Andersen Consulting, Detecon, Telemate Mobile Consultants

The GSM-CDMA Economic Study

Executive summary

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Objective of the study

The GSM family of standards has been successfully adopted by a large number of countries, particularly within Europe, and is now the leading digital wireless standard worldwide. As the growth of the GSM market continues to accelerate, operators facing the prospect of over-crowded networks are looking for cost-effective expansion solutions. For example, GSM operators in Beirut, Guangzhou, and Melbourne, to name a few, are already experiencing “hot spots” -- core areas where demand is much higher than the average capacity of the network. Other European operators are likely to encounter similar situations in the medium term. As a result, a variety of solutions for network enhancement and expansion have been proposed.

Existing and proposed solutions for GSM operators include the deployment of micro-cells, half-rate codecs, improved frequency reuse techniques and dual band solutions. A newly proposed solution uses the CDMA air interface (IS 95 based) instead of, or along side, the current TDMA technology incorporated within the GSM standard. The use of a CDMA radio front end within a GSM network entails the addition of CDMA base stations and base station controllers. Seamless operation for end-users is achieved through the use of dual-mode GSM/CDMA handsets. The CDMA solution is referred to as "GSM-CDMA" since it is fully compatible with the existing GSM-MAP network standard. GSM operators facing significant network expansions over the next few years need to analyze the short and long-term costs associated with the various proposed solutions. In addition, new and emerging wireless operators are concerned about the level of investment needed to compete successfully in their respective markets.

To evaluate the possible cost benefits of a GSM-CDMA solution in relation to other GSM solutions, a study utilizing different traffic and network deployment scenarios was performed between July 1997 and January 1998.

Organization of the project

Andersen Consulting in Europe, along with Detecon of Germany and Telemate Mobile Consultants of France, led this comprehensive economic evaluation program. The consulting team has strong GSM and wireless technology expertise as well as economic analysis capabilities. Several leading European operators and manufacturers also participated actively in the study, providing input on scenario definitions, network data, and technology and cost assumptions.

A steering committee comprised of senior executives from ten key European operators, manufacturers and an interested association, provided guidance to the consultants and supervised the overall economic evaluation program. The list of steering committee member companies involved in this study includes in particular, Mannesmann Mobilfunk, Omnitel, Qualcomm, SFR, Siemens, Telecom Italia Mobile, Vodafone and others. Some of these companies acted primarily as observers, while others provided significant direction to the study. Qualcomm of San Diego, California sponsored this major study.

The Approach

To illustrate the economic comparison of the CDMA and TDMA technologies within GSM networks, we established two network scenarios over the 2000-2005 period using the same traffic and geographical data for the GSM and GSM-CDMA network designs. We refer to these two scenarios as the "overlay" network and the "greenfield" network scenarios. The "overlay" network represents an expansion or enhancement of certain high-density areas in an existing GSM network. The "greenfield" scenario represents the deployment of a new network utilizing new spectrum.

The "overlay" and "greenfield" network scenarios do not reflect the current situation; they are hypotheses of two market situations that operators may have to cope with in the medium term. The starting point for the economic evaluation is represented by the 1999 network scenarios, which are projections of what the load of a typical, large metropolitan GSM network might be by that time.

For the planning exercise, we used geographical data from a typical medium-size European metropolitan area (163 km²) composed of a city core, suburban areas, a business area and an airport. This metropolitan area is representative of many large cities. We also developed traffic levels for each of our scenarios. These busy hour traffic levels for the 2000-2005 period are higher than in contemporary networks as we assume that:

- A large number of subscribers living outside the city are commuting to the city center (28 km²).
- Mobile telephony penetration and usage (both voice and data) will continue to increase,
- Users will migrate from wireline-based services to wireless-based services (convergence) as mobile tariffs continue to decrease.

The "overlay network" scenario corresponds to a capacity-driven situation. An established operator serves the metropolitan area with a GSM macro-cell layer over a 12.5 MHz x 2 band at 900 MHz. The operator faces a steady traffic increase, especially in the city core, which results in "hot spots" with densities in the range of 300-400 Erlang / km². "Hot spots" are areas where demand is higher than the average capacity of the network. By 2005, the city core becomes a single large "hot spot." These high traffic levels have already been encountered in some cities (e.g. Beirut, Guangzhou, Melbourne and Paris) and will likely be encountered by several European operators in the future.

To serve this traffic growth, the operator needs to deploy an "overlay network" in the city core and is considering two alternative solutions: one with a standard GSM micro-cell layer and a second with GSM-CDMA cells.

The network traffic parameters in the "overlay network"(city core = 28 km²)

year	*2000*	*2003*	*2005*
Total traffic in the "overlay" network (city core) in Erlang	3600	7200	9700
Average total (macro-layer and overlay) traffic density in the city core in Erlang / km²	130	260	350
Average total (macro-layer and overlay) traffic density in the "hot spots" (city core) in Erlang / km²	298	408	416
"Hot spot" area in percentage of city core area	23%	60%	83%

The “greenfield” network scenario corresponds to a coverage-driven situation. In 1999, a new entrant is granted a GSM 1800 MHz license with an allocation of 2x15 MHz. Before deploying its metropolitan area network in 2000, the operator will compare two radio network alternatives: a GSM layer and a GSM-CDMA layer.

The network traffic parameters in the ”greenfield network” (total metropolitan area = 163 km2)

year	*2000*	*2003*	*2005*
Total network traffic in the “greenfield” network in Erlang	950	4700	11350
Average traffic density in the metropolitan area in Erlang / km2	5.3	28.8	69.3
Average traffic density in the city core in Erlang / km2	7	40	150

The “overlay” and “greenfield” radio network designs

The network designs are based on well-accepted and validated assumptions and results.
The application of half-rate vocoder to GSM networks was not taken into account as this solution has not been implemented on a large scale at that time. Additionally dual band solution were not considered.
The CDMA network designs assume successful integration of the GSM core network at the “A “ interface and GSM-CDMA / CDMA-GSM hand-over capabilities.

The “overlay” network design (900 MHz with a 2x12.5 MHz):

We compared firstly a set of GSM and GSM-CDMA solutions that are already available or will be within a few months :

- An established GSM radio network solution based on a frequency reuse factor of 15 to 12, with Phase 2 standard features (frequency hopping, power control and discontinuous transmission) and with micro-cells (up to 3 TRXs). This solution is referred as “GSM”
- A GSM “capacity enhanced” solution which is now appearing in the market place. It is based on improved frequency reuse techniques (concentric cells, MRP,...) leading to a reuse of 9 to 6[1] for macro-cells and on up to 4 TRXs per micro-cell. This solution is referred as “GSM capacity enhanced” solution
- An established CDMA solution based on the IS-95 standard radio features with a vocoder rate of 13 kb / s and handling 10 to 13 simultaneous active users per sector and per carrier. This solution is referred as “GSM-CDMA 13 kb / s”.
- A variant of the previous CDMA solution, with a vocoder rate of 8 kb / s with EVRC (Enhanced Variable Rate Codec) instead of 13kb / s and handling 16 to 20 simultaneous active users per sector and per carrier. This solution was included as its voice quality is very close from the 13kb / s solution and will be available in 1998. This solution is referred as “GSM-CDMA 8kb / s”.

[1] This corresponds to a reuse of 9 to 6 for the traffic channels and 12 for the BCCH channels . The average reuse factor varies then between 10.3 and 6.9.

We then compared a second set of solutions that includes :

- The "GSM capacity enhanced" solution
- An enhanced IS95 solution (at 13kb/s and 8kb/ EVRC) that will be available in 1999. This "enhanced IS-95" solution will result in a doubling of the number of concurrent users per radio channel. This solution is referred as the "GSM-CDMA enhanced 13 kb/s" when used with a vocoder rate of 13 kb/s and as the "GSM-CDMA enhanced 8 kb/s" for a vocoder rate of 8 kb/s (EVRC) .

We designed the 1999 macro-layer network, comprised of 45 GSM macro-sites (three sectored) in the city core, using the well-established "GSM" solution. This represents the starting point of the "overlay" design.

Results of the first comparison set:

- To meet increased traffic in the high-density areas after 1999, both the overlay "GSM" and "GSM capacity enhanced" (with a frequency reuse of 6) network designs require large numbers of micro-cells (805 [2] and 483 respectively in 2005). [3]
- Due to the specific characteristics of GSM-CDMA cells, both "overlay" "GSM-CDMA" designs (at 13 kb/s and 8kb/s) consist only of macro-cells and comprise a small fraction (1/7 and 1/10 respectively) of the total number of micro-cell sites required for the "GSM capacity enhanced" solution. This ratio is further increased by a factor 2 when comparing the "GSM-CDMA" solutions to the "GSM" solution.

Number of sites in the "overlay network" for GSM, "GSM enhanced" and GSM-CDMA solutions

year	*2000*	*2003*	*2005*
GSM (micro-sites)	224	585	805
GSM capacity enhanced* *(micro-sites)*	134	351	483
GSM-CDMA 13 kb/s (macro-sites, tri-sectored)	33	52	76
GSM-CDMA 8 kb/s EVRC (macro-sites, tri-sectored)	22	35	49

*An additional "GSM capacity enhanced" design with a frequency reuse of 9 was developed, but the differences were minimal

Results of the second comparison set:

- When using the two "GSM-CDMA enhanced" solutions, the total number of GSM-CDMA "overlay" cells drops by approximately 50% in 2005, compared to "GSM-CDMA", thus improving by a factor 2 the ratio of the GSM-CDMA solutions with respect to the "GSM capacity enhanced" solution.

Number of "GSM capacity enhanced" and "GSM-CDMA enhanced" sites in the "overlay network"

year	*2000*	*2003*	*2005*
GSM capacity enhanced *(micro-sites)*	134	351	483
GSM-CDMA enhanced 13 kb/s *(macro-sites, tri-sectored)*	19	26	36
GSM-CDMA enhanced 8kb/s *(macro-sites, tri-sectored)*	16	18	24

[2] It is not suggested that an operator would build a network with such a large number of micro-cells

[3] It is expected that with such a high micro-cell density , indoor coverage will exceed the study requirements

Spectrum utilization:

- The four GSM-CDMA solutions are more spectrum-efficient than the GSM solutions. In 2005, the GSM macro-layer with the GSM-CDMA overlay needs 84% of the total available bandwidth while the GSM solutions utilize 97% to 100% of the available bandwidth.

The "greenfield" network design (at 1800 MHz with a 2x15 MHz):

We limited our design comparisons to:

- The "GSM " solution
- The "GSM-CDMA 13 kb/s" solution handling 13 to 14 simultaneous active users per sector and per carrier
- The "GSM-CDMA 8 kb/s" solution handling 20 to 21 simultaneous active users per sector and per carrier

As this network is coverage-driven, the "GSM" and the two "GSM-CDMA" networks consist of macro-cells only. The maximum pathloss difference between the "GSM " and "GSM-CDMA 13 kb/s" solutions is 2dB, and for "GSM-CDMA 8kb/s", the difference is 4dB. The "GSM-CDMA" solutions require 29% and 44% less sites respectively to provide the same coverage and capacity than the "GSM" solution.

Number of sites in the "greenfield" network for the "GSM" and "GSM-CDMA" solutions

year	*2000*	*2003*	*2005*
GSM *(macro-sites, tri-sectored)*	187	188	202
GSM-CDMA 13 kb/s *(macro-sites, tri-sectored)*	144	144	145
GSM-CDMA 8 kb/s *(macro-sites, tri-sectored)*	112	112	113

The "GSM-CDMA" solutions bring substantial spectrum savings. The "GSM" network uses almost the entire (96%) assigned frequency spectrum, while the "GSM-CDMA" networks need only 43% for the 13kb/s solution and 35% for the 8kb/s EVRC solution.

The economics of the radio network designs

A cost model has been developed to compare the costs of the GSM solution with the costs of the GSM-CDMA solution for those elements which are different for both the "overlay " and the "greenfield" networks.

The cost model contains capital expenditures (CapEx) and operational expenditures (OpEx) related to the base station subsystem (base stations and base station controllers) and transmission links. It is assumed that there is no cost impact on the network subsystem.
Examples of CapEx included in the model are sites, base stations and base station controllers. Example of OpEx included are site rental, leased lines, maintenance costs, site utility costs and subsidization costs for the dual mode (GSM/GSM-CDMA) handsets that will have to be used in the GSM-CDMA networks.
The GSM-CDMA operator will have to subsidize :

– in the "overlay" scenario : the dual mode handset price to facilitate the users' migration from the macro-cell GSM layer to the new GSM-CDMA overlay network,
– in the "greenfield" scenario : the dual mode handset price difference with the GSM handset.

The starting point for GSM and GSM-CDMA equipment and service prices are equivalent to those observed in the 1997 market. Price evolution for the services (e.g. leased line monthly fees) are based on trends observed in the market, and price evolution for the radio network and handset equipment is based on an 80% experience curve as accepted by several manufacturers.

The "overlay" network scenario

Results of the first solution set:
The CDMA solutions provide, in this case, a cost-effective alternative to GSM micro-cell solutions.

In 2005, due to much lower numbers of sites, the Cumulative Capital Expenditure and the Yearly Operational Expenditure costs of both "GSM-CDMA" solutions are significantly lower than the "GSM" and "GSM capacity enhanced" solutions:

– The cumulative CapEx for GSM-CDMA 13 kb/s and 8 kb/s solutions represent only 50% and 36% of the "GSM enhanced" cumulative CapEx respectively.
– This ratio is further improved for the yearly OpEx.

Over the 2000-2005 period, the cumulative OpEx for the "GSM-CDMA 13kb/s" solution, including the dual mode handset subsidization costs, represents 65% of the cumulative OpEx of the "GSM enhanced" solution. Results for the "GSM-CDMA 8kb/s" solution are even better, representing only 54% of the "GSM enhanced" solution.

Relative costs of the" overlay network" for GSM, "GSM capacity enhanced" and GSM-CDMA solutions in percent

	Cumulative Capital Expenditure			*Yearly Operational Expenditure*		
year	*2000*	*2003*	*2005*	*2000*	*2003*	*2005*
GSM	130%	133%	133%	150%	151%	152%
GSM capacity enhanced	100%	100%	100%	100%	100%	100%
GSM-CDMA 13 kb/s	72%	49%	50%	149%*	55%	43%
GSM-CDMA 8 kb/s	55%	36%	36%	134%*	44%	31%

*Impact of the dual mode handset subsidization costs, based on a "middle of the range" product

Relative costs of the" overlay network" for "GSM", "GSM capacity enhanced" and "GSM-CDMA " solutions in ECU (Millions)

	Cumulative Capital Expenditure			*Yearly Operational Expenditure*		
year	*2000*	*2003*	*2005*	*2000*	*2003*	*2005*
GSM	8.2	25.4	34.3	3.2	8.9	12.5
GSM capacity enhanced	6.4	19.1	25.8	2.1	5.9	8.2
GSM-CDMA 13 kb/s	4.6	9.3	13.0	3.2*	3.2	3.5
GSM-CDMA 8 kb/s	3.5	6.9	9.4	2.9*	2.6	2.6

*Impact of the dual mode handset subsidization costs, based on a "middle of the range" product

Over five years, the average CapEx and OpEx costs per Erlang for the "GSM-CDMA 13 kb/s" solution decrease rapidly as the impact of the dual mode handset subsidization is minimized. The

CapEx and OpEx costs are 1500 ECU and 410 ECU respectively in 2005. In contrast, the GSM micro-cell solution costs are 2970 ECU and 950 ECU respectively.

Results of the second comparison set:

The "GSM-CDMA enhanced" solutions are compared with the "GSM capacity enhanced" solution. In 2005, the "GSM-CDMA enhanced" solutions provide, in this case, a very cost-effective alternative to the "GSM capacity enhanced" micro-cell solutions.

In 2005 the Cumulative CapEx and the Yearly OpEx costs of both "GSM-CDMA enhanced" solutions are much lower than the "GSM capacity enhanced" solution :

- The cumulative CapEx for the "GSM-CDMA enhanced 13 kb/s" and "GSM-CDMA enhanced 8 kb/s" solutions represent only 31% and 25% of the "GSM enhanced" cumulative CapEx respectively.
- The ratio is even better for the yearly OpEx in 2005: 25% and 19% of the "GSM capacity enhanced" OpEx for the respective 13kb/s and 8 kb/s solutions.

Over the 2000-2005 period, the cumulative OpEx for the "GSM-CDMA enhanced" 13kb/s solution, including the dual mode handset subsidization costs, represents 48% of the cumulative OpEx for the "GSM capacity enhanced" solution. Results for the "GSM-CDMA enhanced" 8kb/s solution are even better at 43%.

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Relative costs of the "overlay network" for "GSM capacity enhanced" and "GSM-CDMA enhanced" solutions in percent

	Cumulative Capital Expenditure			*Yearly Operational Expenditure*		
year	*2000*	*2003*	*2005*	*2000*	*2003*	*2005*
GSM capacity enhanced	100%	100%	100%	100%	100%	100%
GSM-CDMA enhanced 13 kb/s	49%	31%	31%	129%*	39%	25%
GSM-CDMA enhanced 8 kb/s	44%	25%	25%	124%*	33%	19%

*Impact of the dual mode handset subsidization costs, based on a "middle of the range" product

Relative costs of the "overlay network" for "GSM enhanced" and "GSM-CDMA enhanced" solutions in ECU (Millions)

	Cumulative Capital Expenditure			*Yearly Operational Expenditure*		
year	*2000*	*2003*	*2005*	*2000*	*2003*	*2005*
GSM capacity enhanced	6.4	19.1	25.8	2.1	5.9	8.2
GSM-CDMA enhanced 13 kb/s	3.1	5.8	8.0	2.7*	2.3	2.0
GSM-CDMA enhanced 8 kb/s	2.8	4.8	6.4	2.7*	2.0	1.6

*Impact of the dual mode handset subsidization costs, based on a "middle of the range" product

The "greenfield" network scenario

The design of the "greenfield" network is coverage-driven. As both GSM 1800 MHz and GSM-CDMA 1800 MHz designs incorporate only macro-cells, their cost difference is now much smaller than in the "overlay" network scenario. In 2005, as compared to the "GSM " solution, the "GSM-CDMA" cumulative CapEx represents 86% for the 13 kb/s solution and 70% for the 8 kb/s solution. The same holds true for OpEx.

Over the 2000-2005 period, the cumulative OpEx for "GSM-CDMA", including the impact of the dual mode handset subsidization costs, represents 92% of the cumulative OpEx for the "GSM enhanced" solution at 13kb/s and 75% at 8kb/s.

The GSM-CDMA solution does not yield significant cost savings in this scenario when compared to the "overlay" case.

Relative costs of the "greenfield" network for the "GSM" and "GSM-CDMA" solutions in percent

	Cumulative Capital Expenditure			*Yearly Operational Expenditure*		
year	*2000*	*2003*	*2005*	*2000*	*2003*	*2005*
GSM	100%	100%	100%	100%	100%	100%
GSM-CDMA 13 kb/s	84%	82%	86%	104%*	89%	87%
GSM-CDMA 8 kb/s	65%	65%	70%	87%*	73%	71%

*Impact of the dual mode handset subsidization costs, based on a "middle of the range" product

Costs of the "greenfield" network for the "GSM " and "GSM-CDMA" solutions in ECU (Millions)

	Cumulative Capital Expenditure			*Yearly Operational Expenditure*		
year	*2000*	*2003*	*2005*	*2000*	*2003*	*2005*
GSM	19.2	21.7	26.3	5.2	5.7	6.8
GSM-CDMA 13 kb/s	16.3	17.7	22.6	5.4*	5.1	5.9
GSM-CDMA 8 kb/s	12.6	14.9	19.5	4.5*	4.2	4.8

*Impact of the dual mode handset subsidization costs, based on a "middle of the range" product

Conclusions

Given the study network scenarios and costs assumptions, the results of this collective effort with leading European manufacturers and operators indicate that:

- In the capacity-driven situation, a GSM-CDMA solution yields substantial cost savings when compared to the proposed GSM solutions. The GSM-CDMA solution provides savings on cumulative capital expenditures over the five year period ranging from 50% to 75%, depending on the solution ("GSM-CDMA" or "GSM-CDMA enhanced"), when compared to the "GSM capacity enhanced" solution. Similarly, cumulative operational savings for GSM-CDMA solutions range from 35% to 57% when compared to "GSM capacity enhanced" over the five year period.
- In the coverage-driven situation, a "GSM-CDMA" solution brings relatively minor cost benefits (approximately 10% for 13kb/s and 30% for 8kb/s for the total CapEx +OpEx) as compared to a "GSM " solution over the 2000 - 2005 period.
- In the "greenfield" network scenario, the "GSM-CDMA" solution brings significant spectrum savings: 53% for 13kb/s and 62% for 8kb/s when compared to "GSM".