol into use, i.e., *the number of users*, which is a subset of the potential adopters. Data sources for estimating the usage include Internet traffic measurements, handset-based measurements, end user surveys, and server-side measurements (Smura, Kivi, & Töyli, 2009). Measuring usage level interests especially other potential adopters that are interested in communicating with the protocol, Internet service providers who manage their networks, and application service providers whose revenues depend on the usage of their services.

Combination and comparison of the measures can be used to explain the dynamics of protocol deployment. Also gaps (or delays) can be identified between the measures of different steps. The total potential buyer population covers the whole market (in a simplified scenario), and the potential adopter population includes the users who have already acquired the SW product. Therefore, a gap can be calculated between these two numbers. Similarly, a gap exists between the potential adopters and users, also called as an assimilation gap (Fichman and Kemerer, 1999). Previously, Riikonen, Smura, Kivi, & Töyli (2013) identified significant delays between the introduction of the mobile handset features (availability) and their diffusion into the handset base (capability), but did not calculate and analyze the assimilation gap. Comparing the gaps for different protocols and deployment models may shed light on the role of different stakeholders and the success of protocol implementation strategies. These are valuable information for protocol developers that are interested in improving the success rate and adoption speed of protocols.

B. Measurement setup and data

The developed framework is applied to measure the deployment of protocols in the Finnish mobile market from 2003 to 2012. In total, 11 protocols were selected for the analysis from the network, transport, and application layers.

First, the importance of the deployment models for mobile handsets in 2003-2012 was studied. The initial analysis indicated the dominance of the pre-installation model. Post- and update installation models have become more commonly used only with the emergence of the newer smartphone operating systems, for which most of the selected protocols are also pre-installed. Therefore, the data collection and quantitative analysis focused on the pre-installation model. It should be noted, that if a similar analysis was conducted, for instance, for personal computers, the importance of the post-installation and update models would be higher and should be taken more carefully into account in the quantitative analysis.

The later research process was divided into two steps. First, the existence of the pre-installed protocols in mobile handset models was identified from the data on the capabilities of mobile handset models (protocol data). Second, diffusion data were collected about mobile handset sales (sales data), installed base of mobile handsets in use (population data), and usage of mobile services (usage survey data). These three diffusion datasets are directly linked with the measures presented in Figure 1, whereas Figure 2 describes the data sources, the utilized datasets, and the linkage between the datasets and the measures. Mapping protocol data with the diffusion data enabled studying the penetrations of protocols over time from the different datasets, i.e., along the protocol deployment process. The following subsections introduce the research approach and used data in more detail.

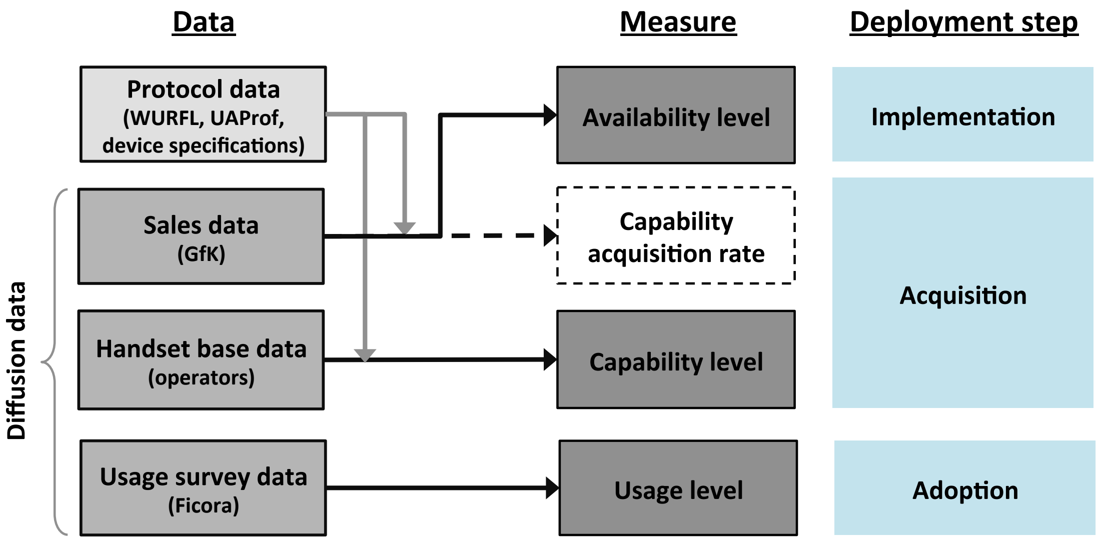

Figure 2. Collected datasets and measures

1. Protocol data

Information about the pre-installed protocols of different handset models was collected so that protocol penetrations in the diffusion data could be calculated. The selected protocols cover the basic network and transport layer protocols IPv4, TCP and UDP, widely used security protocol TLS, and the key application layer protocols for email (SMTP, IMAP4, POP3), web browsing (HTTP), video streaming (RTSP, RTP) and voice over IP (SIP). Since the email protocols POP, IMAP, and SMTP typically co-exist, they are handled as a single protocol (EMAIL) in this study.

The protocol data were collected from several sources, due to the large number of device models on sale and in use, and the lack of a single, comprehensive data source. First, a script was created to fetch the data from the WURFL repository (ScientiaMobile, 2012) containing information about device capabilities and features for a variety of mobile devices. The capabilities included the URLs of UAProf files that describe the capabilities of a mobile handset model in an XML format standardized by the Open Mobile Alliance (OMA) (2006). Second, the UAProf files were downloaded and parsed programmatically to complement the WURFL data. Finally, the missing information was collected manually from the handset specifications available in the handset vendors' web pages and in online databases, such as GSMArena.

Internet protocols were rarely mentioned directly in the used data sources. As a consequence, the existence of protocols in the handset models was identified based on other capabilities. For example, the inclusion of wireless application protocol (WAP) version 1.x into a device model indicates that the model is IPv4 and UDP capable, whereas version 2.x adds support for TCP, TLS and HTTP (OMA, 2002). Similarly, support for OMA packet-switched streaming (PSS) standard translates into RTP and RTSP support (Gabin, Kampmann, Lohmar,

& Priddle, 2010), certain Java APIs (MIDP, SIP API) and applications (email, VoIP, push to talk (PoC), video streaming) indicate support for other protocols, and some protocols are included as features in OSes. Finally, application layer protocols typically run over certain lower layer protocols. Consequently, the availability of application layer protocols indicates the availability of lower layer protocols, whereas the lack of lower layer protocols translates into the lack of application layer protocols. The selected protocols and the rules used for identifying the existence of the protocols in the handset models are listed in Appendix 1.

Protocol information was not found for every handset model in the diffusion data. This applies particularly for SIP and RTSP, leading to notable shares of unknown for these protocols. The device models, for which no protocol information was found, were assumed not to have the protocol pre-installed. In total, protocol information was found for approximately 1000-1400 handset models. This amount of models covers over 92% of the handset models on sale, over 99% of the total unit sales, and over 99% of the handset base data depending on the point in time and the protocol. Exceptions are RTP, RTSP, and SIP protocols, for which the coverage is notably lower, and therefore the reliability of the results is worse.

2. Diffusion data

Different data sources were used to measure the availability level of protocols in the handset models on sale, level of protocol capability in the installed base of mobile handsets, and the usage levels of the protocols.

Sales data were received from the market research company GfK. Data on the model-level unit sales included a time period from January 2003 to September 2012. The sales data covers roughly 70-90% of the Finnish mobile handset retail market over the measurement period. The sales data were used to study the availability levels and the capability acquisition rates of the protocols in the Finnish market. Availability level was defined as the share of handset models on sale equipped with the protocols out of all handset models on sale. In order to exclude the models that were limitedly available to the end users, the number of handset models on sale was calculated as all the models that had been sold more than 10 units during a month. The capability acquisition rate was defined as the share of monthly unit volume sales of devices equipped with a specific protocol out of total unit volume sales.

Handset base data were used to identify the shares of handsets equipped with each protocol out of all handsets using mobile networks. The data were collected from all three Finnish mobile network operators annually in the end of September from 2005 to 2012, consisting of the number of units of each handset model that the operators had identified in their networks. Data collection was based on the charging functionalities of mobile networks and the unique identifiers of handset models, Type Allocation Codes (TAC), from which the handsets using mobile networks were identified. The installed base data covers roughly 80-99% of the handset base in Finland over the measurement period.

Usage survey data on mobile services were used to estimate the protocol usage levels. Ficora, the Finnish communication regulation authority, has collected this data yearly from 2006 to 2012 from representative samples of 15-79 year old Finns and makes the results publicly available. The sample sizes of the surveys increased from 1500 to 3000 over time, and the confidence level is over 95% in all of the surveys. Web browsing and email were the only mobile services surveyed in the data that were possible to be linked to the studied protocols (HTTP and EMAIL, respectively).

C. Results

This section reports the results for the diffusion analysis, divided into two parts. First, general descriptive statistics about the diffusion of the selected protocols are presented, after which HTTP and EMAIL protocols are analyzed in more detail.

1. General protocol diffusion patterns

The general protocol diffusion patterns were studied by calculating and visualizing the identified deployment measures. Figure 3 presents a) the protocol availability level, b) the capability acquisition rate, c) the capability level, and d) the usage level of the selected protocols in Finland from 2003 to 2012. On a general level, four groups[1] of protocols were identified by visual inspection of internally similar diffusion patterns: 1) IPv4 and UDP, 2) TCP and HTTP, 3) TLS and EMAIL, and 4) RTP, RTSP, and SIP. The diffusion patterns of the groups are related to the diffusion of the following mobile services: WAP browsing (group 1), HTTP browsing (group 2), email (group 3), and real time communications (group 4). The last group is not as internally similar as the other groups, because real time communications protocols can be divided into streaming and VoIP related parts. Even though TLS is important also in securing HTTP browsing, the results indicate that its deployment has been primarily driven by EMAIL.

[1] One reason for the emergence of the groups is that the identification of the protocols' existence on the mobile handsets was done based on the dependencies between different protocols (e.g., EMAIL runs over TCP) and common features (e.g., WAP 2.x indicates existence of both HTTP and TCP).

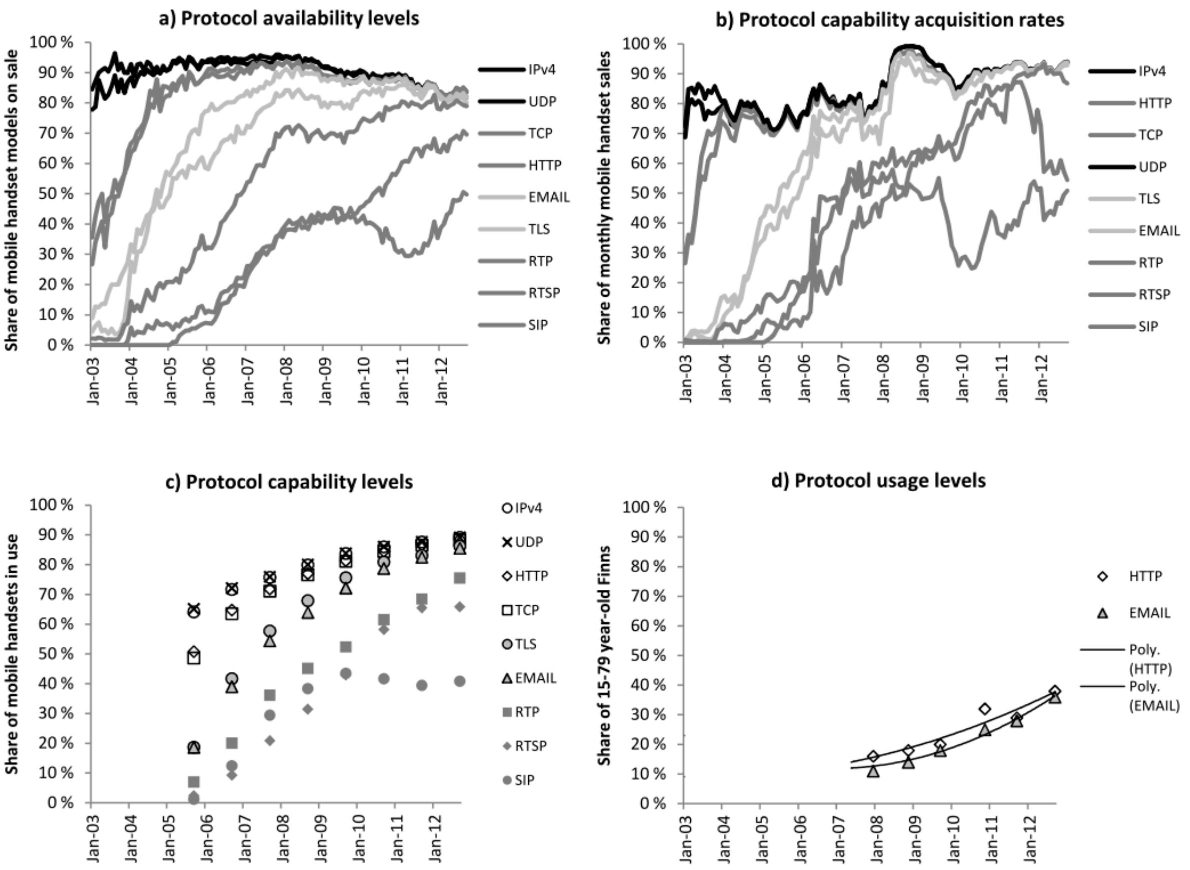

Figure 3. Protocol a) availability levels, b) capability acquisition rates, c) capability levels, and d) usage levels

Figure 3a illustrates the historical protocol availability levels, that is, the share of handset models on sale equipped with the protocols. There are large differences on the availability levels between the protocols and the groups. For example, the availability levels of IPv4 (group 1) were between 78% and 96% during 2003-2012, whereas for SIP (group 4) the availability level remained below 51% during the same period. Within the groups the availability levels were close to each other, group 4 (real time communications) with the largest differences. There RTP was identified to have higher availability levels than RTSP and SIP, which is natural since RTP is used with both video streaming and VoIP applications, whereas RTSP and SIP relate to only one of those. It should be noted that the number of models on sale increased during the measurement period from tens in 2003 to a level of roughly 200-300 as of 2007. This means that even though the relative availability levels of some protocols stayed rather stable, the absolute number of handset models on sale including the protocols increased considerably.

Figure 3b shows the capability acquisition rates that measure the share of handsets including the protocol from the monthly handset unit sales. Handset models including protocols from groups 1 and 2 were popular in sales almost throughout the measurement period with protocol capability acquisition rates of 68%-99% during 2004-2012. Also the protocols of group 3 reached groups 1 and 2 in 2006, after which the three groups have followed closely each other. For the protocols of group 4 (RTP, RTSP, SIP), Figure 3b shows a particularly abrupt increase in sales in 2006. These peaks fall on the point in time when bundling of mobile subscriptions and 3G handsets was allowed in Finland. This change affected sales behaviour of 3G devices positively in short term and was discussed in more detail in Kivi et al. (2012). Another unexpected pattern is the sudden drop for SIP in 2009. One reason for this drop could be that Nokia's Symbian S60 devices with pre-installed SIP were possibly replaced with Apple iPhone and Google Android devices that did not include SIP at that point.

When comparing Figures 3a and 3b, some differences and similarities can be found. Both the availability levels and acquisition rates follow traditional sales development growing over time. On the other hand, it seems that during the initial stages of the protocol diffusion, the availability level of some protocols is higher than the capability acquisition rate, meaning that the protocol is introduced into a higher share of models than what the popularity of those models is. Then, during later stages of diffusion the capability rates become higher than the availability rate, meaning that the popularity of the models equipped with the protocols increases. Besides the supplier selection, this evolution may be caused by the general market shift from basic phones to smart phones.

Figure 3c illustrates the capability levels, *i.e.*, the share of handsets equipped with each protocol out of all devices using mobile networks. Many of the selected protocols seem to diffuse slowly towards 90-95% saturation level. One clear exception is SIP, for which the previously identified drop in capability acquisition rates is also visible in the capability levels of Figure 3c. This supports the presented reasoning that S60 handsets were replaced by handsets without pre-installed SIP.

Figure 3d shows the usage levels and fitted polynomial trend lines for two protocols, EMAIL and HTTP, for which usage data was available. The usage levels of EMAIL and HTTP were notably lower than capability levels (Figure 3c), but increased over time. When comparing Figures 3d and 3c, one can see that an assimilation gap exists between acquisition and adoption of the protocols. This indicates that browsing and email have not been the most important services to the users of mobile handsets, in general.

2. Diffusion of EMAIL and HTTP

To study the dynamics between the different deployment steps, a more detailed analysis was conducted for EMAIL and HTTP. The reasons for selecting these protocols were that they belong to different protocol groups, they are rather independent from each other, and usage data were available for both of them. The shares of unknown devices for both protocols were also low, decreasing error margins of the analysis.

Figure 4 illustrates the diffusion patterns of EMAIL in the Finnish mobile market in terms of all the previously identified measures: availability level, capability acquisition rate, capability level, and usage level. Availability levels and acquisition rates are plotted with black line and dotted line, respectively. For the annual measures, *i.e.*, capability levels and usage levels, the data is presented with box and diamond markers, respectively. Polynomial trend lines were added to the figure for capability and usage levels to better show the trends over time. It should be noted that all the measures are on a relative scale, but have large differences on an absolute scale. The number of handsets on sale per month, the monthly volume of handset sales, the total number of devices in use in the mobile networks, and the number of 15-79 year old Finns are different and, therefore, not directly comparable.

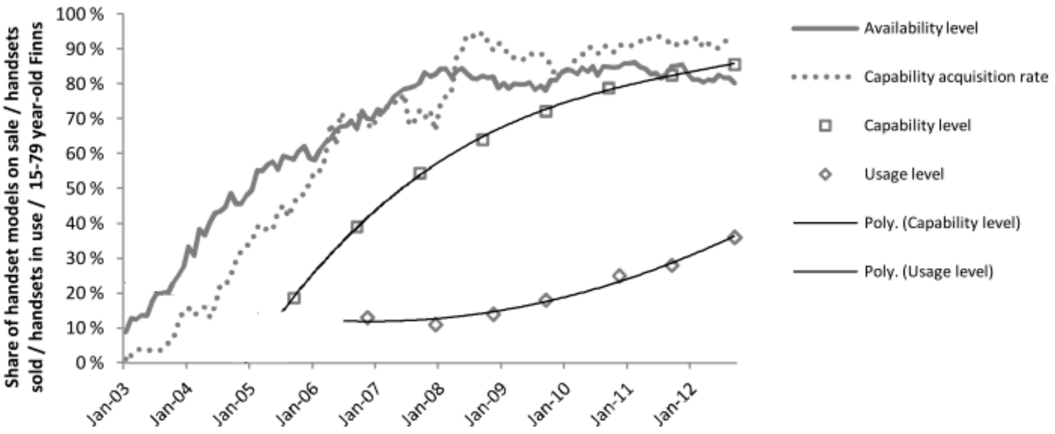

Figure 4. EMAIL deployment in the Finnish mobile handset market 2003-2012

Several observations related to the measures are visible in Figure 4. For example, the point when the capability acquisition rate increases higher than the availability level shows the point when the handset models equipped with a protocol became more popular in sales than the models without the protocol. For EMAIL this took place for the first time in 2006. After this the availability level and capability acquisition rate for EMAIL have followed each other rather closely, the acquisition rate on average being higher than the availability level. Therefore, the results indicate that there might be a gap between a specific availability level and the capability acquisition rate, which can be quantified and analyzed.

Figure 4 also shows gaps between the capability acquisition rate and the capability level, as well as between the capability level and the usage level of EMAIL. For example, the capability acquisition rate of EMAIL was 72% in September 2006. The capability level was only 39% at the same point in time, and reached the 70% level only after two to three years. Similarly, the capability level of 39% for EMAIL in September 2006 was notably higher than the usage level of 13% in November 2006. After this, the 26% gap increased to 50-55% before 2009, and stayed on that level since then. The large assimilation gap indicates that EMAIL was introduced in popular models, but the popularity of these models was caused by other factors than EMAIL. This is supported by the survey data showing that the interest towards new mobile services, such as email, had only small impact on the decision to acquire a 3G handset in 2006-2009. Other explanations for the gap could be that the applications utilizing email protocols did not provide good usability or that the pricing of mobile data connectivity prohibited people from using mobile data services.

For comparison, Figure 5 shows the diffusion patterns of HTTP in the Finnish mobile market. Also for HTTP, a notable gap between the capability level and the usage level of the protocol is visible in the figure. The capability level of HTTP grew from 65% in September 2006 to 89% in September 2012. On the other hand, the survey results indicate that during the same time period the usage level of the protocol grew from 13% to 38%, showing an assimilation gap of about 52% for the two points. The most notable difference between EMAIL and HTTP is that HTTP usage level increased almost linearly, whereas for EMAIL the growth was slower in the beginning. However, more recently EMAIL usage level has increased fast, indicating growing importance of the protocol for the end users.

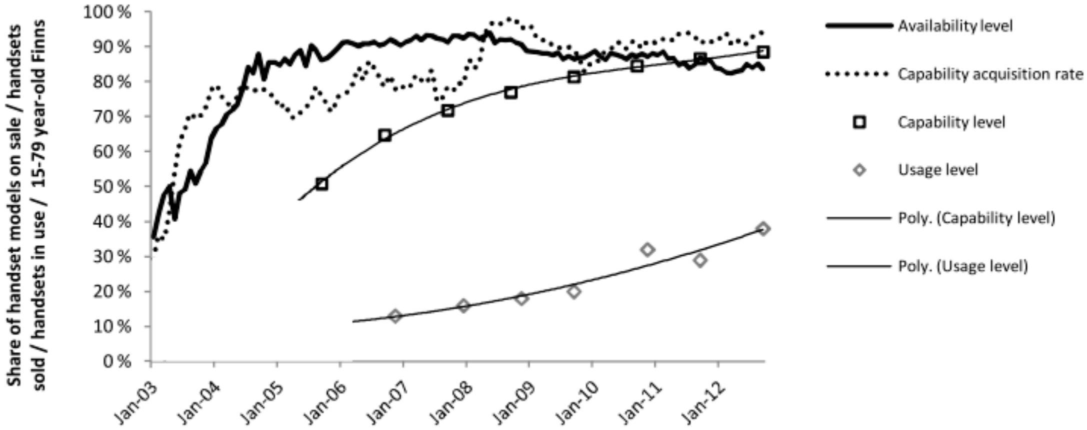

Figure 5. HTTP deployment in the Finnish mobile handset market 2003-2012

D. Conclusion

Protocol deployment is a process consisting of several successive phases, during which the protocol is first made available to end users that then acquire and start using the protocol. The actual deployment model varies depending on the involved stakeholders, deployment environment, and the protocol in question. This paper developed a framework for measuring protocol diffusion during the different deployment steps, which is relevant in order to analyze all the critical factors affecting protocol diffusion. The framework includes three deployment models – pre-installation model, post-installation model, and update installation model – that differ from each other in how the end users acquire the software product containing the protocol. The framework was then applied to study how a set of 11 protocols has spread into handset models on sale, handsets in use, and actual usage in the Finnish mobile market from 2003 to 2012.

The measurement results provide insights into the dynamics of protocol deployment. The studied protocols have diffused in groups linked to four applications: 1) WAP browsing (IP+UDP), 2) HTTP browsing (TCP+HTTP), 3) email (EMAIL+TLS), and 4) real-time communications (RTP, RTSP, SIP). The results show that the availability levels and the capability acquisition rates of protocols in the handset models on sale have followed each other rather closely. However, the availability levels seem to be higher in the early stage of protocol diffusion, whereas the capability acquisition rates and even the capability levels exceed the availability levels in the later stage of diffusion. It also seems that the changes in the availability levels are slower than in the capability acquisition rates, indicating that the demand side changes are more abrupt than the supply side decisions on product portfolios. These results suggest that both implementing the protocol in high numbers and on the most popular models affect the diffusion of protocol capability to the handsets in use. However, the high capability level does not necessarily translate into actual use, as the identified gaps between the capability and usage levels of EMAIL and HTTP show. This supports the finding of Warma et al. (2011) that the protocol capabilities are often acquired unintentionally alongside handset acquisitions motivated by other reasons than the protocols or the services enables by them. It also verifies the assimilation gap concept proposed by Fichman and Kemerer (1999). Thus, adoption should be studied by measuring the actual usage of a protocol instead of using the acquisition of the protocol capable hardware and software products as a proxy for adoption.

Due to the limitations of the study, the results should be taken with care. Firstly, the different datasets are not fully comparable to each other. For example, the data on handset models including all the mobile handsets in Finland do not match with the sample of 15-79 year old Finns surveyed for the usage of email and browsing. Secondly, the quantitative analysis includes only the pre-installation model, although some end users may have acquired the protocol capability along other deployment models by installing new or updating existing software in their handsets. Thirdly, information on the existence of the protocols was not found for all handset models. These unknown data were considered as models that do not have the protocol. Consequently, the capability level in this paper presents the lower bound of the capability. Fourthly, the analysis does not explain the motives behind the stakeholders' deployment decisions nor provide direct explanations for the diffusion patterns.

The research could be continued to multiple directions. First, measuring mobile Internet traffic per end user would provide data on usage for a larger number of protocols. With this kind of data, the usage analysis could be extended from the analysis of binary adoption decisions to the frequency of use. Second, the identified gaps between the different deployment steps could be analyzed mathematically by fitting regression curves and using, for example, the survivor analysis suggested by Fichman and Kemerer (1999). Third, studying a case where also post- and update-installation models were relevant would allow comparing the gaps and the adoption levels between the different deployment models. This would also help in capturing theoretical findings related to the framework. Fourth, comparing the diffusion patterns between different markets, either geographic or device markets (mobile handsets vs. PCs) could help to explain the role of deployment environment on the diffusion patterns. Fifth, using the framework to analyze deployment of protocols on the server-side of communication (i.e., the content service providers) could explain some of the observed diffusion patterns on the client-side. Sixth, using the framework with other software components than protocols, such as mobile games, could help to validate its expandability to other software innovations. Finally, a deeper analysis of the modularity of software; the evolution and diffusion of the related software components, products, and platforms; and standards wars could help to improve the framework and provide interesting insights on the protocol deployment strategies.

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Appendix 1 - Rules for identifying the existence of protocols in the handset models

Protocol	Features indicating protocol support (and non-support)
EMAIL - *SMTP (* Simple Mail Transfer Protocolm RFC 5321*)* - *IMAP4 (* Internet Message Access Protocol v4, RFC 3501*)* - *POP3 (* Post Office Protocol v3, RFC 1939*)*	1) Email application **OR** 2) UAProf: <prf:Email-URI-Schemes> = POP or IMAP or SMTP NO SUPPORT: 1 ≠ true **AND** 2 ≠ true
HTTP (HyperText Transfer Protocol, RFC 2616)	1) HTML browser **OR** 2) WURFL: <j2me_midp_1_0> or <j2me_midp_2_0> = true **OR** 3) WURFL: <j2me_http> = true **OR** 4) WAP version = 2.x NO SUPPORT: 1 ≠ true **AND** 2 ≠ true **AND** 3 ≠ true **AND** 4 ≠ 2.x
TLS (Transport Layer Security, RFC 5246)	1) WURFL: <j2me_https> = true **OR** 2) UAProf: <prf:SecuritySupport> = SSL/TLS **OR** 3) WAP version = 2.x NO SUPPORT: (1 ≠ true **AND** 2 ≠ SSL/TLS **AND** 3 ≠ 2.x) **OR** *IPv4* = false
SIP (Session Initiation Protocol, RFC 3261)	1) JSR-180 SIP API for J2ME **OR** 2) PoC (Push-to-talk over Cellular) application **OR** 3) VoIP application, including also FaceTime **OR** 4) OS = Android 2.3 --> **OR** Symbian v9.1 / S60 3E --> **OR** Windows Mobile 6.0 --> NO SUPPORT: (2 ≠ true **AND** 3 ≠ true) **OR** IPv4 = false **OR** WAP version = 1.x **OR** OS = (Windows Phone **OR** Samsung Bada **OR** Blackberry)
RTSP (Real Time Streaming Protocol, RFC 2326)	1) WURFL: <streaming_real_media> = true **OR** 2) UAProf: <rdf:Description rdf:ID="Streaming"> = exists **OR** 3) OS = Nokia S40 3E FP2 --> **OR** Symbian v8.1 / S60 2E FP3 --> **OR** Blackberry 4.3 --> **OR** Android **OR** Samsung Bada 1.0 --> NO SUPPORT: RTP = false **OR** IPv4 = false **OR** WAP version = 1.x **OR** OS = (iOS **OR** Windows Phone**)**
RTP (Real-time Transport Protocol, RFC 3550)	1) *SIP* **OR** 2) *RTSP* **OR** 3) Video streaming support **OR** 4) WURFL: <streaming_video> = true **OR** 5) UAProf: <pss6:RtpProfiles> = RTP **OR** 6) UAProf: <rdf:Description rdf:ID="Streaming"> = exists NO SUPPORT: (1 ≠ true **AND** 3 ≠ true) **OR** IPv4 = false **OR** WAP version = 1.x
TCP (Transport Control Protocol, RFC 793)	1) *EMAIL* **OR** 2) HTML browser **OR** 3) WURFL: <j2me_socket> = true **OR** 4) WAP version = 2.x NO SUPPORT: 1 ≠ true **AND** 2 ≠ true **AND** 3 ≠ true **AND** 4 ≠ 2.x
UDP (User Datagram Protocol, RFC 768)	1) *RTP* **OR** 2) *SIP* **OR** 3) WURFL: <j2me_udp> = true **OR** 4) WAP version = 1.x or 2.x NO SUPPORT: IPv4 = false
IPv4 (Internet Protocol, version 4, RFC 791)	1) EMAIL **OR** 2) HTTP **OR** 3) GPRS **OR** 4) WAP version = 2.x NO SUPPORT: 3 = false **AND** 4 = 0 (i.e., no WAP)