Mobile Communications: Diffusion Facts and Prospects (*)

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Abstract: This paper discusses the diffusion of different generations of innovative mobile services and compares actual market performance with expectation at the time of introduction of each generation. Whereas 1G and 2G were an unexpected success under this point of view, 3G did not live up to expectations. This poses the question to which extent technology was too much pushed on the supply side, rather than pulled on the demand side. While discussing the intermediary technologies leading up to 4G, the question of service innovations is posed, such as the convergence of fixed and mobile technologies. The paper thus dwells on possible reasons for actual market performance and tries to assess the perspective of the introduction of innovations still to come.

Key words: Mobile telecommunications, diffusion of technology generations, mobile broadband services, fixed-mobile substitution.

Twenty years ago, mobile phones were thin on the ground. Today, this industry has surpassed fixed access and accounts for more than 1% of the GDP (OECD, 2007) in many countries. Although the basic concepts of wireless interaction were known since the late 19th century and some relatively poorly performing mobile telecommunications systems were built after World War II, mobile phones belong to a relatively young industry. The vast improvements in semiconductor and microwave technology, allowed the construction of the first commercial cellular networks at the beginning of the 1980s. Since then, mobile telecommunications have experienced explosive growth. In particular, the new industry has acquired as many users in two decades as the fixed managed in more than a century.

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This evolution has reinforced the market's confidence in the platform and spurred vast investments in numerous services. Nevertheless, simple voice telephony remains the killer application of the industry and there are hardly any indications that this situation can significantly change in the foreseeable future.

This extraordinary growth story can be mainly attributed to two factors: technological progress and regulation (GRUBER, 2005). Both are predominantly supply-side factors. Concerning demand, the need for mobility in communications has played a pivotal role. Some earlier attempts to introduce similar services were hampered by very high prices and unconvincing performance. This is reminiscent of a relatively old debate in economics of innovation; is it technology push (supply side effects) or demand pull (demand side effects) that determine the launch of products/services in the market? SCHMOOKLER (1966) demonstrated that demand in the capital goods industry was leading the supply of it. This was contrasted with the view that innovation was rather shaped by the emergence of technological opportunities (ROSENBERG, 1974). This paper proposes to tackle the issue by dissecting the market into appropriate subsets. While technical change can occur both at discreet steps and in more continuous fashion (NORTON & BASS, 1987), mobile phones have evolved in technological generations. Significantly improved service capabilities determine the advancements of successive generations. First generation (analogue) mobile telecommunication technology was introduced in the early 1980s for voice services only. There was a relatively large number of different first generation systems (based on seven mutually incompatible national standards) installed at the world-wide level. This competition of standards hampered the drive to equipment cost reduction and the development of services such as international roaming. Second generation (digital) mobile telecommunication technology was introduced during the first half of the 1990s. The capability to provide voice services was improved and new data services were developed. At that point technology introduction was much better coordinated, especially in Europe with the setting of the GSM standard, and the total number of different systems installed worldwide was reduced to four. GSM was the first standard to be introduced in a large number of countries and since then it has remained, by far, the most widespread system both in terms of adopting countries and subscribers. There is also strong empirical support that standardisation accelerates diffusion (GRUBER & VERBOVEN, 2001; KOSKI & KRETSCHMER, 2005).

Whereas the first and second generation of mobile telecommunications systems were mainly designed for voice transmission, the next technological step was the development of systems for data transmission. Third generation (3G) systems were thus designed to significantly increase data transmission rates and allow for multimedia services and applications. The overall performance of the 3G market has been disappointing under most aspects: services started late and there was generally much less demand for them than originally expected (GRUBER, 2007). Hence the diffusion of third generation subscribers was much slower than its predecessor.

Long Term Evolution (LTE) is the next standard of the 3G mobile broadband telecommunications, mainly based on WCDMA. The core characteristics of LTE include its capability to provide peak data rates of up to 100 Mbit/s in the download and 50 Mbit/s in the uplink for 20 MHz of spectrum. While it still belongs to 3G it is expected to pave the way for fourth generation systems (4G). Along with this, significant changes in the business environment are expected.

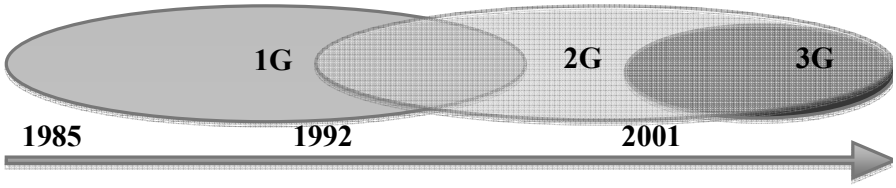
This paper makes a critical assessment of the different generations of innovative mobile services and compares actual market performance with expectation at the time of introduction. It also revisits the old question of market pull and technology push on this particular matter and tries to delve into the reasons for the 3G market underperformance. We also discuss the important benefits from the introduction of the LTE, while we try to assess the perspective of the innovations still to come.

■ The diffusion of the market for 2G and 3G mobile telecommunications services

Historically, mobile communications evolved in a sequential manner (see GRUBER, 2005). The successive generations sometimes overlapped with their predecessors thus creating a form of inter-generation competition (see figure 1). Mobile phones began to proliferate after 1985 with the introduction of cellular networks. These networks included multiple base stations located relatively close to each other and operated with handover protocols, which indicated the moves from one cell to the others. All standards for first generation networks used analog radio signals and voice encoding was modulated to higher frequencies. NMT standard was used in the Nordic countries, AMPS in the United States and Australia, TACS in the United

Kingdom, C-450 in West Germany, Portugal and South Africa, Radiocom 2000 in France, RTMI in Italy and NTT in Japan. None of these standards was compatible with the others and subsequently this situation hampered international roaming, handset prices and equipment competition.

Figure 1 - The timeline for mobile technologies



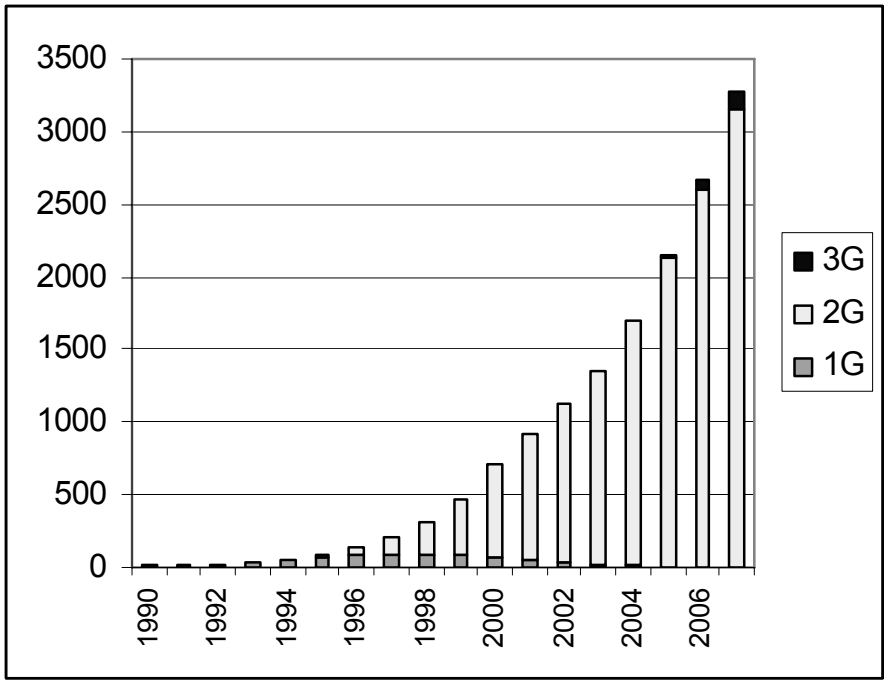
In accordance with the development of the Common market, the European Commission decided to develop a pan-European mobile phone standard in 1982. The new system had to operate in the 900 MHz spectrum, allow seamless roaming throughout the continent, be fully digital and offer voice and data service (SCHILLER, 2003:11). Standardization for GSM finally occurred in 1991 and it still remains the most widespread mobile telephony standard. As plotted in figure 2, second generation networks experienced unprecedented growth, of which GSM represents the great majority. Second generation quickly became dominant relative to the first generation and until 2007, not only the number of subscribers but also the adoption rates were still increasing year by year. The introduction of lighter and more efficient mobile phones coupled with the SMS services and the pro-competition regulation, all contributed to the very rapid adoption too.

Third generation networks started to develop after the launch of the first commercial second generation networks. Pre-commercial 3G networks were launched in 2001, when almost a billion subscribers of 2G were in place. The advent of higher data throughput and the new services that could be offered on the mobile platform fuelled the operator's plans for further investments. Evidently, the voice services continued to provide the main income for the operators and data services failed to meet the expected demand after 6 years in the market.

Several years later a European-wide survey (European Commission, 2006) included a question about the need of upgrading to a 3G phone. In particular, participants were asked the following question:

"Please tell me which of the following features would make you personally switch to an advanced mobile phone service (the possible answers define what an advanced mobile phone is- e.g. 3G)". The results are presented in figure 3.

Figure 2 - Worldwide mobile subscribers (in millions), by technology generation

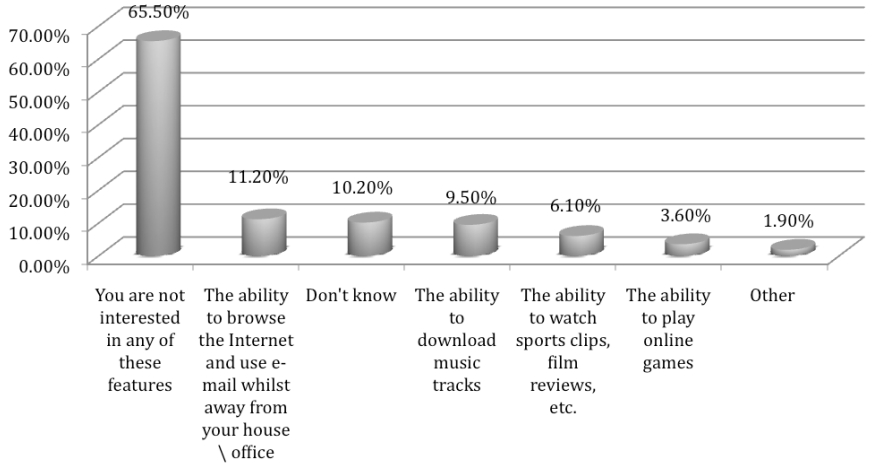


Source: Informa

While participants could include more than one option in their answers, the majority (65.5%) revealed a lack of interest in the upgrade. The second most favored response – though far less popular than the uninterested cluster – demonstrated a need for Internet access and e-mail use in a 3G mobile device. However, only 11.2% of the participants chose to have this option enabled. Moreover, many 2G phones used to have simple browsing capabilities and e-mail access. Perhaps part of the respondents either did not know or could not compare the two services offered. Therefore this 11.2% of the participants might be overestimated. Notably, the third most popular response demonstrated that an important part of the population does not know the pros and cons of the upgrade. This part was equal to 10.2%; adding the uninterested and the unknowledgeable we get a

surprising 75.7%. This result manifests that more than three out of four people in Europe, would not think to upgrade to a 3G phone on the eve of 2006. The rest of the responses included an interest in music tracks download (9.5%); a smaller part interested in sports clips, films and reviews (6.1%) and a lower percentage asking for online gaming (3.6%) or other services (1.9%).

Figure 3 - Survey results on reasons that would induce switching to 3G



Source: Eurobarometer

All this suggests that there was relatively little demand for 3G. It may thus be useful to compare this with previous generations in the context of a simple diffusion model. The reference model is described in detail in BOHLIN *et al*. (2010), an appropriately modified version of GRUBER & VERBOVEN (2001) used to estimate the diffusion of mobile telecommunications in general. In many countries the number of mobile subscription exceeds the population number, often to a considerable degree indicating a tendency towards saturation in terms of primary diffusion. For instance, the data used in BOHLIN *et al*. (2010) shows that at the end of 2007 Italy had a mobile penetration rate of 148.1% and Spain 121.8%. In such a market context it becomes more appropriate to study the innovations within mobile communications through the study of the diffusion of generations of mobile technologies.

BOHLIN *et al*. (2010) model the diffusion of subscribers of third generation z_{3G} as follows:

$$z_{3G_{ijt}} = a_j^0 + x_{jt}\left(Urban + Regulation + GDPC + BBPen + Diff\_Speed_{2G}\right) + \left[\beta_j^0 + x_{ijt}\left(HH_{Competition} + HH_{Technology}\right)\right] t \quad [1]$$

Model [1] uses as location variables urbanisation (*Urban*), *Regulation* (as measured by the Telecommunications Regulatory Governance Index; KOUTROUMPIS & WAVERMAN, 2009), per capita GDP (*GDPC*), Broadband Penetration (*BBPen*) plus the second-generation network diffusion speed (*Diff_Speed*). These variables represent the location effects for each country in the sample. Additionally the diffusion 'growth' effects are captured by the Herfindahl concentration indexes of inter-generation ($HH_{Generation}$) and inter-firm competition ($HH_{Competition}$). These variables are used to assess the growth impact of competition among firms and different standards on 3G adoption.

All diffusion speed variables used here - and in Models [2] and [3] - are considered as location and not growth effects. In other words we say that the diffusion speed of second-generation networks is a location parameter for 3G adoption and not a growth promoting factor. Despite the fierce competition among different generations the focus in this regression is the diffusion of 3G. The additional 2G lines relative to the total mobile lines is – conceptually – a location effect of the 3G diffusion. The diffusion 'speed' variables for Model 1 are the concentration indexes of inter-technology and inter-firm competition.

The diffusion models for second generation adoption are models [2] and [3]

$$z_{2G_{ijt}} = a_j^0 + x_{jt}\left(Urban + Regulation + GDPC + InternetPen + Diff\_Speed_{1G}\right) + \left[\beta_j^0 + x_{ijt}\left(HH_{Competition} + HH_{Technology}\right)\right] t \quad [2]$$

$$z_{2G_{ijt}} = a_j^0 + x_{jt}\left(Urban + Regulation + GDPC + InternetPen + Diff\_Speed_{3G}\right) + \left[\beta_j^0 + x_{ijt}\left(HH_{Competition} + HH_{Technology}\right)\right] t \quad [3]$$

Model 2 uses as location variables Urbanisation, Regulation, per capita GDP, Internet Penetration (*Internet Pen*) and 1G diffusion speed. The regressions here use a sub-sample between 1990 and 2001 when both 1G and 2G co-existed. Additionally the diffusion 'growth' effects are captured by the concentration indexes of inter-technology and inter-firm competition. Model 3 uses the same location variables as before substituting 1G diffusion

speed with 3G diffusion speed. The regressions range from 2001 to 2007 when both technologies co-existed. Again the diffusion 'growth' effects are captured by the concentration indexes of inter-technology and inter-firm competition.

Table 1. Results of the inter-generation competition

	(1) *3G*	*(2)* *2G (1990-2001)*	*(3)* *2G (2001-2007)*
Location Variables			
Urban	+	+	+
Regulation	+	+	not significant
GDPC	+	+	+
Broadband Pen	+		
Internet Pen		+	+
Diffusion $Speed_{xG}$	-	+	not significant
Diffusion Variables			
HHI Competition	-	-	-
HHI Technology	-	-	+
Obs (Groups)	296(62)	1186(129)	369(62)

Source: BOHLIN et al.*, 2010*

From the results presented in Table 1 we observe that across all models the location variables positively affect diffusion. In particular, urbanization, GDPC and Internet/Broadband penetration are always positive and significant. Regulation is positive and significant for 2G and insignificant for 3G.

Perhaps the most interesting discussion derives from the inter-generation diffusion speed variables. Model [1] regressed third generation diffusion into second-generation speed. Evidently the continuous rise of second-generation adoption – reflected by the Eurobarometer and the Informa sample statistics – had a negative and significant effect on third generation diffusion. Moreover in model [2] we find that the effect of first-generation on second-generation adoption was positive and significant. Model [3] measured the reverse effect of model [1], namely the impact of third-generation on second-generation adoption; the results showed that this effect is insignificant.

From this discussion we understand that the effect of first generation on second generation was positive whereas the effect of second generation on third was negative. Instead, the effect of third generation on second was insignificant.

In terms of the speed diffusion variables, the results suggest that competition is always a positive enabler of mobile diffusion, regardless of generation. We note here that the lower the Herfindahl index the higher the competition, thus the minus sign reflects a higher level of competition. In terms of multiple technology standards it is found that 3G adoption is strengthened by the existence of more technology standards and the same goes for the early years of 2G (1990-2001). During the maturity period of 2G adoption, markets tilted towards a single standard were faster growing than multi-standard markets.

Looking at the evolution of mobile technologies at an aggregate level, one can argue that the long gestation period for 1G would indicate an element contains a mixture of supply pull and demand push. However, the rapid diffusion of 2G definitely indicates demand-pull in innovation. This has probably been less so with 3G, where there are several indications that supply push elements were in place, such as the reservation of spectrum, early deployment of technology and the disappointing take up rates in the market.

■ Perspectives for 3.5G+ diffusion

In spite of the initial expectations, the lack of convincing service propositions combined with the high prices for broadband access have resulted in a slow adoption process for 3G. The obvious question is what will happen after 3G? Will there be a repetition of the success like in 2G or will there also be a lumbering on as with 3G? While the "killer application" with 2G was voice, could it be high-speed broadband access with 4G? Indeed 2G has eaten very much into the fixed line market, especially as fixed voice subscriptions fall relative to mobile subscriptions. But, the evidence for fixed-mobile substitution is not strong enough to justify a rolling back of fixed line regulations (VOGELSANG, 2010). Will we also observe a comparable degree of fixed to mobile substitution for broadband with 4G?

A cursory inspection of available data shows that after 2005 mobile broadband is has been becoming increasingly relevant as a source of

broadband access for individual private users. This could be observed in particular in countries where fixed mobile substitution for voice was already fairly adavanced, such as Finland and Austria. Finland is the first country where the absolute number of DSL subscribers is actually declining: DSL subscriptions peaked during the first half of 2008 and have been declining since then (Ficora, 2009). The overall number of broadband subscriptions is nevertheless increasing thanks to the expansion of mobile broadband which more than compensates for the decline in DSL. This means that the share of mobile broadband subscriptions as a percentage share in total broadband is increasing, passing from 8% at the end of 2007 to 14% in mid 2009. Finland seems thus on the track to evolve towards a system where the mobile networks are shouldering the bulk of broadband access. For this, the country is also among the first to "refarm" 900 MHz frequencies for 3G services and operators are already rolling out UMTS networks in this frequency spectrum. The choice of compatible handsets is still limited to a few, but supply is expected to increase, especially when it becomes clear that GSM services will be phased out in this frequency range and be fully taken over by UMTS.

Also in Austria the share of mobile broadband subscribers out of total broadband subscribers is increasing rapidly: it passed from 13% at the end of 2006 to 36% in March 2009 (RTR, 2009a). The Austrian regulator made a survey (RTR, 2009b) of the migration of connection, showing that the number of migrating customers moving from DSL to mobile broadband is two and a half times higher than the number of customer moving the other way round. Moreover, 70.6% of the mobile broadband customers are satisfied with the service.

There are several drivers for adoption of mobile broadband. With the implementation of High-Speed Downlink Packet Access (HSDPA), transmission speeds are becoming comparable to fixed line access . This enables browsing the Internet or sending e-mails using HSDPA-enabled notebooks. Thus users have incentives to replace their fixed DSL modems with HSDPA modems or USB dongles, and send and receive video or music using 3G phones. However, data from a European Commission (2009) report shows that the number of connections using only dedicated data cards, modems or keys, which typically allow mobile Internet access via laptops is with an EU average of 2.4% of the population which is significantly lower than the share of mobile broadband subscribers, equivalent to 13% of the population. There is also a large variance across EU countries around this average of 2.4%, between Austria displaying 11.4% and Latvia and Cyprus with 0.4% each.

This trend is still very much constrained by pricing considerations. In the past, mobile broadband capabilities came at a relatively high price for the end users. However with the introduction of more attractive flat rate tariff schemes, mobile broadband service becomes competitive with fixed broadband services as long as access performance requirements are not too demanding. This trend towards flat rate plans puts pressure on mobile service providers to revise their overall pricing regimes. Mobile (voice) services are typically charged by time. But as overall mobile traffic increases the charging structure does not reflect the underlying traffic flow. Data traffic, which is becoming the bulk of the traffic for mobile operators does not attract revenues in proportion, and as soon as customers become able to arbitrage their voice traffic over the data streams mobile operator will find themselves challenged to revise the overall traffic pricing along with the interconnection regimes.

With technologies going beyond the 3G domain such as Full Broadband Access/LTE, the end user will be able to access more demanding applications like interactive TV, mobile video blogging, advanced games or professional services at speeds similar to those currently prevailing in fixed line access. To the extent that broadband services would be sold in a seamless broadband environment, it should become increasingly difficult for operators to charge today's high premiums for the mobile accessibility. The repercussions of operating in such a market should lead to lower costs for end users accessing broadband services through a mobile network and thus advance fixed-mobile substitution for broadband services. This could be also the moment when a genuine demand pull effect could set in and drive further mobile broadband diffusion.

The increased diffusion of broadband connectivity (fixed or mobile) should fuel the further demand of such new IP based services. In order to avoid becoming exclusively bit-pipeline providers with little scope for product/service differentiation and to benefit from the potential revenues of these services, traditional operators are increasingly tending to regain control of these types of broadband services and providing them to their customers with the now available value added fixed-mobile convergence, and their large scale customer relations capabilities. The failure to do so would reduce the mobile operators to invest in new transmission capacity and risk leading to a deterioration of service performance.

Among the different attempts is IP Multimedia System (IMS), which is an architectural framework for delivering Internet Protocol (IP) based services (e.g. VoIP, mobile video blogging, interactive TV) to both mobile and fixed

(converged) networks. It is designed to allow seamless convergence of both technologies, making the services provided to the end user independent of the form of access. However the jury of the market on this technology is still to be awaited. But there could be the risk that suddenly there is a strong demand for traffic while the operators are struggling to raise financing for infrastructure. At this point demand pull for technological innovation may have taken over definitively.

■ Conclusions

This paper suggests that after a long period of gestation time appears ripe for mobile broadband services to take off in the marketplace. With retrospect, something similar could be observed for first generation services, where a similarly long gestation period for 1G indicates a mixture of supply pull and demand push. However, the rapid diffusion of 2G for voice services at low prices definitely indicates demand-pull in innovation, in particular pre-paid cards. This demand pull has been less so with 3G, where there are several indications that supply push elements were in place, such as the reservation of spectrum and the early deployment of technology. Moreover, while second-generation technologies retained a high rate of diffusion, third generation technologies had to absorb part of the existing 2G subscribers and at the same time were not able to extend the scope of the market by attracting new subscribes. This may be partly due to the fact that the mobile penetration was much higher around 2000 than in the early 1990's, leading in several countries to saturation points. But it also suggests that second-generation subscribers were composed of two, not necessarily equal, parts: voice service and data service subscribers. The former needed just the voice service provided by second generation and thus did not actually need to migrate to third generation services. Only data users with stringent performance requirements had to migrate to 3G. Moreover, attracting intensive data users did not really pay off in terms of increased revenues as a new pricing regime based on flat rates became predominant. Having found mobile broadband as the "killer applications" for 3G+, mobile operators have now the problem to cope with building high performance infrastructure in a context of dwindling revenues from customer services. The market success depends on the extent to which they are able to raise sufficient funding from operations, in particular to provide additional services for which consumers are prepared to pay (possibly a price premium).

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