1. Introduction
The main question in this paper is: Which standard/technology will win the 3G mobile market? The most prominent contenders are WCDMA (also known as UMTS) and cdma2000. In addition, EDGE will also play a role as will (presumably) the Chinese TD-SCDMA standard. Furthermore, other kinds of wireless solutions such as WLAN (WiFi) are spreading fast and may pose a threat to (or complement) the cellular mobile technologies. Such phenomena should not be overlooked. However, in this paper we will concentrate on 3G technologies and specifically on the two main contenders, WCDMA and cdma2000.

GSM is the worldwide dominating 2G standard with 5-6 times as many subscribers as cdmaOne. The question is whether the proponents of GSM technology (who are supporting the WCDMA solution) will be able to extend this dominant position into the 3G mobile markets. Currently, cdma2000 (which is supported by the cdmaOne community) seems to be doing better in the markets than WCDMA. In South Korea, cdma2000 technology has obtained an impressive number of customers, and in the Japanese market, the NTT DoCoMo 3G solution FOMA, based on WCDMA technology, has not had nearly the same success as the KDDI au-offer, based on cdma2000 technology. Does this indicate that cdma2000 in the future mobile markets will be the preferred standard or will WCDMA eventually dominate the markets?

In addition to this main question, there are two groups of sub-questions being dealt with in the paper:

- Which kind of victory will it be? Will one technological solution be all-dominating or is co-existence more likely?
- Which are the most decisive factors in the battle between the different standards? Which roles do respectively technology path-dependence and strategic concerns play?

In order to approach answers to these questions, the paper will first briefly examine important institutional aspects of the development history of 3G standards. This is followed by a technology oriented description of the migration paths from 2G to 3G solutions. And finally, before concluding there is a discussion of the issues dealt with in the paper on basis of a stakeholder analysis, encompassing infrastructure and terminal manufacturers, network operators, policy makers and administrators, and end users.

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1 For abbreviations, see list at the end of the paper.
2. Development history

It is often the case with new technologies that technical committees, standardization organizations, company R&D departments, etc. have been working on their specification and development long before they hit the headlines in the news. With respect to 3G technology, the work with developing the specifications started even before the 2G solutions had reached the markets. Work has been performed in several organizations and parts of the world in parallel and cooperation. However, in the context of this paper we will take our point of departure in the work performed in relation to EU, ETSI and ITU and examine how this intersects with work done and decisions taken in Japan, South Korea and, last but not least, the US.

Work in the EU context on 3G technology started in 1988 in relation to the first communication technology research programme RACE I with participation from European based equipment manufacturers, telecommunication operators and universities. Work continued in the RACE II programme and the subsequent ACTS programme, and results from this work were submitted to the European standards institute ETSI as candidates for UMTS air interfaces and to ITU as IMT-2000 submissions. The proposals for air interfaces were in 1997 grouped by ETSI in 5 different categories: WCDMA, WTDMA, TDMA/CDMA, OFDMA and ODMA. At that point of time, there was no definite decision as to which air interface technology would eventually be favoured by ETSI. It was still not a closed game; however, with the decision of ARIB in Japan later in 1997 to support WCDMA, it was decided in ETSI (in 1998) to select WCDMA as the preferred air interface for 3G.

Ericsson and Nokia already favoured WCDMA, which was part of the background for the Japanese decision. Therefore, there were, actually, already strong indications that WCDMA would be given priority. And, to continue working together in a broader international context, ETSI in 1998 took part in the establishment of the so-called 3GPP with participation from Europe (ETSI), Japan (ARIB and TTC), South Korea (TTA) and USA (T1P1) and later in 1999 CWTS from China.

ITU had started working on 3G specifications already in 1986 - at that point of time it was called Future Public Land Mobile Telecommunication System (FPLMTS). However, ITU has not had a decisive role in the processes of 3G standardization. The most important organizations in this field are 3GPP and its counterpart 3GPP2 (organizing the proponents of cdma2000 technology) and the regional standardization organizations behind these two conglomerates and the different equipment manufacturers and telecommunications operators. The contributions of ITU in the field have mostly been centred on a coordinating role in relation to the IMT-2000 project and the decisions taken in the context of the World Radio Conference (WRC) in 1992 on the allocation of spectrum frequencies for 3G solutions.

The initial vision with IMT-2000 was to develop a common worldwide 3G standard. However, because of strong strategic and economic interests of the different players, this vision could not be realized, and presently the aim of the IMT-2000 project is to secure as much compatibility as possible between the different 3G standards. To that effect, the idea of the concept of a family of standards was introduced - the IMT-2000 family, see figure 1.

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3 Ibid pp. 43-44.
Figure 1 shows the different radio access technologies in the IMT-2000 family of standards as well as the possible flexible assignment of core networks, in principle, enabling roaming. Compatibility is the main intention of the IMT-2000 project. In practice, however, there is no roaming, presently, between WCDMA and cdma2000 systems.

**Figure 1: The IMT-2000 family of standards**

With respect to frequency allocations, frequency bands for IMT-2000 were defined at the WRC in 1992, identifying specific frequency bands to be available worldwide for 3G mobile communication systems. In Europe and Japan, small parts of the IMT-2000 frequency bands were already allocated for DECT and PHS systems – resulting in smaller overall frequency bands for the IMT-2000 systems. However, this was easily overcome compared to the situation in the US, where most of the IMT-2000 frequency bands were being used for 2G networks or reserved for other use – making 3G an open question. The IMT-2000 frequency allocations and IMT-2000 frequencies in Europe, China, Japan and North America are depicted in figure 2.

**Figure 2: frequencies for IMT-2000 in a global perspective**

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2.1 Regional decisions
Standardization regarding Radio Transmission Technology (RTT) has been conducted in four major regions (plus China), where ETSI was the main driver in Europe, ARIB and TTC in Japan, TTA in South Korea, and TIA and T1 in the US. However, there has been some overlap in the standardization processes, as different companies and organizations from the four regions contributed to the standardization work in more than one of the standards organizations.

In Japan, ARIB received several proposals for 3G mobile systems but the WCDMA air interface technology was selected in 1997 as their IMT-2000 proposal. One of the main reasons for choosing WCDMA was the close cooperation with ETSI, as the Japanese and European WCDMA technology proposals were very similar. (In Japan, TTC is responsible for higher layer specifications and was, therefore, also an important player in the standardization and selection process).

In Europe, ETSI also received several proposals for IMT-2000 air interfaces, which all basically were able to fulfil the requirements set out at the beginning. In 1998, ETSI selected WCDMA as the preferred air interface technology. In the selection process, the fact that the Japanese had already chosen WCDMA and the relatively close cooperation between ETSI and ARIB definitely had an influence on the choice made by ETSI.

In the US, T1P1 worked on GSM related standardization and submitted WCDMA N/A (N/A for North America) as their IMT-2000 proposal. The WCDMA N/A proposal had many similarities with the WCDMA proposals from ETSI and ARIB, as several of the contributing organizations had been involved and active in the ETSI and ARIB standardization work as well. Furthermore, a cdma2000 air interface proposal was submitted by the TIA TR45.5 working group. The proposal was based partly on the IS-95 standard as a migration road towards 3G cdma systems. This US based cdma2000 proposal has a high degree of similarity with the South Korean cdma proposal.

In South Korea, TTA selected two 3G air interface standards – TTA 1 and TTA 2. TTA 1 is based on WCDMA and is similar to the standards chosen in Europe and Japan, while TTA 2 is similar to the US version of cdma2000.

2.2 3GPP

As more or less comparable standards were being developed in different regions around the globe and with some players participating in all regions, it became evident that creating identical specifications in order to secure equipment compatibility, with work being done in parallel, would be very difficult. A single forum for WCDMA standardization was, therefore, created – the 3rd Generation Partnership Project (3GPP)

During the late nineties, ETSI, ARIB, TTA, TTC and T1P1 handed over their WCDMA standardization work to 3GPP for further development of the Universal Terrestrial Radio Access (UTRA) standard. The ‘old’ standardization organizations are, presently, participating as very active partners within 3GPP. In addition to the standardization organizations, operators and manufacturers of telecommunication equipment are also participating in the 3GPP work. Currently, 3GPP is, furthermore, responsible for ongoing developments and standardization of GSM, GPRS and EDGE technologies.
2.3 3GPP2

Similar to the WCDMA development situation, work carried out in the US TR45.5 and the South Korean TTA standardization groups was merged into 3GPP2, which focused on the development of cdma2000 Direct Sequence (DS) and Multi Carrier (MC) modes for the cdma2000 3G specification. And, as in the case of 3GPP, other organizations and manufacturers and operators have joined up.

Following the creation of 3GPP and 3GPP2 and the handover of standardization work from the national/regional standardization organizations to the two 3G partnership programmes, there has been a period of harmonization and negotiation activities in order to bring the different cdma2000 and WCDMA solutions into line. Currently, 3GPP and 3GPP2 are the main driving forces in the standardization processes together with equipment manufactures and operators to some extent.

3. Migration paths

This section analyzes and describes the possible 3G migration paths, which 2G mobile operators can choose from and, furthermore, describes the different aspects of choosing a specific technology path and how this influences the operator and its customers.

Looking at the mobile market regarding choice of technology, the market situation has somewhat changed over the last decade – concerning the front runners. Where Europe – in particular the Nordic countries – seemed to lead the way during the 1990s with the successful GSM system, Japan took over after the introduction of i-mode in 1999 and have led the way into the new millennium. Currently, however, the cdma2000 operators in Japan and South Korea have gone to the front.

Considering the 2G mobile communication market regarding numbers of subscribers, GSM is by far leading the way with more than 1 billion subscribers compared to the 202 million cdmaOne and 111 million US TDMA subscribers (March 2004). When looking at 3G mobile technologies and services, the picture is somewhat different, as the world’s first IMT-2000 network (cdma2000 1x) was commercially deployed in October 2000, whereas the first WCDMA network was commercially launched one year later (FOMA in Japan). However, it should be noted that, even though the cdma2000 1x standard is defined as a member of the 3G IMT-2000 family, its data speed is just slightly higher than GPRS data rates and the services which can be provided also look very much the same as in the case of GPRS. Rather than comparing WCDMA and cdma2000 1x, it is, consequently, more relevant to compare cdma2000 1x and GPRS. Unfortunately, there are no comparable general statistics for GPRS diffusion. GPRS has generally been slow to take off. However, lately many subscribers have starting taking up GPRS. In Denmark, for instance, the number of GPRS subscribers increased from 24,852 ultimo 2002 to 289,770 ultimo 2004. When examining mobile technology solutions with higher bit rates, WCDMA and cdma2000 1x EV (DO or DV), the number of subscribers are a comparable level (see able 1).

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### Table 1: Number of 3G subscribers, June 2004

<table>
<thead>
<tr>
<th>Technology</th>
<th>Subscribers</th>
<th>Operators / countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>WCDMA</td>
<td>5,960,000</td>
<td>29 operators in 14 countries</td>
</tr>
<tr>
<td>cdma 2000 1x</td>
<td>101,000,000</td>
<td>67 operators in 35 countries</td>
</tr>
<tr>
<td>cdma 2000 1x EV (DO/DV)</td>
<td>7,650,000</td>
<td>7 operators in 6 countries</td>
</tr>
</tbody>
</table>

Source: [http://www.3gtoday.com/index.html](http://www.3gtoday.com/index.html)

In the following sub-sections, the possible evolution or developments paths for GSM, cdmaOne and US TDMA operators towards either WCDMA or cdma2000 solutions are described and analyzed. The TD-SCDMA development path is not included, as China, so far, is the only country promoting this solution - but has, at the same time, postponed its launch of 3G services until 2005 at the earliest7.

#### 3.1 GSM operators

In theory, GSM operators could go both ways – WCDMA or cdma2000 - as the core network is more or less identical (based on SS7) and both migration paths require a new radio interface for the GSM networks. However, the preferred migration path for GSM/GPRS operators seems to be WCDMA.

For GSM operators without 3G spectrum licenses, a WCDMA VMNO or EDGE solution is believed to be the most reasonable one. Operators without 3G spectrum can reuse their GSM allocated spectrum when deploying EDGE on their GSM/GPRS network and thereby provide high data rate services in a very cost effective manner. The biggest question regarding EDGE is believed to be terminal availability. Where GSM/EDGE terminals are available today, there is no clear indication of future EDGE/WCDMA terminals, which are expected to be necessary in the future in order for EDGE to come through.

A notable difference between GSM and cdmaOne is that with GSM the service network layer is largely standardized, meaning that SMS, MMS and other GSM services are being launched as global solutions, whereas proprietary variants of cdma exist - which from a service perspective often lead to a fast service launch, but at the same time cause poor interoperability between operators.

A second service differentiator, and maybe the most important one, is the support for roaming. Here, the ubiquity of GSM networks and already established roaming agreements between GSM/GPRS network operators will provide WCDMA subscribers with almost global coverage – as the WCDMA operators are reusing the already established roaming agreements, however with WCDMA data roaming as the long term scenario8. In addition to the roaming issue itself, another important aspect is the revenue generated by roaming agreements. Presently, the revenue streams generated by roaming contribute substantially to most mobile operators’ revenues, and as people in general are travelling more and more, these revenue streams are believed to increase significantly in the future – other things being equal. Overall, WCDMA operators stand to benefit the most form this development, as they have roaming agreements in place.

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8 At the moment, there are also difficulties with handover between WCDMA and GSM networks.
Thirdly, the market size is also believed to be a significant factor, as a greater market size will create greater manufacturing volumes and thereby in theory lower manufacturing cost per unit, as the fixed costs are shared between more units. Based on the high numbers of GSM/GPRS operators, this may turn out to be a long term advantage for the WCDMA markets. In the current market situation perspective, however, this seems to be a cdma2000 advantage, as the cdma2000 networks are clearly leading the deployment race.

An evolution from GSM to cdma2000 suggests two possible paths, one being the deployment of two parallel systems or the deployment of cdma2000 access on top of the existing GSM network. The deployment of two parallel systems does not seem like a rational path, as the operators would have to operate two systems without roaming possibilities between the two. However, there are examples of this, e.g. China Unicom and Telstra, where the Chinese solution is believed to be based on industrial policy and political incentives, whereas the Telstra solution in Australia is based on the extremely low population density making high coverage the primary consideration9.

3.2 cdmaOne operators

As with GSM operators, cdmaOne operators can in theory choose either a cdma2000 or WCDMA path. However, the cdmaOne to cdma2000 evolution path is the most obvious and is happening on a considerable scale with, e.g., 67 cdma2000 1x networks in 35 countries accounting for over 100 million subscribers as of June 2004.

The cdma2000 path for cdmaOne operators is straightforward and can be viewed as a step-by-step migration path towards 3G including some network upgrades and network replacements along the way, e.g. from cdma2000 1x to cdma2000 1x EV-DO and cdma2000 1x EV-DV.

The cdmaOne migration to cdma2000 1x mainly consists of implementing and integrating an overlay packet switched core network. This is done by adding a new channel card in the transceiver station (allowing for doubling the voice capacity), adding a packet data serving node in the core network and software upgrades in the different network nodes – comparable to the GSM/GPRS transition10. Furthermore, the fact that cdma2000 is based on the same carrier frequency as cdmaOne should provide a smoother and less complicated transition path regarding the transition to cdma2000 1x as well as to 1x EV-DO. However, it should be noted that the 1x EV-DO solution uses a separate carrier frequency for data but will be able to handover to a 1x carrier if both voice and data is needed.

At the same time, cdmaOne operators choosing to deploy cdma2000 can fairly easy migrate their current service offerings to the cdma2000 platform, allowing operators to build on existing service and application offerings and, at the same time, provide seamless introduction of new services and applications. Another and somewhat related issue concerns the availability of terminals. Currently, there is a significantly higher number of cdma2000 terminals compared to WCDMA terminals, which from a user perspective clearly gives cdma2000 the upper hand.

A cdmaOne or cdma2000 1x evolution to WCDMA would require a whole new network being implemented on top of the existing cdma network and, furthermore, the option/question

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10 http://www.cdg.org
of first implementing a GSM/GPRS network before actually implementing the WCDMA solution. This solution is believed to be difficult. However, overall operational or political considerations might pave the way for this solution, e.g., if an international mobile operator should want to deploy the same networks in all markets, instead of cdma2000 in some and WCDMA in other markets in order to centralize and harmonize service development using the same technology platform. It is also foreseen in South Korea because of a political decision to deploy WCDMA networks11.

3.3 TDMA operators

For TDMA operators, the decision concerning the 3G technology path is somewhat different, as these operators cannot stay on their current TDMA path but have to choose between the WCDMA and the cdma2000 development pathways.

Starting with the WCDMA solution, the TDMA operators will have to deploy a GSM/GPRS as a parallel overlay on the existing TDMA network and then follow the GSM road to 3G, depending on spectrum availability12. Factors supporting this development path are mainly related to roaming and service capabilities and thereby also terminal aspects. The roaming and service aspects are highly interrelated, as the extended GSM roaming coverage allows for extended service and application capabilities no matter on which network the user is located. Regarding terminals, the GSM/GPRS/WCDMA terminal market is expected to become a global mass market over time, allowing customers to use their terminals almost anywhere and, furthermore, the services and applications they have signed up for - whereas the cdma2000 development path in the short run will provide more terminals.

Looking at the cdma2000 evolution path for TDMA operators, the picture is somewhat different. However, also in this scenario the core network needs to be upgraded and, furthermore, a cdma2000 1x radio access network needs to be deployed.

One of the advantages in this scenario is the wide availability of cdma terminals, which allow for a gradual migration to cdma2000 and, at the same time, maintaining the old TDMA customer base. Secondly the cdma2000 1x deployment path reuses the circuit switched part of the TDMA network, requiring a smaller investment in network upgrades and replacements. Compared to a complete WCDMA implementation, a cdma2000 1x and eventually a DO/DV implementation should provide the TDMA operators with better infrastructure reusability and thereby a better overall gradual investment in networks and equipment.

In conclusion, the TDMA development path being WCDMA or CDMA2000 is believed to be highly influenced by external factors regarding specific market requirements, regulatory and spectrum issues, operator ownership structure and actions/paths chosen by leading TDMA operators etc.

In figure 3, the most rational migration paths for GSM, cdmaOne and TDMA operators towards 3G deployment are depicted, based on the analysis carried out above.

4. Discussion and analysis
As mentioned in the introduction of the paper, the main question dealt with is to determine which 3G technology will win the markets. Related to this overall question are the issues concerning the kind of victory it will be and the factors influencing the outcome. Furthermore, a question of theory is raised: Which is an appropriate theoretical framework for understanding this development?

In order to deal with the question of winning the markets, there are, at least, three different but interrelated factors to be examined:

- Factors affecting the selection of technology solutions
- Factors affecting the deployment of the technology solutions
- Factors affecting the diffusion/take-up by customers

With respect to all three factors, there are technology-based aspects, market and economic aspects, policy and regulatory aspects, and a range of broader social aspects to be considered. Furthermore, it should be remembered that aspects which, presently, have a technology shape, at a point of time, may have been based on policy decisions, as for instance the decision to deploy GSM networks taken in the 1980s in Europe, which has greatly influenced the technology basis on which new networks are to be established. Some of the aspects can, therefore, be seen as technology aspects as well as market or policy aspects. Finally, the actual stakeholders and decision makers should also be included in the analysis in order to ‘bring life’ to the factor analysis. The analysis will, therefore, start with the stakeholders.

4.1 Stakeholders
The first factors to de examined are the factors affecting the selection of technology solutions. ‘Selection’ is an ambiguous word encompassing market selection as well as policy choices. And, as in most other technology areas, the processes of selection of standards/technologies in the 3G area are influenced by de facto as well as de jure elements. Accordingly, the stakeholders with influence on the selection of technology solutions in this area are market players – in this case equipment manufacturers and telecommunication operators – as well as policy decision makers and administrators. Other market players such as content providers and aggregators also have an interest in the development of 3G technologies and markets, but their interests are primarily related to the relationships between operators and content providers – where the different 3G options do not differ in essence – and they have no real
influence on the selection between different 3G solutions. They may, on the other hand, have an influence on the deployment and take-up factors, as their products and services are important for the decisions of network operators to deploy new networks and the decisions of users to take up new communication systems and services.

Equipment production in the field of mobile communication, roughly speaking, includes the production of network technology (core networks and radio interfaces) and the production of handsets. Divisions of labour among the different companies in the field are diverse and are found along the dimensions of networks vs. handsets and software vs. hardware, etc. In most of the cases of the large equipment manufacturers, companies are involved in several market segments. However, some companies specialize in or have an emphasis on one of the different market segments. Ericsson, for instance, is ‘heavy’ on the networking side, whereas Nokia has more emphasis on handsets. Even though this potentially could lead to differences in interests in accordance with the differences in customer groups, there is no indication that this has had any influence on the processes of technology selection.

Basically, equipment suppliers have an interest in selling as much equipment as possible. In the handset market, the more often end users change their terminals the better. In the network market, equipment suppliers will willingly provide the necessary equipment if mobile operators are prepared to invest in entirely new systems—if only they have the necessary patents and/or licenses. This is the important thing: The interests of equipment producers in promoting a specific technology solution is dependent on their patent rights and licenses acquired in the area—and on the technology competences they have.

For network operators, the issue looks somewhat different. Not only must they convince end users that a shift to a new technology is desirable, they also depend on the already installed equipment base that they have. Equipment producers also indirectly depend on this, as they have to sell their goods and services to the network operators. However, the prime basis of path-dependent behaviour in the mobile field is among the network operators. They must see to it that they can reuse as much of their existing infrastructure as possible and only invest in new systems if they can foresee a profitable market possibility.

Another important category of stakeholders in this area are the policy makers and administrators, seeking to represent the interests of their countries and of the companies located in their countries. The intervention of policy makers and administrators are multifaceted, but the direct influence has gradually decreased with the liberalization of the telecommunication markets. However, technology selection, deployment and take-up are still influenced in many diverse ways, for instance via decisions on frequency allocations (e.g. the fact that the so-called IMT-2000 frequencies were already occupied in the US), licensing of operators (where the EU has favoured UMTS, although technology neutrality was emphasized after pressure from the US), direct support for specific standards (with China as the prime example with the promotion of TD-SCDMA), or via influences on standardization organizations (for instance in relation to the decision of ARIB in Japan to go for WCDMA in order not once again to be stranded with a purely national standard as in the case of PDC). It is not always possible for policy markers and administrators to serve all national interests at the same time. There may be differences in interests between equipment producers and network operators, and their may be strategic industrial policy interests which run counter to the interests of operators as, for instance, in the case of South Korea.
The last group of stakeholders are the end users. They do not have a direct noticeable influence on the technology selection processes – representatives of user groups have, for instance, very little representation even in official de jure standardization organizations. But users have an influence on the deployment mode and speed of technologies via the take-up ratio and, therefore, indirectly on the development of standards.

To sum up, equipment manufacturers and policy makers/administrators are the most influential stakeholders with respect to technology standard selection; operators, manufacturers, policy markers/administrators and, to some extent, end users all have different ways of influencing technology deployment; finally, end users, operators, handset producers and policy makers/administrators all have some influence on technology take-up. Put together, the stakeholders in their different roles all have an influence on the outcome of the battle between different technology solutions (who will win?) but also on the development and shaping of the technologies themselves.

4.2 Factors affecting the selection of technology
In the first stages of the conceptualization of the new high-speed mobile technology (3G), the intension was to develop one global standard – with the obvious advantages for users in such a scenario. This, however, could predictably not work because of the many economic and strategic interests in the field. The enormous worldwide success of GSM technology has pointed at such a schism between the ideal of a common system and the forces of dissociation. GSM has illustrated the great advantages of having a common system with respect to roaming, costs of production and, therefore, end user prices, but has also shown that a system with a point of departure in one region of the world (in this case Europe) leads to the dominance of certain stakeholders over others. Nokia and Ericsson would not be likely to have had the same position in the world market, had it not been for GSM.

Equipment manufacturers and policy makers and administrators all over the world have learned from this experience. In Europe, the lesson has been that a common standard (with a strong European influence) is the best way to go. In Japan, one of the lessons has been that there are problems in being stranded with a purely national standard (PDC). And in the US, they have learned that one should not let the Europeans dominate the game with a single standard. Admittedly, these are not entirely new lessons, and they are based on different traditions for standardization in, e.g., the US and Europe, where there is a long tradition in the US for more inter-standard competition and for a greater degree of market based de facto standardization, while in Europe, with the establishment of the EU, there is not only the old European tradition for de jure standardization but also an intension to create a European-wide single standard in each technology area and to focus on intra-standard competition. These traditions and the lessons from the GSM development have certainly influenced the standardization of 3G technology.

The mobile operators with existing 2G networks were not entirely enthusiastic about a new 3G system in the first part of the 1990s. At that point of time, 3G was conceptualized as a totally new system, and 2G operators were more concerned with building their 2G networks and – very importantly – to begin making money on their investments. However and partly based on this reluctance from the mobile operators, 3G began, from the mid-1990s, to be seen not as a revolutionary new system but as an evolutionary development on top of existing 2G
systems. The core networks would be the same as in the 2G systems, and it would only be the radio interfaces (and the terminals) which were to be changed. Furthermore, the core networks of the different existing 2G systems (GSM, cdmaOne, etc.) were basically the same, based on the SS7 signalling system, and could be combined with different air interface technologies. The battle between different 3G standards are thus mainly about new air interfaces and the possible migration pathways from existing interfaces to the new ones.

As explained in section 2 concerning the institutional development history of 3G, it was not decided in Europe until 1997 which air interface would be preferred. However, the major GSM producers, among them Nokia and Ericsson, were favouring WCDMA, and with NTT DoCoMo’s and ARIB’s decision in Japan in 1997 to go for WCDMA, ETSI in Europe also finally decided to go that way. NTT DoCoMo operated a 2G system based on the Japanese PDC standard, while other operators in Japan used cdmaOne technology. The initiative of NTT DoCoMo was partly based on the strategic decision to distance them self from the other operators in the Japanese 3G environment. Although the Europeans quickly followed suit, there was not necessarily any great enthusiasm with the Japanese decision, as this caused a precipitation of the European decision before a well-founded agreement had been reached.

Seen in a technology migration perspective, an important issue is to choose a technological solution, which in an evolutionary manner builds on the existing technology solution. GSM is a time division system, while cdmaOne is a code division system. And, even if wideband time division technologies were considered also in Europe in the first part of the 1990s and was part of the proposals examined in ETSI, the general technology road has been to opt for CDMA technology for 3G solutions – although combinations also can be seen as in the case of the Chinese TD-SCDMA standard. An important reason for choosing CDMA technology is that code division technology is more flexible with regard to the assignment of free capacity on the networks.

An obvious question in this connection is whether a migration from a time division GSM based technology to code division technology is more difficult than a migration from cdmaOne to cdma2000. And furthermore, whether this could be a technology reason for the swift deployment and take-up of the cdma2000 1x solution as compared to WCDMA. Again a word of caution is necessary, as it is probably more appropriate to compare cdma2000 1x with GPRS than with WCDMA. However, the basic question remains, i.e. whether the migration path to 3G is more demanding from a GSM point of departure than from cdmaOne. However, according to technology specialists, this is not the case\textsuperscript{13}. The core network is, as mentioned, the same, and the air interface will at any rate have to be changed in order to accommodate wideband data services. With GPRS, an overlay on the GSM networks has already been implemented. With WCDMA, a new overlay network has to be installed.

There is, therefore, not just one natural migration path – there is no technological path-dependency at this level - and, in the case of the equipment manufacturers, the selection of a 3G solution is based mainly on other considerations. Their main considerations are related to patent rights and licenses, and two of the main players in this field are Ericsson and the US based company Qualcomm. These two companies have also been the main contenders in the standardization battles between WCDMA (Ericsson) and cdma2000 (Qualcomm).

\textsuperscript{13} Based on interview with Ole Mørk Lauridsen, Director of Corporate Research in Nettest.
Furthermore, production costs and, consequently, end user prices will be affected once a decision on technology path has been chosen. Moreover, the maintenance costs for the different kinds of technology solutions will be important. And in this area, WCDMA seems to be far cheaper, which is an important reason for the market potentials of WCDMA to be greater than in the case of cdma2000

4.3 Factors affecting the deployment of technology solutions

Once a general decision has been taken with respect to technology selection, including a migration path, the decisions of individual operators regarding choice of technology are in most cases fixed. Operators can, in principle, choose to have alternative air interfaces established on top of their existing networks. But most operators will follow the general migration paths, as these will be the less costly. Some operators will ‘cross the lines’: There will be cdma operators establishing WCDMA interfaces and vice versa. But it will not be the general picture. Generally, GSM operators are opting for WCDMA and cdmaOne operators for cdma2000. In this field there is a strong degree of path-dependence.

The main reason for this path-dependence is the well-defined migration paths laid out by the specifications. These will ensure a smoother transition to the new network solutions. Included in the migration paths is also a backward compatibility with existing 2G networks – GSM for WCDMA operators and cdmaOne for cdma2000 operators. This means that users with WCDMA terminals, in principle, can roam not only on other WCDMA networks but also on GSM networks all around. The strength of the GSM technology will, therefore, be transferred to the new WCDMA networks. This also entails a strong degree of path-dependence.

It can be discussed whether there are network effects based on positive feedback mechanisms involved in the battle between the different 3G technologies. Positive network effects are at work if the utility for the users of a network increases with an increasing number of users – with the implication that users derive more utility from joining a larger network than a smaller one. The reason is that if the two networks are not interconnected, users will potentially be able to initiate and receive more calls on the larger than on the smaller network.

But if the networks are interconnected, this kind of network effect will not arise. And, this is the case with different telephony networks. Calls are transferred from one network to the other based on interconnection between the networks. This, however, is not a ‘sure thing’ with all kinds of communications between users. Some data services may not work in communications between users on different networks and some services, e.g. information services, may only be accessible from one network because of exclusive agreements between network operators and content providers. In both cases, there will be positive network effects – in the first case there is a direct positive network effect and in the second case an indirect positive network effect. This also applies, so to say, on an inter-operator level in the sense that an operator using one technology will benefit from other network operators using the same technology, as their customers can benefit from the roaming possibilities and, therefore, will be inclined to subscribe to their service.

The extent to which these network effects will play a role in the 3G markets is not yet clear. In the 2G markets, there are as mentioned no network effects of this kind, as voice can be

14 Ole Mørk Lauridsen (se previous note) estimates that maintenance costs are almost twice as high for cdma2000 networks as for WCDMA networks.
exchanged between the operators. The only issue is coverage, which to some extent is related to the number of subscribers and certainly to the roaming agreements that operators have. In the 3G field, however, this is different or intensified, as there are issues relating to communicative data services, information services and roaming, which are the basis of some degree of network effects. Network effects are thus stronger on 3G networks than on 2G networks. However, it does not seem likely that these network effects are so strong that they will lead to a winner-takes-all situation. Even in countries where different standards are battling directly against each other, it is likely that there will be some kind of co-existence of the different standards. Furthermore, on a global scale, different standards in different countries will co-exist.

It is only in some markets that there will be a direct battle between the WCDMA and cdma2000 and where positive network effects in a national context will play a role. But in the international context, the international roaming possibilities may play a role – if the choice of technology is not already made by the path-dependent evolution from, for instance, GSM. In Japan and South Korea, there is or will be a competitive situation between WCDMA and cdma2000. In Europe, WCDMA solutions totally dominate the picture because of the path-dependent development from GSM and because there has been a strong political pressure to opt for the WCDMA way. However, at the ‘fringes’ there are some cdma2000 systems being established. This applies, e.g., to the Czech Republic, where Eurotel – which already operates a GSM network as well as and NMT-450 network – has launched a cdma2000 1x EV-DO network for data communications\textsuperscript{15}. In the US, there will also be a battle between different high-speed mobile networks. But in this case, EDGE will play an important role, as there is a lack of vacant IMT-2000 frequencies in the US.

In Europe, it is to a large extent a strategic and politically influenced initiative, which forms the basis for the deployment of WCDMA (UMTS) networks. This does not mean that is has been an irrational choice, but there is no question that UMTS has been heavily politically promoted in Europe. Even tough the 3G licenses that have been awarded, in principle, have been technology neutral (to a large extent, after pressure from the Americans), there have only been UMTS solutions receiving a license. Another example of political intervention is the South Korean decision to distribute two WCDMA licenses in spite of the development of cdma solutions in the market in South Korean. Thus, policy decisions also play a role in the deployment of 3G solutions.

Finally, there are a variety of important economic aspects to take into consideration. One of them deals with the advantages of large scale production and the build up of broadly expanding competences in the field. This may lead to an advantage of the most widespread system – which in all likelihood will be the WCDMA system. However, the size of the production of cdma2000 equipment will also be so significant that this potential advantage will probably not be important. Actually, Qualcomm has sold equipment very cheaply to KDDI in Japan in order to promote cdma2000 technology in Japan.

Last but not least, it should be mentioned that the very high 3G license fees in some European countries have contributed to the set back of the mobile sector in Europe and has had a part in the slow start for 3G developments in Europe. This has probably contributed to holding back

\textsuperscript{15} EMC Market Data: ’Eurotel to launch CDMA-450 1xEV-DO’, \url{http://wcis.emc-database.com/}
WCDMA developments. However, the question could be raised whether this has had as great an importance as the European mobile sector will have us believe. Maybe the slow start has as much to do with the lack of relevant services offered to the users on 3G systems.

4.4 Factors affecting take-up

With the main question of this paper in mind – who will win? – it is important to include the actual take-up in the analysis. A standard/technology can be perfect and it can be offered widely by suppliers; but it is of no great importance if it is not take up by users. The question in our connection, however, is whether there are any differences in this regard between the different 3G standards.

The important factors affecting take-up in this field are the general ones, i.e. availability and quality of services and prices, which in this field more specifically includes availability of handsets, backward compatibility with 2G network, roaming possibilities, and other users with whom to communicate. With respect to telephony, there are no problems with the last mentioned issue, as 3G voice services are interconnected with other networks offering telephony services. But it is a crucial issue with respect to other communicative services, video telephony for instance, as the value of such services is a function of the number of other users (the network externality discussion).

The availability and quality of services is of prime importance and has not really been solved in the case of 3G networks. The remarkable success of the i-mode service in Japan has pointed at the centrality of easy access to a variety of relatively cheap services. However, the success of this service has probably also held back the development of the NTT DoCoMo 3G FOMA service. For the users to shift from i-mode to FOMA there must be significant advantages and these advantages are apparently not obvious to the great mass of users.

In Europe, the development of mobile data services has not been nearly as impressive as in Japan. Nevertheless, a similar issue regarding significant advantages of new services is on the agenda. The operator ‘3’, which has been the most active operator in Europe with respect to launching 3G services, has obvious problems in convincing prospective customers that there are clear gains in switching to their 3G service. The most highly profiled new service which they are advertising is video-telephony. The question could be raised whether users will really demand this service, but there is presently the additional problem that video-telephony is only interesting if someone else also has a video-phone. There is a lack if a real killer-application (or killer-applications) and the present strategy of ‘3’ has, therefore, become to offer low voice tariffs – lower than most 2G operators.

The other operators having acquired 3G licenses in Europe have been very slow to commence offering 3G services. The main reason is that they have difficulties in finding the applications and services that will kick-start the market and in developing the appropriate business models. Furthermore, GPRS has just started to develop in the European markets, and although GPRS could be seen as a road towards a 3G environment, it may also – as in the case of i-mode – hold back the development of 3G offerings.

16 A comparative analysis of the development of mobile data services in Europe, Japan and South Korea can, e.g., be found in Anders Henten, Henning Olesen, Dan Saugstrup and Su-En Tan: ‘New Mobile Systems and Services in Europe, Japan and South Korea’, forthcoming in info, 2004.
UMTS (WCDMA) has been conceptualized as a multimedia service, encompassing many different service categories in addition to voice\textsuperscript{17}. In the case of cdma2000, the picture is more diversified in the sense that, for instance, cdma2000 1x EV-DO is specified for data services specifically. This means that operators can set up networks for specific usages as in the case mentioned with Eurotel in the Czech Republic setting up an EV-DO network in parallel with their GSM and NMT networks. In the US, the vision of the future mobile environment is much more oriented towards data services – home office services – than in Europe. This does not mean that there is no mobile multimedia vision for the cdma2000 path. But it remains to be seen whether the step-by-step approach of the cdma community or the multimedia strategy of the WCDMA community present the most successful business opportunities.

The availability of a variety of high quality handsets is also important for user take-up. In this regard, UMTS networks in Europe have not been well-positioned. Very few UMTS handsets have been on the markets, and they were in the beginning rather clumsy. In contrast to this, there have, for some time, been a much bigger variety of handsets available for cdma2000 customers. On the longer term, a multitude of handsets for WCDMA networks will reach the markets, but the lack of attractive handsets has been holding back the market.

Finally, backward compatibility, roaming possibilities and other users with whom to communicate, using new and enhanced data and voice services, are equally important for the different 3G offerings. The only area, where there may be significant differences between the different technology solutions is the roaming issue, where WCDMA will have an advantage because of the relationship between GSM and WCDMA.

5. Conclusions
The main question of the paper is if it is possible point at one of the existing 3G technologies as the one that will dominate the markets in the coming years. An important background for this question is that cdma2000 technology until now has been doing better in the global market than WCDMA technology. However, the answer in the paper is that WCDMA, in all likelihood, will dominate the markets, but that there will be a co-existence of different solutions – also inside the countries where more than one solution is implemented. In Japan and South Korea, WCDMA and cdma2000 systems will co-exist. In the US, different solutions will likewise co-exist, and EDGE will be one of them. In China, there will also be different standards applied in the market with the special Chinese standard, TD-SCDMA, as one of them. We are, therefore, not witnessing an evolving winner-takes-all game; but WCDMA is the likely candidate to be the dominant standard.

The prime reason for the likely dominance of WCDMA is not that it’s a better solution than the one provided by the cdma2000 family. The prime reason is that a migration path from GSM to WCDMA has been constructed and that this pathway leads to a path-dependent development for most GSM operators towards WCDMA. WCDMA can, therefore, build on the strength of the GSM system. There may, indeed, be other factors pointing in direction of WCDMA – e.g. the differences in the costs of maintenance of WCDMA systems and cdma2000 systems respectively. But the most important reason is that there has been a strong community of interests deciding to opt for WCDMA – primarily the European institutions ETSI and the European Union and the European based mobile equipment manufacturers plus

\textsuperscript{17} See, for instance, the publications from UMTS Forum.
the subsidiary DoCoMo of the Japanese incumbent NTT and the industry and standardization organization ARIB. Strategic interests, resulting in policy interventions, have thus been strong in this area. But once a decision was taken and the migration paths from 2G to 3G developed, technology path-dependence has become important.

6. References


Schiller, J. (2003) Mobile Communications, Boston, Addison-Wesley


### List of most important abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>3GPP</td>
<td>Third Generation Partnership Project</td>
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<tr>
<td>3GPP2</td>
<td>Third Generation Partnership Project 2</td>
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<tr>
<td>ACTS</td>
<td>Advanced Communications Technologies and Services</td>
</tr>
<tr>
<td>ARIB</td>
<td>Association of Radio Industries and Business</td>
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<tr>
<td>cdma2000</td>
<td>code division multiple access</td>
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<tr>
<td>EDGE</td>
<td>Enhanced Data Rates for GSM Evolution</td>
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<tr>
<td>ETSI</td>
<td>European Telecommunications Standardization Institute</td>
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<tr>
<td>GPRS</td>
<td>General Packet Radio System</td>
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<tr>
<td>GSM</td>
<td>Global System for Mobile Communications</td>
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<tr>
<td>IMT-2000</td>
<td>International Mobile Telecommunications for the year 2000</td>
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<tr>
<td>ITU</td>
<td>International Telecommunication Union</td>
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<tr>
<td>PDC</td>
<td>Pacific Digital Cellular</td>
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<tr>
<td>TD-SCDMA</td>
<td>Time Division Synchronous CDMA</td>
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<tr>
<td>RACE</td>
<td>Research and Development in Advanced Communications Technologies for Europe</td>
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<tr>
<td>TDMA</td>
<td>Time Division Multiple Access</td>
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<tr>
<td>UMTS</td>
<td>Universal Mobile Telecommunications System</td>
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<tr>
<td>WCDMA</td>
<td>Wideband Code Division Multiple Access</td>
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<tr>
<td>WLAN</td>
<td>Wireless Local Area Network</td>
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