ECONOMIC ASPECTS OF TECHNOLOGICAL INNOVATIONS IN INFORMATION TECHNOLOGY

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Abstract

The paper devotes to ICT tools and services that are omnipresent nowadays, from the point of view of the economic efficiency of their improvement. Several use-cases (world wide web, e-mail and digital signatures) are analyzed and the outcomes are presented showing different endings. Some economic aspects of internet frauds are also briefly mentioned.

Keywords

IT Innovation, WWW, E-mail, Digital Signature, Economic Efficiency

I. Introduction

Nowadays, various tools and services based on Information and Communication technologies (hereinafter "ICT tools") are used in almost all facets of life, not only in technological businesses but in daily life of ordinary people. The internet usage ratio increases worldwide (varying from more than 90% in Europe and U.S. to less than a half in poorest regions) as Internet Usage Statistics (2023) documents. Along with this increase, even sharper increase in mobile internet usage happens because more that 60% of internet traffic was originated from mobile devices globally (despite significant fluctuations, e.g. in U.S., the ratio is less than 50%) (Ruby 2023). Anyway, the number of internet mobile users keep increasing, and got up to 5.3 billion this year (Ruby 2023). Together with these increases, also the quality and availability of internet services increases, both in fixed (namely households and corporate) and mobile internet connections.

On the other hand, many ICT tools lock their users inside (at least in some aspects) resulting in more or less serious troubles when you want to switch from one service you use to another one (like transferring contacts etc.). Therefore, it is obvious that many users of ICT tools (e.g. smartphones, mobile apps and/or communication services like e-mail, WhatsApp etc.) ask questions like how likely is that my mobile phone brand or communication service will survive for the next few years or even decade, how much shall I pay for data transfers next year etc. Answers to many such questions depend not only on business policy of providers of IT services (like device producers, telecommunication operators), but also on the pace of technological innovations in the sense how quickly the service parameters (e.g. data transmission rate) improve.

Therefore, the main aim of this study is to assess whether IT innovations yield a reasonable benefit for users. Despite the fact that benefit for users is difficult to evaluate, an inspiration has been taken, among others, from Quality of Experience (QoE) metrics as analyzed in detail in Möller, S., & Raake, A. (Eds.) (2014).

II. Existing research in economic impact of ICT

There are some published studies focusing on various facets of IT applications and their economic impact. Most of them published recently focuses on mobile and wireless transmission efficiency (e.g. Ku, I., Wang, C. X., & Thompson, J. 2013 or Akhtman, Y., & Hanzo, L. 2010), while others analyze impacts of internet service on productivity, either from global view (Thompson Jr, H. G., & Garbacz, C. 2007). or with detailed focus on a specific region (like Uri, N. D. 2001 in the U.S. Uri, N. D. 2001). Other publications focus on the implementation efficiency of security measures in networks, e.g. Savenko O. et al. (2020) or Weishäupl, E., Yasasin, E., & Schryen, G. (2015).

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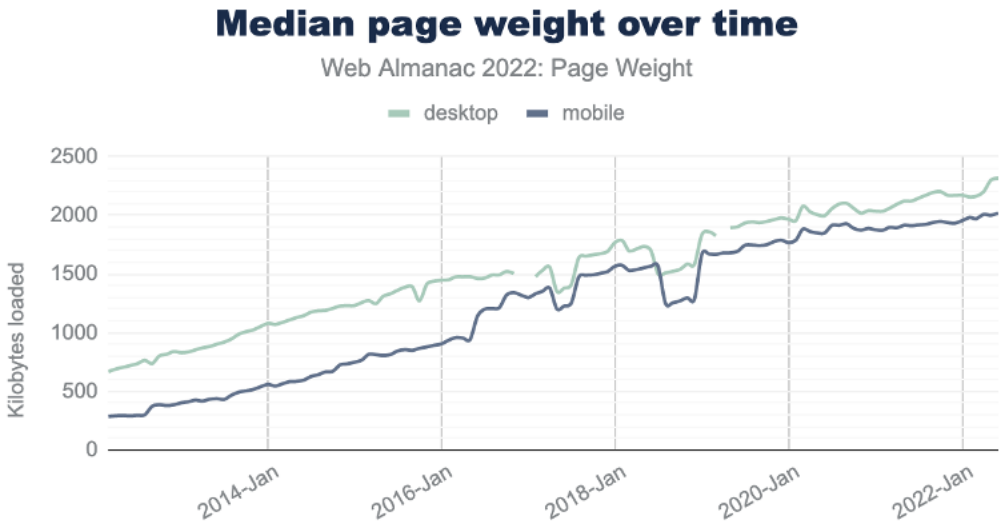
Nevertheless, no published papers have been found focusing solely on the economic efficiency of implementation of new techniques aimed to improve the user QoE in various ICT tools. Therefore, the author decided to analyze this aspect of ICT development. The analysis is based on several use-cases illustrating various stories in ICT development.

III. Use-case 1. World-wide web

The world-wide web service is ranked among the most frequently used services on the internet nowadays (see e.g. Ruby D. 2023). Nevertheless, one should bear in mind that the present www service differs a lot from what was invented by Tim Berners-Lee in 1989. Not only communication standards (HTTP and HTML) have evolved, also the amount of data to be transferred so that a single web page is displayed, has increased significantly. Therefore, technological innovations are necessary part of the evolution for www service.

Let's imagine that there have been no technological innovations in telecommunication networks since the www the dawn in 1900s. It would result in the fact that majority of web pages could not have been displayed at all. For simplicity, lets shorten the period for last ten years. The average size of web pages in 2013 was about 500 kB while in 2023 it is more than 2 MB as documented by Page Weight: Part IV Chapter 21 (2022). The median web page size evolution is shown in Fig. 1. The web page size increase factor of more than 4 during the selected decade means that at least four times higher transmission speed is required to achieve the same web page load time when transmission rate is the same. If no technology improvement has happened in last ten years, the average web page load time would increase more than four times resulting in timeout exhaustion and inability to display the page many times. Fortunately, due to technological improvements, the typical transmission rate for both fixed and mobile internet connection increased significantly in the same period.

Figure 1 Web page size increase during last decade



Source: Page Weight: Part IV Chapter 21 (2022)

Now, let's focus on data transmission rate aspect of the www service. Unlike the typical size of a web page that is relatively easy to determine (the above data from Page Weight: Part IV Chapter 21 (2022) were calculated as a mean value of many web pages), the typical data transmission rate varies a lot according to numerous factors including the following:

- Data transfer method (e.g. DSL line, wireless, 3G/4G/5G mobile data connection, or even legacy voice modem),

- The data transfer direction (download to client/ upload from the client) because in many (primarily household and end-user) internet connections, the download rates tend to be favored to the detriment of the upload data rates,
- The type of client device (PC/mobile) and operating system,
- Internet Service Provider (ISP) policy regarding data rates available,
- Location (including the distance between client device and ISP site/mobile base station), and many others.

Because of so many factors affecting the transmission rate, this paper focuses just some of them. An example how the data transmission rate increased in U.S. households is given in Cooper (2020), where one can see that while in 2010, the most common data transmission rate for U.S. households was about 4 Mbps download (and this was available for more than 90% of them) while faster data transmission rate (about 25 Mbps download) became typical a bit later and its availability for U.S: households exceeded 90% only in 2018.

Another example of typical data transmission rates can be taken from the development of mobile internet connections. While in 3G (e.g. UMTS in Europe standardized in 2001 and globally adopted about 2005), the expected transmission rate was about 2 Mbps, in 4G (represented here by LTE whose deployment started in about 2012 in some countries), the data transmission rates were about 100 Mbps in typical implementations and client device scenarios. Presently state-of-the-art mobile data technology indicated as 5G, whose deployment started in 2019, recorded average download speed at 186 Mbps according to Wyrzykowski, R. (2023).

In addition to the development of data transfer technologies by itself (demonstrating the data transmission rates in mobile networks from 3G to 5G), several additional new technologies contributed to the improved (or at least not worsened) QoE for www users. Among them, multi-path TCP (MPTCP), the technology allowing to use multiple TCP connection in the transport layer of ISO/OSI model (L4) has played certain role in web page latency decrease as well. Its IETF standardization happening in 2013 by Ford, A., Raisiu, C., Handley, M.& Bonaventure, O. (2013). followed by implementation in iOS in 2022 (Apple 2022) has contributed to the web page latency decrease in many situations as documented e.g. by Manzoor et al. (2018).

Other application layer (L7) improvements include HTTP versions 2 and 3, standardized in 2015 (RFC 7540) and 2022 (RFC 9114), respectively. However, the impact of HTTP/2 and HTTP/3 was ambivalent because on one hand, they improved the web page latency as documented e.g. by Saif et al. (2021). On the other hand, HTTP/2 and HTTP/3 introduced mandatory encryption of the web traffic at the same time, causing significant data volume increase necessary for downloading a web page with a possible side effect in longer web page load time.

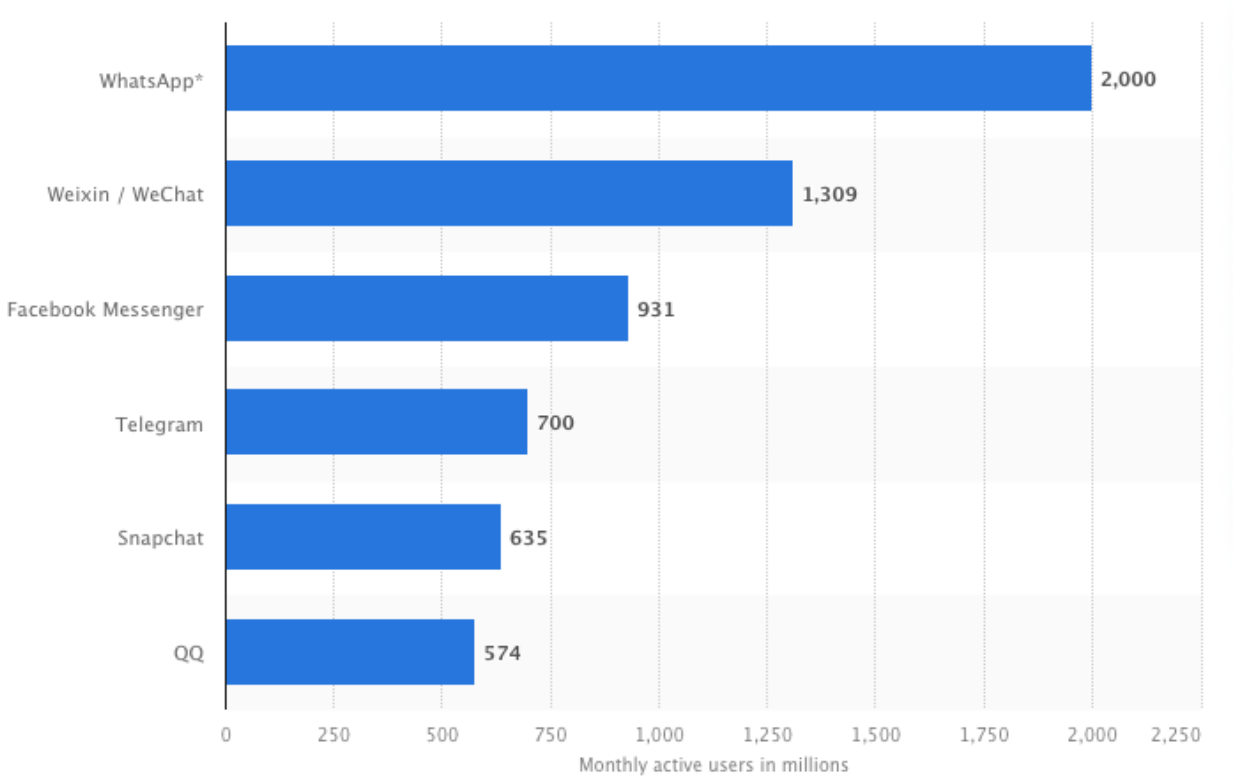
From the above numbers, it is clear that typical data transmission rates have increased gradually and the increase factor for recent ten years was more than 6 for households and roughly between 4 and 20 for mobile. Comparing the increase factor of web page sizes (4), it seems obvious that the QoE for household users (expressed as web page loading time) was relatively stable while for mobile users, it can get worsened sometimes (primarily in adversary mobile signal conditions where the data transmission rate is not high enough for downloading a bigger web page quickly enough).

The main economic aspect of the ongoing development and technological improvements in ICT, namely continuous improvement in data transmission rates, seems to be the issue of efficiency of investments into communicating networks. As demonstrated above, such investments are interrelated with web page size increase. However, the www service is not the most significant service for mobile clients now. It seems obvious that most important drivers for ongoing investments into telecommunication network improvement.

IV. Use-case 2. Electronic mail and other messaging services

Sending and receiving simple messages have been one of the first services since early internet utilization in 1970's in the form of electronic mail. The service was standardized in 1982 by Postel, J. B. (1982) and updated several times up to the current version described in Klensin, J. (2008). Much later, other messaging services were developed (e.g. IRC, ICQ, Skype, Hangouts, Viber, WhatsApp, Facebook messenger etc.). Most of the competing messengers are either free but they are operated by business corporations as one of tools to commercialize the user base. Despite the commercially-backed competition in messaging services, e-mail has kept its dominance as you can see by comparing user numbers in Fig. 2 (topped by 2 billion of WhatsApp users, taken from Statista 2023) to the number of e-mail users in Radicati Group (2022) where the number of e-mail users is as high as 4.26 billion. When comparing to older figures Radicati Group (2014), it seems obvious that the increase in e-mail user number is slow (about 3% a year) but still e-mail clearly dominates.

Figure 2 Number of users (in millions) of commercial messengers in 2023



Source: Statista.com (2023).

Despite numerous weaknesses of email (among them, the most critical seems to be a missing sender authentication of senders leading to frequent e-mail abuse to spread spam, phishing etc.), e-mail still dominates. In should be admitted that there are some weaknesses exist in competing messengers (primarily the fact that none of major messengers is open-source resulting in limited ability to understand and control the delivery of user's messages and it seems difficult to rely on the long-term continuity of the service).

There were several attempts to eliminate e-mail issues (e.g. Sender Policy Framework, DKIM, DMARC techniques) aimed to eliminate missing sender verification, at least in the sense that they made anonymous sending of large volumes of messages (e.g. spam) more complicated. However, the adoption of the above-mentioned techniques was not so massive that their effect could be significant (or, at least, spammers could adopt to the new measures and the typical share of spam did not decrease much).

Even here, an economic aspect of commercial messengers' adoption can be studied. Here, it could seem strange that no one commercial messenger could have overcome e-mail, despite the strength of corporations promoting them. There are several possible reasons for this. Among them, persistence of certain user group on e-mail and lack of motives to switch to a commercial messenger play certain role. Also, using e-mail (at least in the sense having access to an e-mail account for sending and receiving messages, not necessarily its active usage) seems almost inevitable in some situations, e.g. when renewing access to an internet service, having access to an e-mail account is considered as a form of user authentication or distinguishing between human and automated user, and without it, the procedure becomes much more difficult. This role could hardly handed over to any commercial messenger, just because their close relation to a specific IT corporation, unlike e-mail.

V. Use-case 3. Digital signatures and related techniques

In messaging services, primarily in electronic mail services, there is one significant weakness in missing sender authentication (as mentioned in the previous section and explained in more details in Sochor, T., & Chalupova, N. (2019). Since many years, a demand for a tool or technique able to guarantee the sender authenticity (preferably together with the documents being sent) lead to development of various digital signature techniques. Among them, digital certificates according to X.509 were adopted massively as standardized by Cooper D. et al. (2008) and ITU-T (2019).

Despite relatively early standardization, the adoption of digital signatures has been limited up to now, and in the meantime, substitute tools were developed for e,g. public services in many countries, instead of possible use of X.509-based digital certificates and signatures. In this use-case it seems obvious that just insufficient support from big ICT developers and producers was likely the reason why X.509 adoption was not so massive as it could have been.

VI. Conclusion

As the above use-cases illustrated, the continuous development in ICT tools forms an inevitable part of their service. It has been demonstrated that the development leads to a higher quality of the specific service, in certain situations. Economic aspects of the ICT service development were briefly discussed for all three selected use-cases with different outcomes.

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