PLANNING

DESIGN

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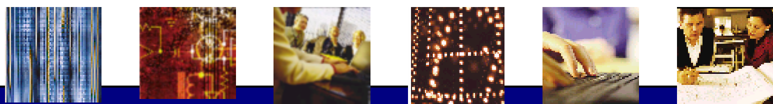
MANAGEMENT

Comparison of 900 MHz and 1800 MHz Network Costs

Final Report
A Study for ONE Austria

25 October 2006

WFI



CONTENTS

1. SUMMARY

1.1 Introduction

This report examines the difference in numbers of sites and transceivers (TRX) between GSM900 and GSM1800 based networks serving the Austrian market.

It is well understood that networks built using 1800 MHz will require many more sites to provide a specified level of coverage than those built using 900 MHz, resulting in substantially higher initial costs. For an explanation see Section 2.1. However, as networks grow additional equipment and sites must be introduced to support higher traffic densities. As a result, the differences between GSM900 and GSM1800 based networks may be expected to decrease with time.

A key question is the extent to which the number of sites and hence costs of networks will ultimately converge or whether networks will continue to have a substantially different level of cost associated with them irrespective of future network growth.

The answer to this question is the main focus of this report. As the results show, differences between GSM900 and GSM1800 based networks will almost invariably remain substantial. However, the precise result will vary depending on the local market conditions. For this reason, the report considers networks that have been designed to address the Austrian market in terms of network coverage, subscriber distribution and spectrum allocation.

Market scenarios have been developed in association with ONE, for whom this report has been prepared. ONE has prepared its own estimates of site and TRX numbers for generic GSM900 and GSM1800 based networks using a modelling tool developed for its own internal business planning. ONE commissioned WFI to carry out this study to validate their model and to provide an independent view.

WFI has modelled the market and technical scenarios using accepted industry models and dimensioning principles. Using this approach, differences between the theoretical model and real world performance are expressed in terms of a few easily understood and verifiable benchmarks.

Comparing the results of this analytic approach with ONE's empirical model based on its radio planning tool produced very similar results. The high level of agreement effectively validates both models and provides confidence in the result.

1.2 Scenarios and Assumptions

1.2.1. Basic principles

In order to investigate differences between generic GSM900 based and GSM1800 based networks, scenarios were chosen to fit the experience of the Austrian market. This includes network topology and coverage, subscriber numbers and distribution, frequency allocations and typical equipment configurations.

Similar network topology and coverage is important as it defines the particular mix of urban, suburban and rural areas found in Austria. This coupled with subscriber numbers and distribution defines the extent to which site numbers will be driven by the need for coverage or traffic. For example:

- In rural areas the minimum number of sites is driven by the need for coverage, and radio propagation range is much greater at 900 MHz than at 1800 MHz.
- In the highest traffic areas found in cities, the number of sites is determined by traffic and depends on total spectrum available but not on the frequency band.

Thus, the results of this study may be expected to be different to results obtained in other markets, for example in those with a greater proportion of urban areas. Austria by contrast has a greater proportion of relatively unpopulated and mountainous areas.

Similarly, frequency allocations were chosen to be representative of the Austrian market. GSM900 based operators Mobilkom and T-Mobile both received 1800 MHz spectrum later to support future traffic growth, while GSM1800 based operator ONE received spectrum at 900 MHz later for future network expansion.

Generic GSM900 based and GSM1800 based networks modelled for this study are also assumed to have access to 900 MHz and 1800 MHz spectrum in later years. As discussed in Section 2.1, sites are not easily moved and the basic site spacing and number of sites will continue to be determined by the original frequency band.

1.2.2. Scenarios

The study compared generic GSM900 and GSM1800 based networks under the following three pairs of scenarios:

- *Coverage only (Base case) Scenarios* - The numbers of sites required to provide 98% population coverage using purely 900 MHz or 1800 MHz spectrum.
- *Low Traffic Scenarios* - GSM900 and GSM1800 based networks that are assumed to grow from 1 million subscribers at 98% population coverage to 2 million subscribers at 99.5% population coverage.

- *High traffic Scenarios* - GSM900 and GSM1800 based networks that are assumed to grow from 2 million subscribers at 98% population coverage to 3 million subscribers at 99.5% population coverage.

3 million subscribers is about a third of the Austrian population and so this represents a reasonable assumption for the point of maximum convergence in a mature market.

Full details of the six scenarios including spectrum allocations are presented in Section 2.2. These represent a realistic evolution of networks in Austria, where network rollout for 98% population coverage is achieved using frequency allocations at 900 MHz or 1800 MHz.

Although additional frequencies at 1800 MHz and 900 MHz are received later, enabling operators to augment their networks, the spacing and number of sites will continue to be determined largely by the original frequency band.

1.2.3. Technical Assumptions

Technical assumptions have been made to provide as far as possible identical conditions for the GSM900 and GSM1800 based networks. Where differences exist in established practice at 900 MHz and 1800 MHz, the study deliberately chose a conservative approach that results in the smallest difference between 900 MHz and 1800 MHz.

Thus, only the following link budget parameters are different, reflecting inherent differences between 900 MHz and 1800 MHz technologies:

- Base antenna gain of 16 dBi at 900 MHz and 18 dBi at 1800 MHz for similar antenna size and cost

- Mobile transmit power of 33 dBm (2W) for 900 MHz and 30 dBm (1W) for 1800 MHz reflecting standard power classes

- Mast Head Amplifiers used at 1800 MHz but not at 900 MHz, reflecting common practice. These provide an extra 3 dB in uplink gain.

Building penetration losses at 1800 MHz were assumed to be typically 2 dB higher than at 900 MHz. This figure arises from research carried out under the European Cooperation in the Field of Science and Technology programme (COST231) and is a conservative estimate compared with values given in the Telekom-Control-Kommission guidelines, Reference 1.

Propagation ranges used to estimate cell coverage were based on a calibrated planning tool propagation model at 1800 MHz. A corresponding 900 MHz model was derived from the 1800 MHz model using the well accepted Okumura-Hata equation as modified by COST231. The results agreed well with guidelines set out in Reference 1.

Finally, the network was dimensioned for capacity where the maximum TRX per sector is determined by the frequency plan and equipment limitations. A conservative frequency plan with no frequency hopping and typical equipment limits was assumed that minimises potential differences between the GSM900 and GSM1800 based network. The maximum number of subscribers per cell was calculated assuming a grade of service of 2% blocking and busy hour traffic of 18 mErl per subscriber.

1.2.4. Use of Benchmarks

The technical assumptions and dimensioning principles described above will result in a theoretical design but will underestimate the resources needed to implement a practical network.

The study therefore used an approach where differences between the theoretical results and the real world performance are applied in terms of a few easily understood and verifiable benchmarks. By contrast, the business modelling tool used by ONE is based directly on outputs from their radio planning tool and automatically takes account of the practical limitations when planning a cellular network.

Benchmarks used by the study are:

- Cell Placement Margins to represent the overlap between cells that occurs in a real network. This typically results in a 30% higher number of coverage sites in practice.

- Cell Load Efficiency to represent the difference between an ideal network and the practical case. Efficiencies are known to vary between about 40% and 70% depending on the number of TRX per sector.

- Average TRX per Sector values that are lower than the theoretical maximum due to the fact that not all sectors are fully loaded in the busy hour.

The results of the benchmarked model were found to produce results that agree well with ONE's empirical model. The ratio of sites and TRX required for GSM900 and GSM1800 based networks were found to be relatively insensitive to variations in benchmark values.

1.3 Results

Section 4 contains full results of the study where numbers of sites and TRX are broken down by Dense Urban, Urban, Rural and Unpopulated area. The main results are also presented below.

1.3.1. Coverage and Low Traffic Scenarios

Results for the base case coverage and low traffic scenarios are presented in Table 1. For the coverage only scenario, numbers for TRX are calculated on the basis of one per sector.

The low traffic scenario assumes subscriber numbers growing from 1 million at 98% population coverage to 2 million at 99.5%. The GSM900 based network requires many fewer sites for coverage and so relatively more sites must be added to support the traffic load.

Table 1 – Coverage and Low Traffic Scenarios

Subscribers and coverage	GSM900 based		GSM1800 based		Ratio	
	Sites	TRX	Sites	TRX	Sites	TRX
98% coverage only	1,530	3,556	4,074	9,558	2.7	2.7
1m @98%	1,552	8,423	4,077	11,854	2.6	1.4
2m @ 99.5%	1,844	13,419	4,175	18,698	2.3	1.4

As a result, the ratio of GSM1800 to GSM900 based network sites falls from 2.7 times for 98% coverage, to 2.6 times for 1 million subscribers, and finally to 2.3 times for 2 million subscribers and 99.5% coverage. Since TRX numbers are more closely related to the traffic load, the TRX ratio falls to about 1.4 times.

1.3.2. High Traffic Scenario

Results for the high traffic scenario are presented in Table 2. It assumes subscriber numbers growing from 2 million at 98% population coverage to 3 million at 99.5%,

By the time the network has reached 3 million subscribers and 99.5% coverage, the Austrian market will have reached maximum penetration and the point where no further network convergence is likely to occur.

The ratio of GSM1800 to GSM900 based network sites at this point is 2 times and the ratio of TRX is 1.4 times. The study predicts identical numbers of sites in the densest urban areas as both networks are dominated by traffic demand. However, elsewhere the GSM900 based network still has a considerable advantage.

Table 2 – High Traffic Scenario

Subscribers and coverage	GSM900 based		GSM1800 based		Ratio	
	Sites	TRX	Sites	TRX	Sites	TRX
2m @98%	1,789	13,221	4,111	18,469	2.3	1.4
3m @ 99.5%	2,119	17,549	4,223	24,521	2.0	1.4

In terms of the scenarios examined in this study these numbers represent the very minimum difference that can be expected between GSM900 and GSM1800 based networks. As discussed in Section 4.4, the difference may be greater still.

1.4 Conclusions

The study shows conclusively that GSM900 and GSM1800 based networks serving the Austrian market will continue to have a substantially different number of sites and level of cost associated with them irrespective of future network growth.

A minimum of 2 times as many sites are estimated to be required for a GSM1800 based network in a mature market and the difference is likely to be even more.

As discussed in the main report, the impact on capital expenditure will be slightly less and a figure of about 1.8 times is estimated for a GSM1800 based network based on industry rules of thumb. Similarly, annual technical operating expenditure is estimated to be 2 times for a GSM1800 based network.

2. BACKGROUND AND MARKET ASSUMPTIONS

2.1 Definitions and Propagation Principles

This report examines differences between GSM900 and GSM1800 based networks. These are networks that were designed and rolled out using GSM at 900 MHz or 1800 MHz respectively. In practice, networks may have been allocated additional spectrum at both 900 MHz and 1800 MHz for later network expansion. However as discussed below, the basic network topology will continue to be determined by the original frequency band.

GSM was originally launched during the early 1990's, based on frequencies in the 900 MHz band. The desire to introduce more cellular competition led to the subsequent introduction of the DCS1800 standard based on GSM at 1800 MHz. This became known as GSM1800.

The disadvantage of 1800 MHz compared to 900 MHz is well understood as discussed in Telekom-Control-Kommission guidelines (Reference 1) and elsewhere. At twice the frequency and half the wavelength 1800 MHz waves do not propagate as far, especially in urban areas. As a result, an 1800 MHz based network requires typically two to four times as many sites as a 900 MHz based network for a given level of coverage.

An advantage of 1800 MHz when it was introduced was the availability of considerably more spectrum, enabling much higher traffic densities to be supported. Today with multi-band GSM handsets, both GSM900 and GSM1800 based networks are able to use frequencies at 900 MHz and 1800 MHz to support high traffic.

However, it is not economic to move sites to new grid locations, for example if a GSM1800 operator subsequently acquires 900 MHz spectrum. Thus, basic network topology and the spacing and number of sites will continue to be determined by the original frequency band.

2.2 Market scenarios

Typical market scenarios have been used to compare GSM900 and GSM1800 based networks. Although the network designs are generic, scenarios were chosen to fit the experience of the Austrian market. This includes network topology and coverage, subscriber numbers and distribution, frequency allocations and typical equipment configurations. Thus, results may be expected to be different to those obtained in other markets, for example with a greater proportion of urban areas. Austria by contrast has a greater than average proportion of relatively unpopulated and mountainous areas.

2.2.1. The Austrian Cellular market

Austria now has three GSM operators and a fourth operator with a UMTS licence only. The three GSM operators are listed in Table 3, together with details of spectrum allocations and launch dates. T-Mobile includes its subsidiary Tele.ring, with whom T-Mobile merged in 2006.

A1 and T-Mobile networks are GSM900 based networks. They were designed and launched using GSM at 900 MHz and later acquired 1800 MHz spectrum allowing them to support higher traffic densities.

ONE is a GSM1800 based network. ONE later acquired limited 900 MHz spectrum in 2004, providing a more cost effective means of extending network coverage in rural and mountainous regions.

All GSM operators were required to provide 98% population coverage, equivalent to approximately 70% area coverage as part of their initial obligation. In June 2006, the total number of cellular subscribers for all networks had risen to about 8.8 million, out of a total population of about 8.2 million inhabitants, an apparent penetration rate of 108%.

Table 3 – Austrian GSM Mobile Networks

Operator	Brand Names	Launch Frequency Band	Launch Date	Final Spectrum Allocation	
				900 MHz	1800 MHz
Mobilkom Austria AG	A1	GSM 900	Dec 1993	2 x 17 MHz	2 x 15 MHz
T-Mobile Austria GmbH	T-Mobile Tele.ring	GSM 900	July 1996	2 x 12.8 MHz	2 x 24.8 MHz
One GmbH	ONE	GSM 1800	Oct 1998	2 x 3.2 MHz	2 x 29 MHz

2.2.2. Generic 900 MHz and GSM1800 based Network Scenarios

Rather than compare particular commercial networks, this study has chosen to compare two generic, GSM900 and GSM1800 based networks under low traffic and high traffic conditions appropriate to the Austrian market. A total of 6 different scenarios have been considered, as set out in Table 4 – Market and Spectrum Scenarios.

This includes two base case scenarios providing 98% population coverage only using GSM900 and GSM1800 frequencies respectively. Low Traffic Scenarios 1 and 3 consider GSM900 and GSM1800 based networks that grow from 1 million subscribers at 98% population coverage to 2 million subscribers at 99.5%. High Traffic Scenarios grow from 2 million to 3 million subscribers respectively.

Table 4 – Market and Spectrum Scenarios

<table>
<tr><th rowspan="2"></th><th rowspan="2">Based On</th><th colspan="2">98% population coverage</th><th colspan="2">99.5% population coverage</th></tr>
<tr><th>Spectrum</th><th>Subs</th><th>Spectrum</th><th>Subs</th></tr>
<tr><td>Base case</td><td rowspan="3">GSM 900</td><td colspan="2">2x17 MHz @ 900 MHz</td><td colspan="2"></td></tr>
<tr><td>Scenario 1</td><td rowspan="2">2x17 MHz @ 900</td><td>1 million</td><td rowspan="2">Plus 2x15 MHz @ 1800</td><td>2 million</td></tr>
<tr><td>Scenario 2</td><td>2 million</td><td>3 million</td></tr>
<tr><td>Base case</td><td rowspan="3">GSM 1800</td><td colspan="2">2x29 MHz @ 1800 MHz</td><td colspan="2"></td></tr>
<tr><td>Scenario 3</td><td rowspan="2">2x29 MHz @ 1800</td><td>1 million</td><td rowspan="2">Plus 2x3.2 MHz @ 900</td><td>2 million</td></tr>
<tr><td>Scenario 4</td><td>2 million</td><td>3 million</td></tr>
</table>

2.2.3. Spectrum

Table 4 identifies additional spectrum assumed to be available for network growth beyond 98% coverage. Spectrum at 1800 MHz is used to provide additional capacity for the GSM900 based network while 900 MHz frequencies allow the GSM1800 based operator to provide more cost-effective coverage when rolling out beyond the 98% coverage point.

It will be seen that spectrum allocations closely reflect the position of the Austrian market. Both GSM900 and GSM1800 based networks are assumed to have practically the same (2 x 32 MHz) total spectrum allocation during the expansion phase.

2.3 Area Coverage

Area coverage figures for 98% and 99.5% population coverage were provided by ONE. The analysis considered four area classes; Dense Urban, Urban, Rural and Unpopulated as shown in Table 5 – Assumed Coverage Areas. It should be noted that 'Unpopulated' does contain subscribers. The figures for relative population density were also derived from ONE's existing network.

Table 5 – Assumed Coverage Areas

	Total area	Area Served for 98% Population Coverage	Area Served for 99.5% Population Coverage	Relative Population Densities
Dense Urban	203 km^2	203 km^2	203 km^2	568.9
Urban	1,038 km^2	1,038 km^2	1,038 km^2	57.7
Rural	33,484 km^2	29,064 km^2	30,772 km^2	3.1
Unpopulated	49,191 km^2	28,334 km^2	30,842 km^2	1

2.4 Subscribers and Traffic

Using the above figures for relative population density leads to the subscriber numbers per area given in Table 6. Busy hour traffic of 18 mErl per subscriber was assumed, resulting in total BH traffic of 18,000, 36,000 and 54,000 Erlangs for 1, 2 and 3 million subscribers respectively. Data traffic was deliberately omitted as it will be small compared to GSM voice traffic. There are various ways in which data traffic could have been be modelled and including data traffic might have resulted in confusion and a lack of transparency. Furthermore, voice scenarios already provide a 3:1 difference in traffic levels and this is considered sufficient to demonstrate the argument.

Table 6 – Subscribers per Area for Different Traffic Scenarios

	Relative subscriber density	Total subscribers per area			
		98% pop coverage		99.5% pop coverage	
		1 m subs	2 m subs	2m subs	3 m subs
Dense Urban	568.9	394,700	789,400	769,078	1,153,617
Urban	57.7	204,600	409,200	398,666	597,999
Rural	3.1	304,000	608,000	627,152	940,728
Unpopulated	1.0	96,700	193,400	205,104	307,657

3. TECHNICAL ASSUMPTIONS

Realistic assumptions have been made as far as possible to provide identical conditions for the GSM900 and GSM1800 based networks. Where differences exist in established practice at 900 MHz and 1800 MHz or there may be different views, the study has chosen a conservative approach that results in the smallest differences between 900 MHz and 1800 MHz.

The study analysed the market and technical scenarios using accepted industry models and dimensioning principles. These principles are also consistent with guidelines prepared for the Telekom-Control-Kommission, Reference 1. Differences between the theoretical results and the real world performance are expressed in terms of a few easily understood and verifiable benchmarks. These are Cell Placement Margin, Cell Load Efficiency and Average TRX per Sector and are discussed further below.

3.1 Link budgets

Link budgets at 900 MHz and 1800 MHz are presented in Table 7 and Table 8. Figures in **bold** text indicate values involving different assumptions for 900 MHz and 1800 MHz.

The following assumptions apply to both technologies:

- Similar feeder, combiner and body losses, diversity gains of 2 dB (for Rural and Unpopulated), 1.5 dB (for Dense Urban and Urban)
- Base and Mobile Receive Sensitivities of -110 dBm and -102 dBm respectively
- 95% probability of indoor coverage in Dense Urban, Urban and Rural areas; 90% probability of outdoor coverage in Unpopulated areas; similar standard deviations of fading.

The following parameters are different, reflecting inherent technology differences:

- Mobile transmit power of 33 dBm (2W) for 900 MHz and 30 dBm (1W) for 1800 MHz reflecting standard power classes
- Base antenna gain is 16 dBi at 900 MHz and 18 dBi at 1800 MHz for similar antenna size and cost
- Mast Head Amplifiers (MHAs) are used at 1800 MHz but not at 900 MHz, reflecting common practice. These provide an extra 3 dB in uplink gain and reduce the difference between 900 MHz and 1800 MHz scenarios.

By chance, the resulting downlink power levels at 900 MHz and 1800 MHz are the same. This is due to the fact that reduced mobile transmit power at 1800 MHz is cancelled by the additional MHA gain.

Table 7 – 900 MHz Link Budget

Up-link Budget (Sector Site)	**Unpopulated**	**Rural**	**Urban**	**Dense Urban**	**Units**
Frequency	**900.0**	**900.0**	**900.0**	**900.0**	**MHz**
Mobile transmitter power	**33.0**	**33.0**	**33.0**	**33.0**	**dBm**
Mobile transmit antenna gain	0.0	0.0	0.0	0.0	dBi
Body loss	-2.0	-2.0	-2.0	-2.0	dB
Base receive antenna gain	**16.0**	**16.0**	**16.0**	**16.0**	**dBi**
Diversity gain	2.0	2.0	1.5	1.5	dB
BS Rx cable losses	-3.0	-3.0	-3.0	-3.0	dB
Interference margin	0.0	0.0	0.0	0.0	dB
Shadow fading margin outdoors	-6.0	-9.7	-11.9	-11.9	dB
MHA sensitivity gain	**0.0**	**0.0**	**0.0**	**0.0**	**dB**
Base receiver sensitivity	-110.0	-110.0	-110.0	-110.0	dBm
Path Loss Capability	150.0	146.3	143.6	143.6	dB
Down-link Budget (Sector Site)					
Frequency	**945.0**	**945.0**	**945.0**	**945.0**	**MHz**
Base Transmit Power	**43.0**	**43.0**	**42.5**	**42.5**	**dBm**
Base Transmit Antenna Gain	**16.0**	**16.0**	**16.0**	**16.0**	**dBi**
BS Tx losses	-3.0	-3.0	-3.0	-3.0	dB
Mobile receive antenna gain	0.0	0.0	0.0	0.0	dBi
Body Loss	-2.0	-2.0	-2.0	-2.0	dB
Interference margin	0.0	0.0	0.0	0.0	dB
Shadow fading margin outdoors	-6.0	-9.7	-11.9	-11.9	dB
Mobile receiver sensitivity	-102.0	-102.0	-102.0	-102.0	dBm
Path Loss Capability	**150.0**	**146.3**	**143.6**	**143.6**	**dB**
Building Penetration Loss	**0.0**	**3.0**	**13.0**	**20.0**	**dB**
Maximum Path Loss	**150.0**	**143.3**	**130.6**	**123.6**	**dB**

Table 8 – 1800 MHz Link Budget

Up-link Budget (Sector Site)	**Unpopulated**	**Rural**	**Urban**	**Dense Urban**	**Units**
Frequency	**1800.0**	**1800.0**	**1800.0**	**1800.0**	**MHz**
Mobile transmitter power	**30.0**	**30.0**	**30.0**	**30.0**	**dBm**
Mobile transmit antenna gain	0.0	0.0	0.0	0.0	dBi
Body loss	-2.0	-2.0	-2.0	-2.0	dB
Base receive antenna gain	**18.0**	**18.0**	**18.0**	**18.0**	**dBi**
Diversity gain	2.0	2.0	1.5	1.5	dB
BS Rx cable losses	-3.0	-3.0	-3.0	-3.0	dB
Interference margin	0.0	0.0	0.0	0.0	dB
Shadow fading margin outdoors	-6.0	-9.7	-11.9	-11.9	dB
MHA sensitivity gain	**3.0**	**3.0**	**3.0**	**3.0**	**dB**
Base receiver sensitivity	-110.0	-110.0	-110.0	-110.0	dBm
Path Loss Capability	**152.0**	**148.3**	**145.6**	**145.6**	**dB**
Down-link Budget (Sector Site)					
Frequency	**1895.0**	**1895.0**	**1895.0**	**1895.0**	**MHz**
Base Transmit Power	**43.0**	**43.0**	**42.5**	**42.5**	**dBm**
Base Transmit Antenna Gain	**18.0**	**18.0**	**18.0**	**18.0**	**dBi**
BS Tx losses	-3.0	-3.0	-3.0	-3.0	dB
Mobile receive antenna gain	0.0	0.0	0.0	0.0	dBi
Body Loss	-2.0	-2.0	-2.0	-2.0	dB
Interference margin	0.0	0.0	0.0	0.0	dB
Shadow fading margin outdoors	-6.0	-9.7	-11.9	-11.9	dB
Mobile receiver sensitivity	-102.0	-102.0	-102.0	-102.0	dBm
Path Loss Capability	**152.0**	**148.3**	**145.6**	**145.6**	**dB**
Building Penetration Loss	**0.0**	**5.0**	**15.0**	**22.0**	**dB**
Maximum Path Loss	**152.0**	**143.3**	**130.6**	**123.6**	**dB**

3.2 Building Penetration Loss

A detailed review of work under the European COST 231 programme by Ericsson concluded that building penetration loss at 1800 MHz is typically 2 dB higher than at 900 MHz. The review considered papers by Technische Universität Wien (A), Aalborg University (DK), CSELT (I), Telefónica Investigación y Desarollo (E), Telia Research and Ericsson Radio Systems (S), British Telecom Research Laboratories, The University of Liverpool, and The University of Leeds (UK) and others (See References 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 & 13).

2 dB compares with losses in the range of 4.5 dB to 9 dB higher when using indoor antennas, reported in the Telekom-Control-Kommission's guidelines, Reference 1.

Thus, 2 dB difference has been assumed here as a conservative figure. The resulting building penetration losses used in this study are based on ONE's assumptions at 1800 MHz and presented in Table 9.

Table 9 – Assumed Building Penetration Losses at 900 MHz and 1800 MHz

	Unpopulated	Rural	Urban	Dense Urban
At 900 MHz	Outdoor coverage only	3 dB	13 dB	20 dB
At 1800 MHz		5 dB	15 dB	22 dB

3.3 Propagation and coverage

3.3.1. Standard Propagation Models

As discussed in Reference 1, the Okumura Hata model as modified by COST 231 provides a well accepted method of estimating average cell ranges based on the maximum Path Loss calculated by the link budget. Theoretical site coverage areas may then be calculated by treating a sector site as three hexagons.

Since this method will underestimate the number of sites required for coverage, a Cell Placement Margin of typically 30% may be added to represent the overlap between cells that occurs in a real network.

The COST231 equation for path loss comes in two slightly different forms. At 900 MHz the path loss (P) is given by:

$$P = 69.55 + 26.16\log(f) - 13.82\log(h_b) - a(h_m) + (44.9 - 6.55\log(h_b))\log(d) - L_c$$

and at 1800 MHz by:

$$P = 46.3 + 33.9\log(f) - 13.82\log(h_b) - a(h_m) + (44.9 - 6.55\log(h_b))\log(d) - L_c$$

In both these equations, f is the frequency in MHz, h_b is the height of the mast, $a(h_m)$ is a correction factor applied to the mobile and d is the distance in kilometres. *Lc* is a clutter offset for different environments and ideally needs to be calibrated separately at 900 MHz and 1800 MHz for the local conditions.

3.3.2. Calibrated model for 1800 MHz

In this study, a slightly different approach was used. ONE has a well calibrated planning tool model for 1800 MHz. Practical site areas were obtained by dividing total areas by the number of sites.

Using the 900 MHz version of the COST231 model as a basis, clutter offsets were adjusted to match closely the 1800 MHz calibrated planning tool results. The results are summarised in Table 10. Average mast heights and average sectors per site are as ONE's 1800 MHz network. The cell placement margin is assumed to be 30%.

Modified clutter offsets in Table 10 may be compared with reference clutter offsets defined by COST 231 for 900 MHz and listed in Table 11.

Table 10 – Parameters for 1800 MHz based on 900 MHz COST model

	Modified Clutter Offset	**Average Mast Height**	**Average Sectors per site**	**Cell Placement Margin**
Dense Urban	1 dB	29 m	2.65	30%
Urban	3.4 dB	27 m	2.5	30%
Rural	10.5 dB	26 m	2.3	30%
Unpopulated	11.4 dB	26 m	2.0	30%

Table 11 - COST 231 Reference Clutter Offsets for 900 MHz Hata equation

	COST 231 category	Clutter Offset
Dense Urban	U2	0 dB
Low Dense Urban	U1	3 dB
Dense Suburban	S3	8 dB
Leafy Suburban	S2	5 dB
Low Dense Suburban	S1	11 dB
Forest	F1	9 dB
Open, No Obstructions	O1	24 dB
Water	W	29 dB

3.3.3. Model for 900 MHz

In the absence of detailed measurements at 900 MHz, the study developed a model based on the 1800 MHz model calibrated for Austria. The Okumura Hata equation and parameters in Table 10 were applied to calculate the cell range and number of sites for coverage at 900 MHz. Alternative approaches were also considered and the results were compared. These were:

- Using different forms of the COST231 equations at 900 MHz and 1800 MHz but with the same clutter offsets
- Using different forms and reducing the clutter offsets in Table 10 by 1.9 dB for the rural case and 2.9 dB for the unpopulated case, as suggested by Reference 1.

The first alternative produced much lower numbers of 900 MHz sites compared to either of the other two methods and was rejected as it would tend to exaggerate the differences between 900 MHz and 1800 MHz networks.

The initial model provided very similar results in Rural and Unpopulated environments as the approach suggested by Reference 1 and only slightly greater numbers of 900 MHz sites in Dense Urban and Urban areas. Since these were areas where traffic rather than coverage was expected to dominate, the initial model was judged to be acceptable.

3.4 Capacity planning

The capacity of a network depends on the number of TRX that can be supported in each cell. Once traffic demand exceeds the maximum capacity of the cell, additional sites will need to be introduced.

Although the theory of traffic dimensioning is straightforward and well understood, the practical results are more difficult to model in practice:

- Not every sector will be fully loaded and overall cell load efficiencies may vary from typically less than 40% to 70% or more. Generally, the lower the number of TRX per sector, the lower the cell load efficiency. This is not a matter of trunking efficiency but due to the need to install an integral number of TRX in a sector.

- In practice, traffic load is not homogeneous but will vary from one sector to another. As a result the average TRX per sector will always be somewhat less that the theoretical maximum TRX per sector.

3.4.1. Modelling Approach

Once again, the study deliberately chose conservative assumptions that would minimise the difference between 900 MHz and 1800 MHz. The number of radio transceivers (TRX) was considered in terms of:

- Standard frequency re-use factors, equipment configurations and a grade of service of 2% to determine maximum theoretical traffic per cell and per TRX.

- Cell Load Efficiency to represent the difference between an ideal network and the practical case, as described above.

A similar approach was used to consider the number of cells (sectors) and sites needed for capacity:

- The maximum TRX per sector was determined by the frequency plan and equipment limitations.

- The model introduced additional sectors as the average load approached the theoretical maximum; to give a realistic number of TRX per Sector.

- Numbers of sites depend on the average sectors per site. Typical values were used based on the Austrian environment.

ONE used a slightly different approach for modelling traffic in their model but achieved similar results.

3.4.2. Dimensioning

Basic capacity dimensioning used in this study is presented in Table 12. A non-hopping frequency plan with 21 BCCH carriers and an average TCH carrier re-use of 18 was assumed. However, the maximum TRX per sector was found to be dominated by equipment limitations of 6 TRX per sector and 12 TRX per site. These have a significant impact on the maximum achievable TRX per sector and hence on the number of sites needed to support a given load. Since these limitations have a greater effect on the GSM900 based network, they were included as the most conservative approach.

Table 12 – Basic Traffic Dimensioning

Bandwidth Available	**17 MHz**	**29 MHz**	**32 MHz**
Total Carriers	85	145	160
Number of BCCH Carriers	21	21	21
TCH Carrier Re-use (Non-hopping)	18	18	18
Maximum Equipped TRX per Sector	6	6	6
Maximum Equipped TRX per Site	12	12	12
Practical Max. Average TRX per Sector	4.3	4.3	4.3
Percentage HR Used by Model	0%	0%	0%
Average Carriers per Cell	4.29	4.29	4.29
Available TS per Cell	30	30	30
Voice Channels per Cell	30	30	30
Voice Grade of Service	2%	2%	2%
Voice Erlangs per Cell	**21.9**	**21.9**	**21.9**
Voice Erlangs per TRX	**5.12**	**5.12**	**5.12**

Table 13 shows how the average TRX per site may be reduced as the result of equipment limitations. The figures take account of the fact that the average TRX per sector will be less than the maximum value. Numbers will vary in practice according to traffic homogeneity.

Table 13 – The Effect of Equipment Limitations on TRX per Sector

Total Spectrum	**2 x 17 MHz**	**2 x 29 MHz**	**2 x 32 MHz**
Due to spectrum alone	4.56	7.89	8.72
Due to 6 TRX sector maximum	4.56	**5-5.5**	**5-5.5**
Due to 12 TRX site maximum	**3.7-4.3**	**3.7-4.3**	**3.7-4.3**

4. MODELLING RESULTS

4.1 Coverage Scenario (Base Case)

Table 14 presents the estimated number of coverage sites at 900 MHz and 1800 MHz for 98% population coverage. These are based on the Market and Technical assumptions. The table provides a breakdown by area and shows the ratio between numbers of 900 MHz and 1800 MHz sites.

This is a precise result for 1800 MHz, based on ONE's calibrated planning tool model. As discussed in Section 3.3.3, the results for the 900 MHz model in Unpopulated and Rural areas also agreed well with the principles set out in Reference 1. Although the 900 MHz model estimates a slightly higher number of coverage sites in Urban and Dense Urban areas than predicted using Reference 1, this difference disappears once the network becomes loaded with traffic and Urban and Dense Urban areas become largely traffic limited.

Table 14 – Coverage Scenarios

	900 MHz sites	1800 MHz sites	Ratio
Dense Urban	199	554	2.8
Urban	317	881	2.8
Rural	729	2029	2.8
Unpopulated	284	610	2.1
TOTAL sites	**1,530**	**4,074**	**2.7**

4.2 Low Traffic Scenario

In the low traffic scenario, there are 1 million subscribers for 98% population coverage and 2 million subscribers at the point where coverage has grown to 99.5%. The total estimated numbers of sites and TRX are presented in Table 15.

Compared with the coverage only case, the ratio in site numbers falls due to the need to add more capacity sites to the GSM900 based network. For the 99.5% case, coverage growth has been achieved in both networks using 900 MHz spectrum. More detailed study indicated that this saves about 100 sites for the GSM1800 based operator.

Table 15 – Low Traffic Scenario

Subscribers and coverage	GSM900 based		GSM1800 based		Ratio	
	Sites	TRX	Sites	TRX	Sites	TRX
98% coverage only	1,530	3,556	4,074	9,558	2.7	2.7
1m @98%	1,552	8,423	4,077	11,854	2.6	1.4
2m @ 99.5%	1,844	13,419	4,175	18,698	2.3	1.4

4.3 High Traffic Scenario

In the high traffic scenario, there are 2 million subscribers for 98% population coverage and 3 million subscribers at the point where coverage has grown to 99.5%. The total numbers of sites and TRX are presented in Table 16.

It can be seen that under maximum load, the GSM1800 based network requires 2 times the number of sites of the GSM900 based network and 1.4 times the number of TRX.

Table 16 – High Traffic Scenario

Subscribers and coverage	GSM900 based		GSM1800 based		Ratio	
	Sites	TRX	Sites	TRX	Sites	TRX
98% coverage only	1,530	3,556	4,074	9,558	2.7	2.7
2m @98%	1,789	13,221	4,111	18,469	2.3	1.4
3m @ 99.5%	2,119	17,549	4,223	24,521	2.0	1.4

The breakdown of sites and TRX for 3m and 99.5% coverage is shown in Table 17. The Dense Urban figures show that both GSM1800 and GSM900 based networks are very strongly driven by capacity and the model estimates similar numbers of sites. Elsewhere, the GSM900 based network still has a considerable advantage.

Comparing these results with results based on the alternative model suggested by Reference 1 provided identical results, since the Dense Urban and Urban areas are now dominated by traffic.

Table 17 – Breakdown of Sites and TRX by Area for 3m Subscribers

3m and 99.5% coverage	GSM900 based		GSM1800 based		Ratio	
	Sites	TRX	Sites	TRX	Sites	TRX
Dense Urban	628	6,455	628	6,455	1.0	1.0
Urban	350	3,346	885	5,380	2.5	1.6
Rural	818	5,778	2,074	9,764	2.5	1.7
Unpopulated	324	1,969	636	2,921	2.0	1.5
TOTAL sites	**2,119**	**17,549**	**4,223**	**24,521**	**2.0**	**1.4**

4.4 Sensitivity of the Results

The study has shown that a GSM1800 based network serving the Austrian market will involve at least twice as many sites as a GSM900 based network, even after network subscriber numbers have reached 3 million. The study chose conservative assumptions that result in the smallest difference between GSM900 and GSM1800.

The sensitivity to various assumptions was checked during the study and most were found to have very little effect on the ratio of 900 MHz to 1800 MHz sites, even though site and TRX numbers themselves might rise or fall.

Two factors have a large effect on the result:

- If Mast Head Amplifiers were included in both networks, the ratio of GSM1800 to GSM900 based network sites is estimated to rise from 2.0 to 2.3 under the high traffic scenario. However, suitable Mast Head Amplifiers were not generally available when GSM900 networks were first rolled out and site locations chosen.

- Equipment limitations have been included on the basis that base station equipment (BTS) commonly used by Austrian Operators does not allow more than 6 TRX per sector or 12 TRX per site. In practice this has little impact on current 1800 MHz networks and network loads but can be seen to have a marked effect on the development of a 900 MHz based network. If the overall sector limit was raised to 8 or 10 per sector based on equipment from other vendors, the ratio of GSM1800 to GSM900 based network sites is estimated to rise from 2.0 to 2.5 or 2.6 under the high traffic scenario.

5. CONCLUSIONS

5.1 Ratio of GSM900 to GSM1800 Sites in a Mature Market

The study has shown that the number of sites and hence costs of GSM900 and GSM1800 based networks in Austria will continue to be substantially different irrespective of future network growth.

The ratio in site numbers depends on the particular environment. Only within Dense Urban areas in Austria can the numbers of sites and TRX be seen to converge. This only occurs completely within these areas once subscriber numbers reach 3 million.

Overall, at least twice as many sites will be required for a GSM1800 based network with 3 million subscribers as for a GSM900 based network and about 1.4 times the number of TRX.

The study has deliberately chosen conservative assumptions that result in the smallest differences between GSM900 and GSM1800. One assumption is the limit on the numbers of TRX per sector and per site. Although this has little effect in practice for current 1800 MHz operators, it has a large effect on a 900 MHz based network. Consequently 900 MHz operators should choose equipment from another vendor as raising the limit to 8 TRX per sector would result in a much more efficient GSM900 design. A GSM1800 based network with 3 million subscribers would then require about 2.5 times the number of sites of a GSM900 based network.

5.2 Effect on Capital and Operating Expenditures

It has not been the role of this study to carry out a detailed study of network costs. However, an indication of relative capital (Capex) and operating expenditure (Opex) can be provided based on typical industry rules of thumb (References 14 and 15):

- Core Network (CN) Capex is typically 30% of radio network Capex for a GSM900 network
- Since CN costs is dependent both on numbers of sites and subscribers, CN Capex for a GSM1800 network will be a smaller proportion and figure of 20% of radio network Capex is assumed here.
- Technical Opex is mainly determined by and therefore proportional to the number of radio sites.

When these numbers are applied to a GSM1800 based network with 2 times as many sites as a GSM900 based network, the result is a Capex figure of about 1.8 times. Annual technical Opex will be approximately 2 times the Opex of a GSM900 based network.

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