SAPHYRE

Contract No. FP7-ICT-248001

Business models, cost analysis and advises for spectrum policy and regulation for scenario III (full sharing)

D5.5

Contractual date:	M34
Actual date:	M35
Authors:	Pieter NOOREN, Frank BERKERS, Thom JANSSEN
Participant:	TNO
Work package:	WP5
Security:	Public
Nature:	Report
Version:	1.0
Number of pages:	64

Abstract

This document presents an evaluation of three sharing scenarios that addresses both the business and the regulatory considerations. The evaluation approach is applied to three sharing scenarios in which both infrastructure and spectrum are shared. The evaluations provide insights in the type of considerations that will play a role in operators' and regulators' judgements and the factors that should be taken into account.

Keywords

Infrastructure sharing, spectrum sharing, RAN sharing, centralised RAN architectures, distributed RAN architectures, regulations, coalition formation.

Contents

Abbreviations

2G/3G	2nd/3rd Generation
3GPP	3rd Generation Partnership Project
BBU	Baseband Unit
BEREC	Body of European Regulators for Electronic Communications
BULRIC	Bottom-up Long-Range Incremental Cost
CAPEX	Capital Expenditures
CoMP	Cooperative Multi-Point
C-RAN	Centralised RAN
CU	Central Unit
HHI	Herfindahl–Hirschman Index
HTN	Heterogeneous Networks
JV	Joint Venture
LTE	Long Term Evolution
MNO	Mobile Network Operator
MOCN	Multi-Operator Core Network
MVNO	Mobile Virtual Network Operator
NRA	National Regulatory Authorities
OPEX	Operational Expenditure
QoS	Quality of Service
OTT	Over-The-Top
RAN	Radio Access Network
RAT	Radio Access Technology
RSPG	Radio Spectrum Policy Group
SAC/SRC	Subscriber Acquisition Cost and Subscriber Retention Cost
SC#	Scenario (number)
TFEU	Treaty on the Functioning of the European Union
TP	Transmission Points
WP	Work Package

1 Executive summary

Sharing is an important practice in today's mobile networks. SAPHYRE studies new, advanced sharing techniques in which both infrastructure and spectrum can be shared to further improve the spectral efficiency, coverage and end-user experience provided by mobile networks. The advanced sharing approaches from SAPHYRE lead to new business and regulatory considerations and trade-off. A number of business and regulatory requirements need to be fulfilled to make the SAPHYRE advanced sharing a viable option for operators. By putting the sharing decision in context of regulation and the market of operators we aim to promote the impact of sharing.

The analysis provided in this document shows that the business and regulatory considerations in sharing are for a large part based on a set of common elements, such as the mobile market structure, cost benefits that can be obtained through sharing and the (remaining) options for retail service differentiation in sharing. The operators' decisions in sharing depend on these elements, and their decisions, in turn, affect these elements. Moreover, regulators examine these elements to determine whether specific sharing proposals are acceptable or not, vis-à-vis an established set of policy objectives, such as the promotion of competition, efficient investments in infrastructure and efficient use of frequencies.

This document presents an evaluation approach that addresses both the business and the regulatory considerations in sharing, thus acknowledging the interdependency between these two areas. A so-called *coalition formation model*, based on game theory, is used to evaluate the implications of sharing for the mobile market (in absence of regulatory intervention) by considering the interdependent strategic alternatives for multiple Mobile Network Operators (MNO). It also provides a set of relevant quantitative measures that characterise the market in the presence of the sharing coalitions, such as the average cost level in the market and the relative entry barrier for new entrants. To complement the model outcomes, the evaluation approach also includes a number of qualitative criteria, such as the effects of sharing on the service homogeneity in the retail market and the scope for innovation in networks.

The evaluation approach is applied to three sharing scenarios: sharing based on Multi-Operator Core Network (MOCN) technology in a i) national and ii) rural mode, and iii) Centralised RAN (C-RAN) sharing. These are all full sharing scenarios in which both infrastructure and spectrum are shared. The evaluations provide insights in the type of considerations that will play a role in operators' and regulators' judgements and the factors that should be taken into account. The aim of the evaluations contained in this deliverable is not to come to a final judgement on the acceptability of the scenarios from operators' and regulators' perspective. This judgement is up to operators and regulators who are in a position to make evaluations on a case-by-case basis after study of the precise sharing arrangement and its consequences.

The quantitative model outcomes show that with our model parameter assumptions Radio Access Network (RAN) and spectrum sharing are attractive for operators. The cost reductions that can be obtained with sharing lead existing operators to prefer comprehensive sharing arrangements. The cost reductions align well with the policy objective of efficient investment and innovation in networks. However, the sharing arrangements do not align with key elements of the policy objective to promote competition. Sharing leads to more concentration in the wholesale market for RAN and thus reduces the level of infrastructure-based competition. Increased concentration on the wholesale market does not necessarily lead to a similar concentration and interdependency between operators on the retail market, as the sharing operators may still have various technical options to differentiate their retail offerings. An assessment of the consequences of the concentration in the wholesale market for the retail market requires a rather detailed analysis of the precise technical and organisational conditions in the proposed sharing arrangement, and falls outside the scope of this deliverable. This is also true for the assessment of the opportunities that the sharing operators have to independently introduce innovations in their networks.

For the entry barrier, another important element related to the policy objective to promote competition, sharing arrangements can work out both positively and negatively. On the one hand, sharing can substantially increase the entry barrier in terms of the relative cost disadvantage that a new entrant faces. On the other hand, if a new entrant is in a position to join an existing sharing coalition, the entry barrier is substantially lower compared to the case in which the new entrant must deploy a full network individually.

In the three scenarios we analysed, we found that RAN and spectrum sharing are not expected to significantly affect the emitted power. As a result, the regulations governing the maximum emitted power levels play a relatively small role in the overall assessment of network and spectrum sharing. Site sharing, a sharing arrangement that typically precedes RAN and spectrum sharing, can certainly be affected by power level regulations though.

In our regulatory analysis, we considered the consequences of four distinct rules that a regulator may enforce with respect to sharing:

1. Regulator does not allow sharing arrangements that increase the market concentration above a certain threshold;
2. Regulator declares ex ante that sharing by new entrants will be allowed;
3. Regulator requires that sharing arrangements are open to future new entrants;
4. Regulator allows rural sharing only.

With our quantitative model outcomes it is possible to indicate what the consequences of such rules would be in terms of impact on entry barrier and competition effects.

Our recommendation to operators and regulators involved in the development and assessment of sharing arrangements is to use a coalition formation model in their assessments. The model provides quantitative insights in preferred sharing coalitions and effects of sharing on cost levels and entry barriers that complement the qualitative assessment on other criteria.

2 Introduction

Sharing is an important practice in today’s mobile networks [1]. Site sharing, in which multiple mobile operators share an antenna site to install their antennas and equipment, is common throughout Europe. There are also more progressive forms of sharing in which more resources, including active network equipment, are shared. SAPHYRE studies new, advanced sharing techniques, based on equal priority resource sharing, in which both infrastructure and spectrum are shared voluntarily to further improve the spectral efficiency, coverage and end user experience provided by mobile networks [2]. Apart from developing technical enablers for advanced sharing, SAPHYRE also addresses the business and regulatory requirements that need to be fulfilled to make this type of sharing a viable option. These business and regulatory requirements are the focus of this document.

A sharing technology will be applied by operators if it meets their business requirements, such as cost reduction. Another important condition is that the sharing is allowed by the regulators involved, typically the national telecoms regulator, the national or European competition authority or a combination. These regulators become involved because sharing affects the mobile market structure and independence of the participating operators, and hence the competition which is an important policy objective. But there are other policy objectives for regulators that are affected by sharing as well, such as cost-efficient investment, innovation in networks, and efficient use of spectrum.

An important observation is that the business and regulatory considerations in sharing are for a large part based on a set of common elements, such as the mobile market structure, cost benefits that can be obtained through sharing and the (remaining) options for service differentiation in sharing. The operators’ decisions in sharing largely depend on these elements, and their decisions, in turn, affect these elements. Moreover, regulators examine these elements to determine whether specific sharing proposals are acceptable or not. The evaluation approach presented in this document therefore covers both the business and the regulatory considerations in sharing, thus acknowledging the interdependency between these two areas.

A key element in the evaluation approach presented here is the analysis of the operators’ preferences for potential sharing coalitions. A so-called coalition formation model, based on game theory, is used to evaluate the implications for the mobile market structure (in absence of regulatory intervention) of sharing by considering the interdependent strategic alternatives for multiple MNO. The inputs to the coalition formation model are various Capital Expenditures (CAPEX) and Operational Expenditures (OPEX) costs incurred by operators, the mobile market structure and a number of assumptions on operator strategies in sharing. Based on these inputs, the model identifies the sharing coalitions that can be expected to develop in the market in the absence of regulatory intervention. It also provides a set of relevant quantitative measures that characterise the market in the presence of the sharing coalitions, such as the average cost level in the market and the relative entry barrier for new entrants. To complement the model outcomes, the evaluation approach also includes a number of qualitative criteria, such as the effects of sharing on the service homogeneity in the retail market and the scope for innovation in networks.

This document presents evaluation results for three full sharing scenarios applied to the Dutch mobile market. Here, full sharing means that both the RAN infrastructure and the spectrum are shared. The first scenario is national sharing based on MOCN technology. The second scenario is also based on MOCN, but with sharing in rural areas only rather than in the whole country. The third scenario assumes C-RAN technology. Due to limitations of time and budget, this scenario is studied without in-depth quantitative modelling. Instead, we have considered in what directions the quantitative analysis would have provided different results.

In separate SAPHYRE deliverables, scenarios in which only the spectrum is shared [3] and in which only the infrastructure is shared [4] have been investigated.

The scenario evaluations in this document provide insights in the type of considerations that will play a role in operators' and regulators' judgements and the factors that should be taken into account. In the end, the judgement on whether certain sharing arrangements are acceptable or not is up to regulators who are in a position make evaluations on a case-by-case basis after study of the precise sharing arrangement proposed by operators and its consequences. Thus, the aim of the evaluations contained in this deliverable is not to come to a final judgement on the regulatory acceptability of the scenarios, but rather to contribute to an improved instrumentation for evaluation. This should be kept in mind in the interpretation of the results and recommendations.

The remainder of this document is organised as follows. Chapter 3 introduces the coalition formation model and the quantitative and qualitative criteria that make up the evaluation approach. Chapter 4 describes the national and rural MOCN and C-RAN sharing scenarios, that are evaluated in Chapters 5, 6 and 7, respectively.[1] Chapter 8 synthesises the results and observations from the scenario evaluations and relates them to the policy objectives of the regulators. Chapter 9 completes the document with conclusions and our main recommendation.

[1] For reading and understanding the scenarios and evaluations (Chapters 4 through 7) it is not necessary, but recommended, to study Section 3.2 on the technical details of the evaluation approach in depth.

3 Scenario evaluation method

In this chapter we describe the method and models used for the analysis. We will evaluate three specific forms combined network and spectrum sharing from a combined regulatory and business perspective. In our evaluation we will compare the sharing scenario with a scenario in which the exact same technologies are applied for the same purposes, i.e. the same mobile traffic volumes, in a non-shared configuration. In the following subsection we will list and describe the criteria that we use for our scenario evaluation. It will become obvious that for two specific evaluation criteria we see a need for a detailed modelling approach. This approach is described separately in Section 3.2. For reading and understanding the scenarios and evaluations (Chapters 4 through 7) it is not necessary, but recommended, to study Section 3.2 on the technical details of the evaluation approach in depth.

3.1 Business and regulatory evaluation criteria

The business evaluation and the regulatory evaluation of the sharing scenarios both deal with the expected behaviour of market players, in particular the behaviour of mobile network operators. Therefore, ingredients like market shares and cost savings play a role in both evaluations, although in different ways. From the business perspective of two mobile operators that consider a mutual sharing arrangement, a stronger position based on cost savings from sharing vis-à-vis a third operator outside the sharing arrangement is attractive. From the regulatory perspective, that same stronger position may present a potential disruption of competition. Given the overlap in areas to be studied, it was decided to combine the business and regulatory evaluation of the scenarios. At the same time, we aim to retain the different perspectives and potentially diverging valuations in our analysis.

Business considerations around sharing include cost savings, strategic considerations as to the partner choice, and the extent to which autonomy can be maintained in a sharing configuration. These are aspects that will be covered in our analysis. In order to deepen our study of business aspects, we have specifically developed a cost model and a coalition formation model for sharing, which is described in Section 3.2.

To structure our approach of regulatory considerations we have looked at several sources. The EU framework directive [5] lists the objectives that National Regulatory Authorities (NRA, such as OFCOM in the UK or OPTA in the Netherlands) have to take into account in their considerations. As explained in more detail in [6], the following objectives are relevant in the context of infrastructure and spectrum sharing:

- *“Ensuring that there is no distortion or restriction of competition in the electronic communications sector, including the transmission of content.”*
- *“Encouraging efficient use and ensuring the effective management of radio frequencies and numbering resources.”*
- *“Safeguarding competition to the benefit of consumers and promoting, where appropriate, infrastructure-based competition.”*

- *"Promoting efficient investment and innovation in new and enhanced infrastructures ..."*

The framework directive also mentions a set of other areas that are of interest. It stipulates that European Member States have to cooperate in many areas relating to the use of radio spectrum, taking into account the *"economic, safety, health, public interest, freedom of expression, cultural, scientific, social and technical aspects of EU policies as well as the various interests of radio spectrum user communities with the aim of optimising the use of radio spectrum and avoiding harmful interference"*. Among other things, this has led to the formulation of limits for the maximal electromagnetic field strengths. These limits need to be taken into account in the evaluation of infrastructure and spectrum sharing arrangements, as the sharing can have an effect on the radiated power and its geographical distribution.

In a joint study, the Body of European Regulators for Electronic Communications (BEREC) and the Radio Spectrum Policy Group (RSPG) have analysed the status of infrastructure and spectrum sharing in Europe in 2011 [7]. In addition, they analysed the considerations for NRA in their evaluations of sharing arrangements. As expected, this analysis reflects the high-level policy objectives from the framework directive and further develops and applies them for the issues typically encountered in sharing. Apart from the sector-specific stipulations from the framework directive, BEREC and the RSPG also take into account the generic legal and economic criteria from Article 101 of the Treaty on the Functioning of the European Union (TFEU, [8]) that aim to protect the competition in the European internal market by prohibiting cartels and other forms of undesired coordination between market players that can disrupt competition.

Based on the BEREC/RSPG analysis and the policy objectives in the framework directive, the following set of criteria has been applied to determine and investigate the regulatory issues introduced by the full sharing scenarios:

- Dominant positions;
- Barriers to entry;
- Homogeneity of product offerings;
- Efficient use of spectrum;
- Cost efficiency;
- Innovation in radio networks;
- Emitted power level.

Each criterion is introduced and further developed in the next sections. The first three criteria play a role in the assessment of the impact of sharing arrangements on competition. The promotion of competition is the key ingredient of two of the policy objectives mentioned above (dominant positions and barriers to entry). The other criteria relate to the other policy objectives. In current practice, regulators will evaluate each individual sharing arrangement on its own merits by looking at the balance between the various criteria.

This study does not aim to make a judgement on whether certain sharing arrangements are acceptable or not, as this judgement is up to the regulators. Instead, the goal is to provide insights in the type of considerations that will play a role in a regulator's judgement and the factors that should be taken into account. These insights are obtained by examining three sharing scenarios qualitatively and quantitatively. This analysis is presented in subsequent sections, which also contains descriptions of these sharing scenarios.

3.1.1 Dominant positions

In telecommunications, the number of competing network infrastructures is traditionally limited. In European countries, the number of mobile network operators is typically three or four. In larger countries, the leading operators typically have market shares of 30–50% [9]. This level of market share is seen as an indication for a dominant position. A market share above 50% is generally seen as proof for a dominant position for a single operator [5]. The key characteristic of an operator with a dominant position is that it has a market power large enough to operate largely independent of the other participants and the customers in the market. For example, a dominant operator is able to raise its prices to obtain a larger profit. Sharing arrangements between operators carry the risk of increasing the market power of the participants or the newly created combination of participants to the degree that dominant positions are created or reinforced.

The simplest measure for dominance is the market share. As mentioned above, a market share above 50% is considered generally seen as proof for a dominant position. This measure only looks at the market share of the leading operator. The Herfindahl–Hirschman Index (HHI) is a measure for the degree of concentration in the market and, by extension, for the level of competition. The HHI index is defined as the sum of the squares of the market shares and can take values between 0 and 10,000. A market with an HHI index above 2000–2500 is considered to be concentrated. In the sharing scenarios studied here, the so-called wholesale HHI values are studied. In the wholesale HHI, the market shares of MVNO are added to the market share of the mobile network operator on which they are hosted. In the retail HHI, the MVNO are counted as separate market participants. As a result, the retail HHI values are typically lower than the wholesale HHI values, reflecting the lower concentration resulting from the presence of MVNO in the retail market. Since the present analysis focuses at the competition between mobile network operators rather than the competition between retail service providers in the retail market, the wholesale HHI is more relevant than the retail HHI and is therefore the measure we will use in our analysis. The wholesale HHI is also the more relevant measure for the assessment of the concentration encountered by MVNO that try to negotiate an arrangement with a mobile network.

The effects of a sharing agreement on the potential creation or strengthening of a dominant position are not only dependent on the market shares involved, but also on the specific arrangements in the agreement:

- Extent of sharing, e.g. what is the geographic coverage of the sharing arrangements? Are all sites of the operators covered by the agreement? Do the participating operators share all of their spectrum or only part of it?)

- Sharing terms and conditions, e.g. Is the sharing agreement open for further participation by other operators? Are there exclusivity clauses that govern sharing arrangements for other (future) radio technologies or spectrum?)
- Information exchange, i.e. to what degree will the information exchanged between the partners necessary for the operation of the shared infrastructure and spectrum lead to undesired coordinated behaviour ("collusion") of the partners in the retail market for mobile services?

3.1.2 Barriers to entry

Barriers to entry refer to obstacles that make it harder for a new operator to enter the market for mobile services. Telecommunications markets traditionally have substantial barriers to entry as they require significant up front investments in network infrastructure and, for mobile networks, spectrum. Moreover, the investments are for a large part sunk as they cannot be easily recovered if an operator decides to leave the market [5]. A sharing arrangement is likely to affect these barriers, as it leads to increased economies of scale for the participating operators. As will be seen in the analysis, sharing can be beneficial but also detrimental for new entrants. This depends on the characteristics of sharing arrangements, such as:

- How large are the cost benefits obtained by sharing, and how are they distributed over the participating operators?
- Can new entrants enter an existing sharing coalition?

3.1.3 Service homogeneity

Service differentiation allows mobile network operators to gain a competitive advantage. They can distinguish their services from the services offered by their competitors in several aspects, such as price, quality and bundling with other services, e.g. in order to appeal to different market segments. Sharing agreements can reduce the freedom of the partners to differentiate their services relative to each other. The result would be a service market in which mobile operators compete on a narrower set of services or service features. Whether sharing indeed has this undesired effect depends on the (as of yet not fully known) technical and organisational characteristics of the sharing arrangements, such as:

- To what extent can sharing partners independently control the QoS delivered to their customers? Can the sharing partners independently choose the QoS classes they use for their services, or are they forced to cooperate and agree on the available classes?
- Can a request from a sharing partner for the installation of an additional base station to meet a specific coverage need be accommodated in the sharing, also when the other partner is not interested or willing to pay for it?

3.1.4 Efficient use of spectrum

Spectrum is a valuable, scarce resource and it should therefore be used efficiently. Infrastructure and spectrum sharing can contribute to the efficient use of spectrum, in various ways:

- Does the spectrum sharing lead to higher spectral efficiency, in terms of the number of Mbit/MHz per cell?
- Does the sharing arrangement lead to more extensive reuse of spectrum through the use of more (but smaller) cells to cover the same geographic area? This leads to a higher efficiency in terms of Mbit/MHz for the whole geographic area under consideration.

3.1.5 Cost efficiency

Cost savings and more efficient use of resources in general are the main drivers for mobile network operators to participate in sharing. Cost savings also contribute to the policy goal of efficient investment in infrastructures. Telecommunication infrastructure is seen as an important economic growth enabler.

3.1.6 Innovation in networks

Sharing arrangements also affect the environment in which operators introduce innovations in their networks. In this study, innovation in networks refers to larger upgrades and migrations of networks, such as the introduction of LTE-Advanced in LTE networks. If the innovation roadmaps of the sharing partners are aligned, the sharing arrangement can promote the innovation as the corresponding costs and investment risks may be reduced. The uncertainties surrounding the investment strategy and business may also be reduced as the innovation roadmap of another operator in the same market is (at least partly) known. The latter effect, though, could also be seen as an undesired effect of the sharing. It increases the market power of the sharing operators compared to the other operators in the same market that do not have access to this information. An existing sharing agreement may also limit the speed of roll-out of new technology as it will have to be coordinated among partners and thus may be determined by the operator with the slowest pace.

Innovation in networks also has an important geographical dimension. Mobile network operators tend to introduce new generations of network technologies in urban areas first, as these areas offer the most attractive business cases: many potential customers can be reached by upgrading a relatively limited number of sites. A number of regulators have recognised this tendency and have concluded that they needed to take specific action, e.g. requirements in licences, to promote the innovation in networks in rural areas alongside the urban areas, e.g. the 800 MHz licenses auctioned in Germany in 2010 contained roll-out conditions that were targeted specifically at rural areas.

3.1.7 Emitted power levels

The emitted power levels in RAN must comply with the limits on maximal field strengths that are imposed by national authorities to limit the exposure of the public to electromagnetic fields. These limits also apply to shared RAN. Network and spectrum sharing can affect the emitted power levels because they are likely to introduce changes in the radio planning of operators. Obviously, sharing arrangements should not result in power levels that exceed the limits.

3.2 Modelling the formation of sharing coalitions

In this section we introduce the models and concepts developed to quantitatively approach the business trade-off between the cost saving of sharing and increased subscriber retention costs that result from a less differentiated retail product offering. Since the sharing decision inherently depends on the willingness of competitors to share as well, we developed an approach that allows for anticipating on other players' preferences by applying game theory, more specifically coalition formation games. The approach can (and is) also deployed to analyse the effects of sharing on the market performance, illustrated in the next subchapter. The coalition formation approach we developed includes two novel aspects: i) we use ordered preferences instead of numeric values to evaluate different options and ii) we introduced a new type of fallback-option in the strategy. These aspects will be elaborated on in Section 3.2.2.

In the model approach we confront the MNO business perspective on sharing and the regulator perspective on the potential market effects of full spectrum and RAN sharing see Chapter 5, 6 and 7) for the roll-out of a new Radio Access Technology (RAT, e.g. LTE). In general, we state that in any market active businesses have a strategy to either maintain or improve their position, roughly by increasing cost-efficiency or by improving the value proposition towards their customers. The strategic trade-off with respect to sharing comprises:

- Owning a new RAT gives MNO a competitive advantage over MNO without this technology, because it can offer a broader range of services;
- Network sharing gives cost reductions, but MNO will also lose options to differentiate from other MNO, because sharing of RAN and spectrum requires coordination between sharing partners on a number of aspects.

In most countries, the mobile telephony market is an oligopoly, i.e. a market served by just a few players. A characteristic of such a market is that activities such as a successful marketing campaign or a technical breakdown of one player can directly be felt by the other players, e.g. increased churn or increased load. This means that many actions have a competitive effect. Sharing definitely has competitive effects, illustrated by the trade-off above. Therefore, this form of collaboration is studied by regulators. A regulator must weigh the different forces that determine the operation of the market. It uses criteria such as cost efficiency, dominance, entry barrier to judge to what extent this collaboration is allowed. Thus both operators and regulators consider (among other things) the same business ecosystem, but evaluate outcomes differently. Business in general strive for growth of market share, profits, revenues, outperforming the competition; regulators strive for a competing market which is not dominated by a single player.

We observe that the effects of sharing for each player and for the market as a whole are interdependent on the other players' choices. The coming about of a sharing can be considered a formation of a coalition. Coalition formation is a subject well addressed in game theory. We will analyse the effect of sharing decisions on market structure by developing a coalition formation model.

We seek to identify whether trade-offs between cost and competitiveness lead to a coalition (by means of applying game theoretical constructs) and if this coalition affects the performance of the market (by analysing a number of performance criteria). If no coalition is expected, then it is assumed that allowing the possibility to share will not affect the performance of the market. We aim to support this analysis by means of a quantitative model in order to be able to analyse different scenarios.

The approach we take here is to set up a cost model to analyse the players' preference for different sharing coalitions versus individual investments. We use these preferences with respect to sharing coalitions in a coalition formation model to derive whether these preferences would lead to a coalition. From both we derive a number of quantitative performance criteria that are combined with other qualitative criteria (for details see Section 3.1) in order to draw conclusions on the market performance as a result of sharing. Thus, we approach the business and the regulator angle in this case simultaneously. The rationale for this is that MNO markets are typically oligopolistic and a sharing decision does involve (and affect) other players and is likely to change the market. Therefore, we expect both regulator and MNO to consider the same ecosystem. Note that we consider sharing decisions between MNO and do not consider business models run by third parties or vendors.

We need to make some more assumptions and scoping decisions in this analysis. We first consider greenfield deployment of LTE from the perspective of the present MNO that already have an installed 2G/3G base and then evaluate the case when a new entrant enters the game. We consider an oligopoly of three present players (K, V and T) with respectively 50%, 30% and 20% market share. The new entrant would directly acquire 10%. We assume that spectrum is already acquired and that the players now consider actually deploying the technology. The choices considered are limited to RAN or full sharing, national or rural and partner selection. We do not consider spectrum-only sharing.

Thus, specifically in this section we model individual trade-off between cost savings and decreased competitiveness and relate this to sharing coalitions by applying coalition formation theory. We derive market performance criteria to evaluate the effect of allowing sharing in a market.

Furthermore, we describe the business decision and link it to game theoretical constructs in order to define the game. Then we describe the cost model and the coalition formation model. We conclude this modelling description in Section 3.2.6 by describing the analytical approach that these models provide.

3.2.1 The interrelated business decision on sharing

The business decision regarding sharing is cascaded. On the highest level, sharing must be in line with the company's business principles, as sharing implies collaboration with competitors or (increased) dependence from suppliers. If sharing is acceptable in principle and the decision depends on the case, there is a number of main considerations, such as the degree of sharing and the partners to share with. The interrelated business decision on sharing is thus cascaded as follows:

- Share, yes or no? If in principle acceptable, then the case depends on:
  - What to share? → either RAN or RAN and spectrum;
  - Where to share? → national or rural;
  - With whom? → a specific partner, any partner or all partners.

The latter question makes the decision different from a 'regular' (independent) business decision as a decision to share requires a sharing partner (a "coopetitor"). Furthermore, the choices in the share (both the partner, the sharing technology and the geographical scope) make up for the effects, because these affect for instance the total number of sites required, the total amount of RAN equipment needed and the operational efficiency of spectrum sharing; and thus for weighing for the benefits versus the costs. We mean this in a broad sense, including strategic considerations such as decreased autonomy as a result of having to coordinate roll-out of networks, increased risk etc. In [10] we identified a number of drivers, barriers and trade-off in this respect.

In this work we will focus on the *interdependence* of the players in the market in their choices to share. Thus the decision to share is affected by the formation of a coalition. It may be clear that, even given the simplified decision-break-down, the number of potential coalitions in a market of a few MNO is large.

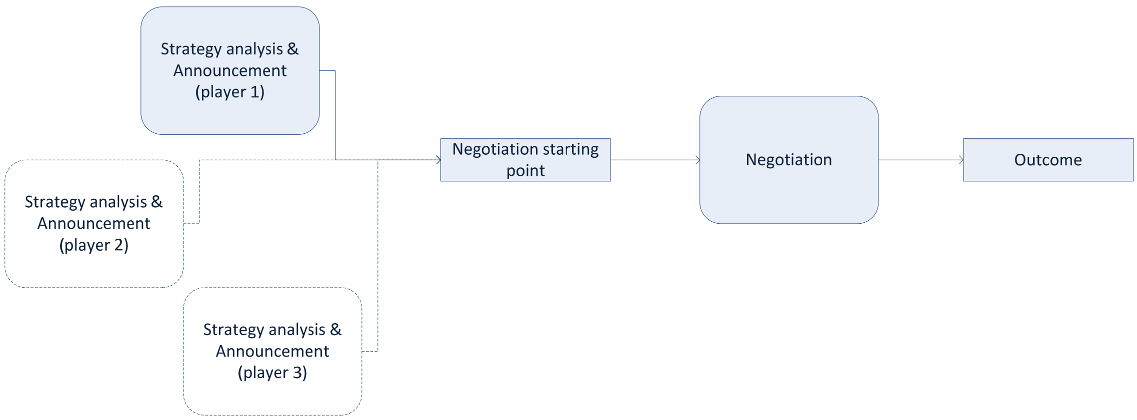

Figure 1: Overview of a simultaneous and interdependent business decision process

We assume a process similar to the one depicted above. In the first stage, all players perform an independent in-house analysis to determine the potential of sharing and prepare a first position on whom they want to share what with. This is not necessarily achievable, as the decision to share needs to be mutual, so there is a necessary distinction between desired outcome and strategy.

The following example illustrates the relation between strategies and outcome.

Assume that K, V and T announce the following strategies:

- *K wants to invest alone;*
- *V wants a coalition with T else alone;*
- *T wants a coalition with V else alone*

➔ *The forthcoming market configuration is (K,VT); K invests alone and VT share.*

Now assume:

- *K wants coalition with V else don't invest;*
- *V wants coalition with K else alone;*
- *T wants the coalition with both K and V or whomever*

➔ *The forthcoming market configuration is (KV,X); a coalition of K and V and T does not invest at all.*

The announcement of the strategies is the starting point for further negotiation. Players with matching first positions will form a coalition and in the negotiation they will try to optimise their coalition. This will result in the final outcome and we assume that this sharing will be realised.

3.2.2 Sharing as a non-cooperative simultaneous exclusive membership coalition formation game

The process above can be described using game theoretical concepts. This provides us with tools to analyse the problem. More background on related considerations and concepts can be found in [11].

In essence, this process consists of two phases: i) an independent phase where players determine their strategy and ii) an improvement phase where the coalition is optimised. In game theory this can be classified as a coalition formation game. The first part is named *non-cooperative*, since the players will determine their positions initially independently and *simultaneously*. In order to do so, each player is assumed to have a *pay-off function* with which it can evaluate the value one derives from an *outcome*. An outcome is a market configuration, i.e. a definition of what player is in which coalition (or not) and what is being shared. There are so-called *spillovers*, implying that being in a coalition brings benefits that cannot be achieved alone, e.g. in total less sites are needed in a coalition.

The coalitions are termed *exclusive membership*, as players are not free to join if the other members do not agree.

There are two types of *rules* in this game. The first type is the process that players announce their preferred coalition (called 'strategy') simultaneously and a coalition is formed if all members agree. The second type of rule is related to the definition of the strategy and the logic of matching. As announcing the preferred coalition does not guarantee that this coalition will be formed, we need players to formulate a "fallback" option: if the announced coalition fails to form, the party will a) make no investment, b) do the investment alone or c) join the 'remaining' coalition, if any [12], [13][2]. Now, the resulting coalition, or rather market configuration, can be determined based on the announcements.

From the perspective of K the following strategies are available:

[2] This combination of fall-back options as rules in a coalition formation appears to be novel in literature.

1. *X: don't invest*
2. *K: invest alone*
3. *KV-X: coalition with V else don't invest*
4. *KV-Γ: coalition with V else invest alone*
5. *KT-X: coalition with T else don't invest*
6. *KT-Γ: coalition with T else invest alone*
7. *KVT-X: coalition with both V and T else don't invest*
8. *KVT-Γ: coalition with both V and T else invest alone*
9. *KVT-Δ: coalition with both V and T else with whomever*

Γ and Δ refer to the strategies as defined in the model from Bloch [15] and Ray and Vohra [16].

Each strategy needs to be specified with either national or rural sharing and RAN or full sharing.

As a means to analyse this part of the game, we suggest to deploy the concept of the Nash equilibrium. This is an outcome in which none of the players can improve its position *by itself*, i.e. by announcing an alternative strategy. This does not mean such an outcome is optimal. One Nash equilibrium can be *dominated* by another, i.e. is beneficial for all involved players. Such an outcome can then only be achieved by collaboration. Therefore, the second part of the game is introduced.

The second part is cooperative. This part is needed, firstly because in practice it does not make sense to assume that such a sharing deal comes about just by announcing the strategy and secondly because the main analytical concept to conclude the first phase is the Nash equilibrium.

In short, the game is a two stage coalition formation game. The first phase is a non-cooperative simultaneous exclusive membership game with spillovers and a fallback-option strategy. The second phase is a cooperative game.

3.2.3 Supporting the business analysis process of sharing

In our approach we are interested in how individual MNOs can come to a reasonable decision with respect to sharing. We assumed that the following phases would play a role in the business decision process from an individual perspective, as depicted in Figure 2 and described below:

1. *Initial self preference assessment.* The focal company evaluates internally the principles with respect to sharing and sorts the list of possible outcomes in order of preference by applying the so-called pay-off function.
2. *Competitive preference estimation.* In order to meaningfully anticipate to what competition is doing, the focal company must (and usually reasonably can) make an estimation on the competitor's strategy and their high-level business case.

3. *Strategy analysis and selection.* Based on the sets of preferences the focal company will make an analysis of the Nash-equilibria and identify dominant outcomes. In order to achieve that outcome a number of strategies, e.g. initial strategy announcements, is at their disposal. After evaluating the outcomes and related strategies the decision is made public and coalitions will be formed correspondingly.

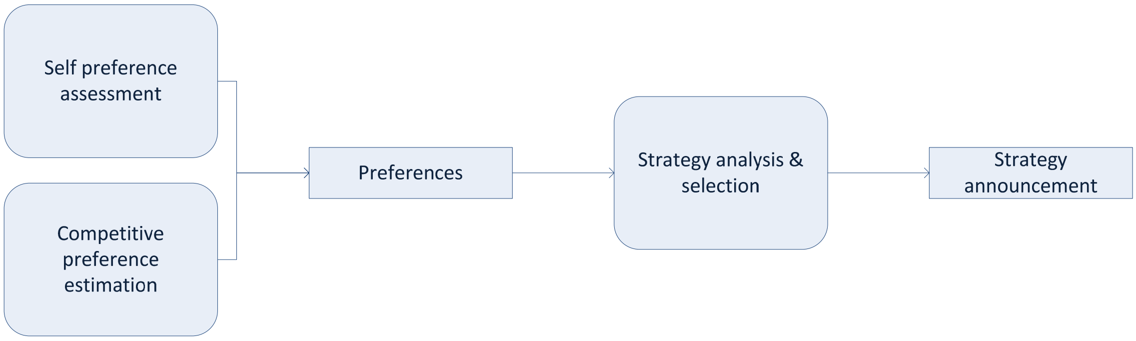

Figure 2: Overview of a business decision flow

We will illustrate these phases further:

First, the business would consider the case for sharing internally. They would determine under what circumstances sharing of either RAN or spectrum is acceptable to the company. These circumstances can for instance include which partner, the acceptable degree of integration, what geographical area, etc. The analysis of the different options at hand shall show that the costs and benefits will vary per sharing partner as each partner has a different profile (e.g. number of subscribers, number of available sites) and thus that the preferred outcome depends on to what extent the outcome is preferred by the potential sharing partner. Put differently, we assume that each player is capable of valuing each of the possible outcomes. Note that this evaluation is not just a business case; it may involve other strategic considerations as well [10], [14]. In a three party market with the given simplified decision-break-down there are 36 different outcomes (market configurations) in which it is determined for all parties who is investing or not, who is sharing and what is shared (rural or national, RAN or RAN and spectrum). We recognise this individual and *independent phase of making up the company strategy* with respect to a technological development in practice. Note that these possible outcomes must include situations on which the focal company has no direct influence, such as the largest competitor deploying LTE individually non-shared.

Selecting the right strategy is not trivial. For example, if two parties announce an all-party-coalition-strategy but the third prefers to do it alone, then the two parties either share together, do it alone or do not invest at all (depending on their chosen and announced strategy). These outcomes may be far from optimal for those parties. Thus, selecting the wrong strategy, or rather making the wrong approach or proposal towards the competitors (and thus revealing some of your intentions) after making your mind up bears some risk.

So, the game is to choose the strategy such that the ***anticipated*** *corresponding outcome cannot be improved by selecting another strategy.* In this situation each of the players can select 30 different strategies, resulting in 27,000 different strategy combinations that again result in one of the 36 market configurations.

By definition of this game, it is known a priori what combination of strategies leads to what outcome. Thus also, for a given perspective of a player (say ‘K’) the possible outcomes per strategy are known. Each player already evaluated each of the possible outcomes, so each player knows a priori what range of values is associated with each of the strategies. In the table we see that these ranges typically vary very much. This indicates that additional information is needed to select the strategy.

What is not known, but essential for estimating the anticipated outcome, is an idea of the *preference structure of the competitors* with respect to sharing. We see that in practice players tend to know the competition pretty well, in terms of strategic considerations and even more in terms of network profile, e.g. technology used, number of sites, number of subscribers. Even if some kind of pre-negotiation is present in practice this still adds up to the competitive intelligence. Now, K can sort the outcomes for both T and V in their expected order of preference. Because we have the a priori link between strategies and outcomes, K also knows what strategies of both V and T lead to what outcome. This means that K can also evaluate whether either V or T can improve by selecting another strategy. In other words, based on K’s estimation of V and T’s order of preference of the outcomes, K can identify which outcomes are an expected Nash equilibrium. Therefore, we put this ‘Competitive preference estimation’ early in the process depicted in Figure 2.

Table 1: A typical ranking for all configurations for three players

Coalition	Where to share	What to share	K	V	T
(X,X,T)			30	30	22
(X,V,X)			31	22	30
(K,X,X)			22	31	31
(X,V,T)			32	23	23
(K,X,T)			23	32	24
(K,V,X)			24	24	32
(K,V,T)			25	25	25
(X,VT,VT)	national	RAN	35	6	8
(KT,X,KT)	national	RAN	8	35	10
(KV,KV,X)	national	RAN	10	10	35
(K,VT,VT)	national	RAN	28	7	9
(KV,KV,T)	national	RAN	11	11	28
(KT,V,KT)	national	RAN	9	28	11
(KVT,KVT,KVT)	national	RAN	3	3	3
(X,VT,VT)	national	full	36	4	4
(KT,X,KT)	national	full	4	36	5
(KV,KV,X)	national	full	6	8	36
(K,VT,VT)	national	full	29	5	7
(KV,KV,T)	national	full	7	9	29
(KT,V,KT)	national	full	5	29	6
(KVT,KVT,KVT)	national	full	2	2	2
(X,VT,VT)	rural	full	34	14	14
(KT,X,KT)	rural	full	14	34	15
(KV,KV,X)	rural	full	15	15	34
(K,VT,VT)	rural	full	27	17	17
(KV,KV,T)	rural	full	16	16	27
(KT,V,KT)	rural	full	17	27	16
(KVT,KVT,KVT)	rural	full	12	12	12
(X,VT,VT)	rural	RAN	33	18	18
(KT,X,KT)	rural	RAN	18	33	19
(KV,KV,X)	rural	RAN	19	19	33
(K,VT,VT)	rural	RAN	26	21	21
(KV,KV,T)	rural	RAN	20	20	26
(KT,V,KT)	rural	RAN	21	26	20
(KVT,KVT,KVT)	rural	RAN	13	13	13

Table 2: Strategy/outcome mapping for player K

Strategy for K	(K,V,T)	(K,V,X)	(K,VT,VT)	(K,X,T)	(K,X,X)	(KT,V,KT)	(KT,X,KT)	(KV,KV,T)	(KV,KV,X)	(KVT,KVT,KVT)	(X,V,T)	(X,V,X)	(X,VT,VT)	(X,X,T)	(X,X,X)
X											X	X	X	X	X
K	X	X	X	X	X										
KV-X full								X	X		X	X	X	X	X
KV-Γ full	X	X	X	X	X			X	X						
KT-X full						X	X				X	X	X	X	X
KT-Γ full	X	X	X	X	X	X	X								
KVT-X full										X	X	X	X	X	X
KVT-Γ full	X	X	X	X	X					X					
KVT-Δ full						X	X	X	X	X	X	X	X	X	X
KV-X rural RAN											X	X	X	X	X
KV-Γ rural RAN	X	X	X	X	X										
KT-X rural RAN											X	X	X	X	X
KT-Γ rural RAN	X	X	X	X	X										
KVT-X rural RAN											X	X	X	X	X
KVT-Γ rural RAN	X	X	X	X	X										
KVT-Δ rural RAN											X	X	X	X	X
KV-X full											X	X	X	X	X
KV-Γ full	X	X	X	X	X										
KT-X full											X	X	X	X	X
KT-Γ full	X	X	X	X	X										
KVT-X full											X	X	X	X	X
KVT-Γ full	X	X	X	X	X										
KVT-Δ full											X	X	X	X	X
KV-X rural full											X	X	X	X	X
KV-Γ rural full	X	X	X	X	X										
KT-X rural full											X	X	X	X	X
KT-Γ rural full	X	X	X	X	X										
KVT-X rural full											X	X	X	X	X
KVT-Γ rural full	X	X	X	X	X										
KVT-Δ rural full											X	X	X	X	X

Table 2 shows for K what outcomes are associated with which strategy. We looked at strategies concerning both national and rural as well as RAN and full sharing.

This Nash equilibrium analysis narrows down the set of possible outcomes per strategy for K, because it is unlikely (and disregarding false estimation of competitive preferences) that a non-Nash equilibrium would be the outcome, since both T and V would not select strategies that lead to outcomes that each of them could improve upon by selecting an alternative strategy. Alternatively, both T and V are expected not to select strategies that lead to an outcome in which K could improve by selecting another strategy and therefore potentially resulting in a less preferred outcome.

Table 3: Strategy/outcome mapping for player K narrowed down by Nash equilibrium analysis

Strategy for K	(K,V,T)	(K,VT,VT)	(KT,V,KT)	(KV,KV,T)	(KVT,KVT,KVT)
Rank	*25*	*28*	*9*	*11*	*3*
K	X	X			
KV-X full				X	
KV-Γ full	X	X		X	
KT-X full			X		
KT-Γ full	X	X	X		
KVT-X full					**X**
KVT-Γ full	X	X			**X**
KVT-Δ full			X	X	**X**
KV-Γ rural RAN	X	X			
KT-Γ rural RAN	X	X			
KVT-Γ rural RAN	X	X			
KV-Γ full	X	X			
KT-Γ full	X	X			
KVT-Γ full	X	X			
KV-Γ rural full	X	X			
KT-Γ rural full	X	X			
KVT-Γ rural full	X	X			

The table shows for K what outcomes are associated with which strategy; the narrowed down set with only Nash equilibria. The bold X is the dominant outcome. The table illustrates that some strategies are riskier than others. Given confidence in e.g. the ranks for T, strategy 5 (KT,X) leads to the coalition with T.

With a narrowed down set of outcomes and strategies, the parties can select their strategies. From the perspective of a single player some strategies lead to exactly one equilibrium with a lower rank, others may end up in different equilibria, either a higher one and a lower one, so this implies a trade-off between outcome preference and risk and measures to mitigate this risk.

The above analysis is assumed to be all done in-house, e.g. without interaction with the competitors (and is assumed to be done by all competitors). After the initial selection and revelation of strategies that will end up in a Nash-equilibrium outcome, we expect the parties to share some information and try to optimise their positions. For some outcomes, even for an equilibrium, there can be an improvement if all parties agree. Such an outcome is said to dominate the others.

Some outcomes may be preferred by all parties, e.g. KVT in our case; these are referred to as dominant outcomes. These outcomes may not have been reachable initially, because the associated strategies may lead to different outcomes as well, e.g. if a player used a slightly different preference order.

Now we have described the coalition formation game and the business decision processes that could accompany them, we present the overview before moving into the details of the models.

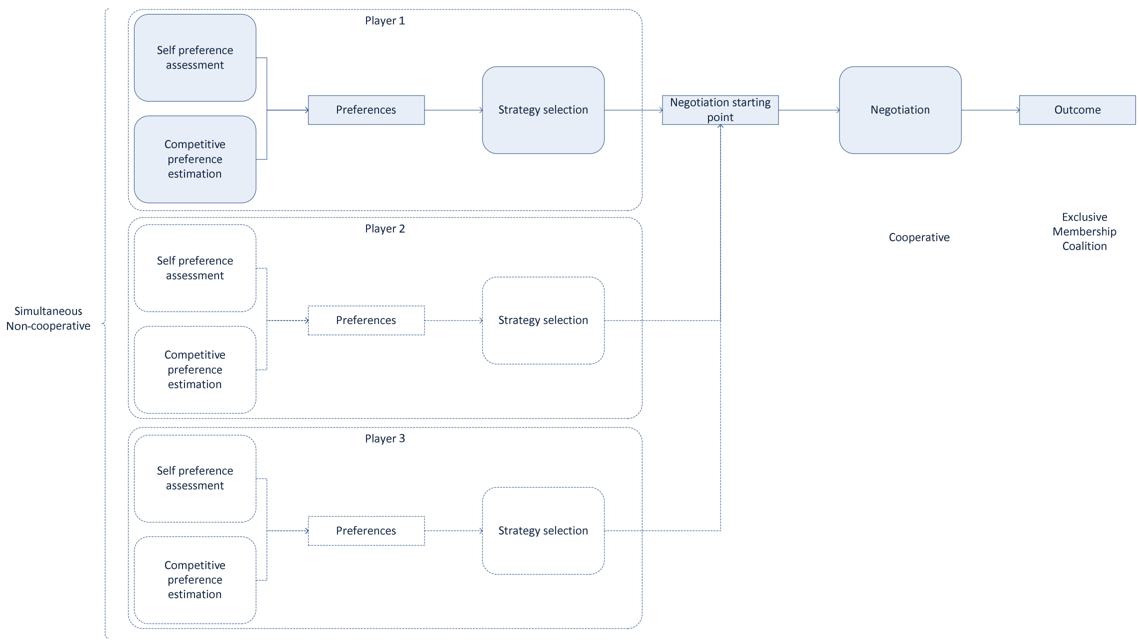

Figure 3: Overview of business decision flows leading to a sharing negotiation and coalition formation

In the figure above the parallel independent processes of taking a position towards sharing is depicted. Of course, in practice if two players decide to start sharing there's not such a formal 'negotiation starting point'. Nevertheless, implicitly there is, as these parties implicitly choose the strategy to bypass the third one.

In order to support analysis of this game we set up two models that are meant to be applied in a process as below.

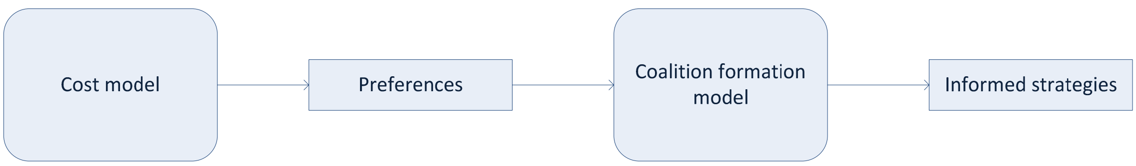

Figure 4: Process flow as implemented in the modelling

The cost model provides us with the cost perspective for each of the players for each of the possible outcomes of the game. The cost perspective is reasonable (but not necessarily the preferred) basis for deriving each player's preference structure. In our case we combined absolute cost levels with relative cost levels to tie-break the different outcomes with equal absolute cost levels and reflect that a better cost price per subscriber has a competitive edge. Furthermore, it is feasible to generate alternative preference orderings taking other strategic considerations into account, e.g. strategies such as "battle the market leader", "avoid collaborations with No. 2", "exclude the challengers", cost leadership. We briefly illustrated this in [17].

This is input to the coalition formation model[3] which determines, based on the preferences and available strategies, what are Nash equilibria, and if these are dominated or not. This process thus results for each perspective in a matrix of what strategies lead to what outcome equilibrium. Note that one strategy can result in many outcomes (depending on others' choices), but also that a specific outcome may be achieved by different strategies.

This toolset can be used in two ways; i) by a 'market observer' to analyse the effects of sharing on the market (main assumption: all estimated preference structures are true) or ii) by a player to analyse its competition (main assumption: estimated preference structures of the competition are true).

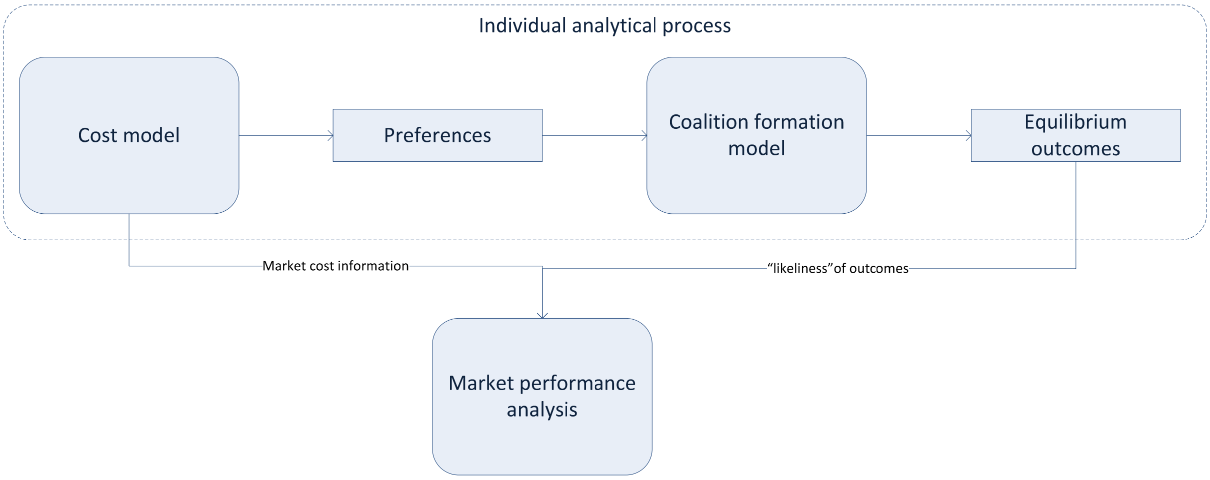

Figure 5: Overview of the steps involved in the market performance analysis

For the latter figures with respect to total cost or relative entry barrier for new entrants are derived from the cost model and indications on the "likeliness" outcomes are derived from the coalition formation model as input to market performance analysis.

In the next sections the cost model and coalition formation model are described.

3.2.4 Modelling cost savings and subscriber retention for sharing

In this section we describe the cost model used for deriving the trade-off between cost savings and decreased competitiveness and the order of preference with respect to coalition outcomes for each of the players. We distinguish two types of inputs: i) scenario parameters and ii) other parameters.

[3] In literature the approach of taking numerical values for outcomes is investigated much deeper. This requires however that outcomes be evaluated quantitatively. We decided to move on with the more generic approach of ordered preferences, since ordering outcomes could for example be achieved in an afternoon's session with a management team and therefore making the coalition formation model much more useful.

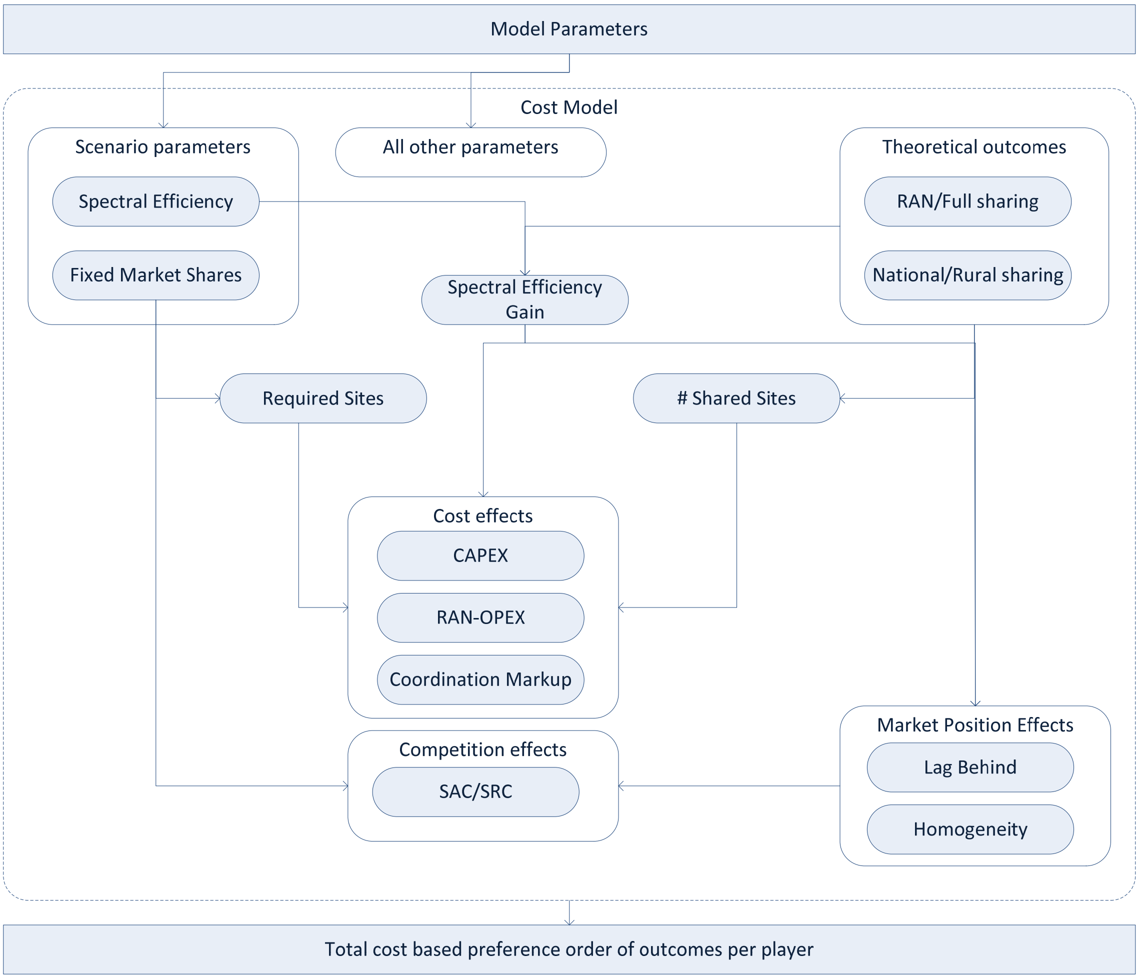

Figure 6: Overview of the cost model

We decided to vary scenarios in only two types of parameters, being the market shares we allocate to players in the market (with either 0% or 10% indicating the share for a new entrant) and spectral efficiency. In the analysis we deployed two main scenarios, being i) “decreasing” with shares 50%, 30% and 20%, and ii) “flat” where the two major parties have an equal share (42.5%, 42.5% and 15%). The efficiency that sharing of spectrum brings is uncertain as of yet, therefore we used values 5% and 10% as efficiency gains incorporated as a reduction of the required shared sites.

The other parameters deal for example with site costs, market size, costs of retention, required coverage and capacity sites etc. This is described below.

The theoretical outcome is an enumeration of all possible market configurations. This means that it lists all combinations of sharing either RAN or full sharing, national or rural for any coalition as well as individual deployments for both the three player market (36 outcomes) and the one with the new entrant (172 outcomes).

For each of the players the cost structure is similar: costs are composed of RAN CAPEX and RAN OPEX for the sites (both expressed in a per year cost). Sharing induces Coordination markup costs for the shared sites, indicating that we expect a shared site to be more expensive upon installation and operation, because of the required coordination. The last major cost component is named Subscriber Acquisition Cost and Subscriber Retention Cost (SAC/SRC). These are the expenses made to get or maintain a subscriber. (Annual reports claim these expenses can run up to 150 Euro per year and subscriber.) We modelled the extra cost a player has to spend in order to maintain its market share as a result of 'lagging behind' and 'homogeneity' as a percentage of the SAC/SRC. Thus, we assume market shares to be constant. Lagging behind occurs if a player does not deploy LTE, while others do. Homogeneity is referring to the fact that in one coalition the same technology is deployed and therefore the subscribers will at least perceive some equality in the product offering. To maintain the market share extra expenses are required.

The number of sites required depends on the required coverage and capacity sites. The number of capacity sites depends on the number of served subscribers (market size times market share). When shared, the required number of sites is based on the joint market share. This represents a major cost saving. We assumed an equal division of the sharing cost/benefit, i.e. the same percentage for each party in the share[4]. The numbers for required coverage and capacity sites are derived from a TNO study comprising an extrapolation for LTE (at 800 MHz) of a public BULRIC study on the Netherlands [18].

Table 4: Number of sites required for coverage and for capacity in our studied network deployment

	Coverage	**Capacity**
Urban	212	318
Suburban	808	105
Rural	447	0

If the outcome under consideration indicates full sharing then the spectral efficiency gain is applied as a reduction in the number of shared sites.

In case of rural sharing, only rural sites are shared. Lagging behind and homogeneity effects are minimal.

Table 5: Overview of parameter settings as applied in our analysis

Parameters	**Value**	**Unit**
Market size	20,000,000	subscribers
RAN CAPEX	12,000	Euro per site per year
RAN OPEX	10,000	Euro per individual site per year
	+10%	Euro per shared site per year
	-5%	if spectrum is shared
Coordination markup	2,000	Euro per site per year
SAC/SRC	150	Euro per subscriber per year (base)
Lag behind markup	10%	of SAC/SRC

[4] We deployed more advanced rules such as Shapley Values but found that preference orders and cost levels were not majorly affected.

Homogeneity	0.10% (0.11%; 0.12%)	of SAC/SRC for coalitions of cardinality 2/3/4
Rural factor	0.02	factor to limit competitive effects of rural sharing
We have taken and processed data from [19], [20] and [21] and these should be taken as order of magnitude estimations. CAPEX is also expressed as a yearly expense.		

Because this cost model enumerates all possible outcomes and calculates for each player, given market shares, what its total cost position is, it's fairly easy to see which outcomes are preferred by which player by ranking the outcomes. This allows us to inspect the trade-off between cost-savings and the price for compensating to keep market shares versus deploying by oneself. This clearly shows an overall preference for full sharing (given the parameter values), but also that if two parties form a coalition, the rank for the third drops substantially, indicating that a coalition indeed affects competition.

Table 6: (Part of) a table containing the ranks of a four player market

Configuration	**NE**	**K**	**V**	**T**
(nKVT,nKVT,nKVT,nKVT) full	2	2	2	2
(nKVT,nKVT,nKVT,nKVT) national RAN	3	3	3	3
(nVT,K,nVT,nVT) full	5	137	5	5
(nKT,nKT,V,nKT) full	7	5	137	7
(nVT,K,nVT,nVT) national RAN	11	136	7	9
(nKV,nKV,nKV,T) full	9	9	9	137
(nKT,nKT,V,nKT) national RAN	13	7	136	13
(n,KVT,KVT,KVT) full	172	12	10	10
(nKV,nKV,nKV,T) national RAN	15	11	13	136
…	…	…	…	…
(nK,nK,VT,VT) full	30	25	44	45
(nK,nK,VT,VT) full	43	37	36	34
(nV,KT,nV,KT) full	45	24	43	36
(n,KT,V,KT) full	170	21	129	31
(nK,nK,V,T) national RAN	49	29	134	134
(n,KV,KV,T) full	168	34	40	129
(n,KT,V,KT) national RAN	169	42	128	48
(n,KV,KV,T) national RAN	167	48	48	127
(n,K,V,T)	153	112	114	114

The left column in Table 6 contains the coding of the outcome (market configuration). The code is composed as follows: the coalition or singleton per player in the order new entrant (NE), K, V, T followed by the sharing deal being either N for national (or R for rural; omitted in this table) and ran for RAN sharing only or full sharing for RAN plus spectrum. (nT,KV,KV,nT). Nran means that there are two coalitions: the new entrant with T and K with V; they share RAN only nationally.

‘Market performance indicators’ such as the total cost for all subscribers, i.e. the total cost the society bears for running the new technology, or the relative cost position of the new entrant versus the average cost per subscriber for the existing players can be derived from the cost calculations.

Table 7: Definition of market performance indicators

Market performance indicators	**Definition**	**Rationale**
Average subscriber cost	Total cost for all MNO divided by total number of subscribers	This reflects the “societal” cost level, i.e. the burden on all subscribers altogether.
Herfindahl–Hirschman Index (HHI)	It is defined as the sum of the squares of the market shares of the (50 largest) firms.	It is an indicator for the concentration in the market. When considering coalitions the shares of the partners are summed before squaring. The same is applied for rural sharing.
Entry barrier	Cost per subscriber for the new entrant divided by average cost per subscriber for the others	This reflects the difference in cost level of the new entrant versus the existing parties. If the entry barrier is too high, a new entrant can only enter the market by accepting loss. Applicable only in the new entrant scenario.

3.2.5 Modelling the coalition formation

The implementation of the coalition formation model takes for each of three players[5] a rank order of preferences with respect to the theoretical outcomes as an input. In our case we derived the preference orders from the cost model described above (by combining absolute and relative cost levels)[6].

The output is a per-outcome indication whether the outcome is a Nash equilibrium, and for those that are it indicates whether the equilibrium is dominated or not. For each of the players a set of strategies is associated with each outcome.

[5] The coalition formation model is currently only implemented for three players. Scenarios dealing with a new entrant are mimicked by calculating preferences for potential coalitions that could be a starting point for the scenario where a fourth (= new entrant) comes into the market. In this coalition formation model the coalition is then modelled as a single player.

[6] Note it is feasible to generate alternative preference orderings taking other strategic considerations into account, e.g. strategies such as “battle the market leader”, “avoid collaborations with No. 2”, “exclude the challengers”, cost leadership. We briefly illustrated this in [17].

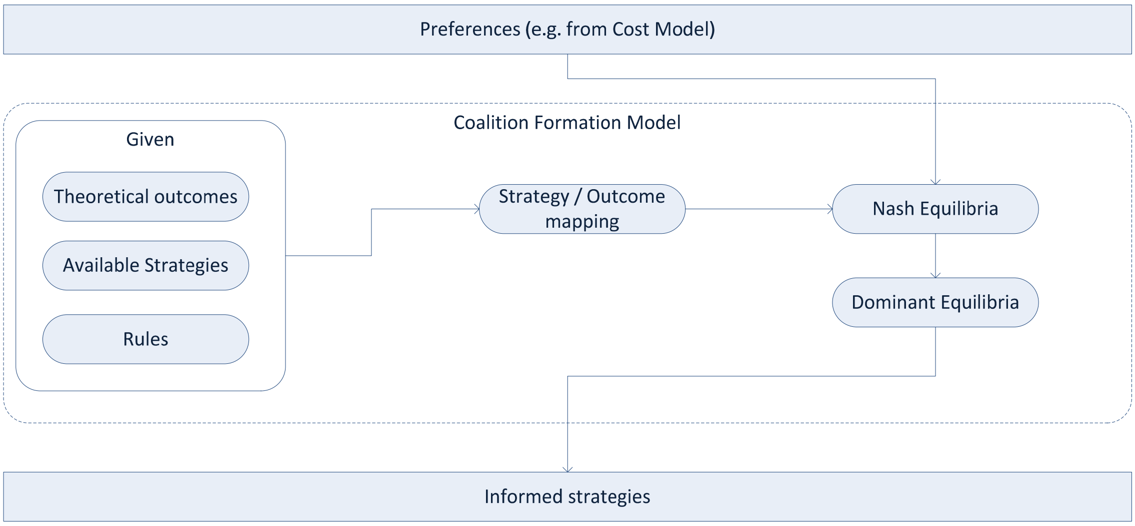

Figure 7: Overview of coalition formation model

The list of theoretical outcomes (market configurations) and the available strategies for each of the players are known inputs. Furthermore, the model also implements the rules for determining the outcome associated with each of the strategy combinations (30^3). As mentioned earlier in this chapter; the combination of strategies and outcome is deterministic (as it is in a card game).

We developed an algorithm that determines for each strategy combination whether the associated outcome is *not* a Nash equilibrium, by systematically checking whether the outcome associated with a single strategy change of one of the players leads to a better outcome for that player. If so, then the outcome is not a Nash equilibrium. Since multiple combinations of strategies lead to a single outcome, we keep track of outcomes already marked as not being an equilibrium (until the last check, all other outcomes are candidates).[7]

Table 8: Ranking of potential coalition formation outcomes from the perspectives of the participating market players K, V and T

Configuration	**K**	**V**	**T**	**Stability**
(KT,V,KT) rural RAN	21	26	21	1
(KV,KV,T) rural RAN	20	21	26	1
(KV,KV,X) rural full	15	15	34	0
…	…	…	…	…
(X,VT,VT) rural RAN	33	18	18	0
(K,V,T)	25	25	25	1

Some equilibria strictly dominate others. This means that the dominant outcome is equivalent to or preferred over the dominated outcome for all players. The dominated

[7] Note that this algorithm is not very efficient. It is beyond the scope of this study to improve this.

outcomes could be avoided by the players as better outcomes exist. We developed an algorithm to classify the Nash equilibria accordingly, by checking for each outcome if any other outcome is ranked equally or higher for each of the players (while keeping outcomes that are dominated out of the loop).

In Table 8 the column on the right indicates the stability of the equilibrium: 2 means the equilibrium dominates others (not applicable in this list); 1 means it is an equilibrium, but dominated; and 0 means it is not an equilibrium.

From the example outcome above it cannot be said that coalition (KT,V,KT) Rran is better than (KV,KV,T) Rran.

We developed a coalition formation model that provides users information on the possible market configurations that can appear if sharing is allowed in an oligopolistic market. The added information is whether the outcome is a Nash equilibrium and to what extent this equilibrium is dominated. Furthermore it provides the users a set of strategies associated with each configuration. This type of information is useful to MNO strategists in considering sharing as well as to regulators in ex ante evaluation of sharing policy.

3.2.6 Analytical approach

We deployed the models described above in the work of this deliverable. We analysed a scenarios of an oligopoly of three present players K, V and T with respectively 50%, 30% and 20% market share. For each of the players we calculated:

- Costs;
- Their preference order based on absolute cost level;
- Their preference order based on relative cost level (to tie-break outcomes with equal cost levels and to represent preference for outcomes that have a better competitive edge).

We determined the “likely” outcome(s) using the coalition formation model. Although the cost analysis already revealed that the full coalition of K, V and T sharing was strictly dominant, we felt the need to consider what was beyond, because such a full share definitely will raise questions both from a regulator perspective as well as a practical perspective. A three party coalition is much harder to achieve than a two party in terms of negotiation and contractual aspects. Therefore, we marked the VT coalition (second and third in the market) to compete with the largest one K also as a likely outcome (KV,T and KT,V were are also likely).

We took these outcomes as an analytical starting point for the scenario in which a new entrant joins and directly acquires 10% market share (and K, V and T decrease proportionally). For this four player market we calculated the cost levels for each player and for each configuration. Since only a three player implementation of the coalition formation model was at our disposal we mimicked the VT coalition as a single player (with 45% market share) and inspected what equilibrium information we got from the coalition formation model. We saw that there is a reasonable chance that the new entrant would be excluded from a big KVT coalition (a big entry barrier), however Kn,VT and K,VTn can also be marked as likely.

We repeated this sequence also for a more “flat” scenario in which both K and V start off with 42,5% market share and found no new insights.

In this chapter we introduced the theoretical concepts and implementation of the cost model and the coalition formation model that are used to underpin part of the analyses performed within scope of this document. Although a fair deal of assumptions is required to operate these models we feel that the approach is valid and can be made to support ex ante evaluation from both a business and regulator’s perspective.

4 Description of full sharing scenarios

In this chapter we describe the scenarios that we will consider in our evaluation. All scenarios are full sharing scenarios, in which both the RAN infrastructure and the spectrum are shared. In separate SAPHYRE deliverables, scenarios in which only the spectrum is shared [3] and in which only the infrastructure is shared [4] are described.

4.1 Market description

In order for our evaluation method – specifically the model described in Section 3.2 – to work well, we need to specify certain key characteristics of the market. They are listed in the table below.

Table 9: Key characteristics of the market that we study in our evaluation.

Characteristic	**Description**
Market situation	Three operators have existing 2G and 3G businesses and want to deploy LTE. In our methodology we will only consider the LTE deployment and assume that the 2G/3G business is left untouched.
Market structure	Two market structures are considered: • Shares of 50%, 30% and 20% • Shares of 42.5%, 42.5% and 15%
Spectrum	The LTE network(s) are deployed in the 800 MHz band (i.e. 3GPP Band 20, see Table 5.5-1 in [22]), in which the operators have obtained licenses of 2x 10 MHz channels each. We consider this to be a typical outcome of spectrum licensing procedures in Europe, as it was the case in Italy [23], Germany [24], Sweden [25] and Spain [26].
Reference scenario	Our reference scenario (to which we will compare the sharing scenario) is the scenario in which there are three operators that do not share spectrum and network. Each operator deploys LTE independently from the other.
Sharing scenarios	The technical characteristics of the sharing scenarios to be evaluated are described in the subsections below. Generally, we consider all possible sharing coalitions in the three party market. Additionally, in order to analyse the effect of sharing on the barriers to entry, we also consider the entry of a fourth market player.

4.2 Sharing in a Multi-Operator Core Network

The Multi-Operator Core Network scenario is illustrated in Figure 8. It is standardised in 3GPP specifications such as [27]. Each operator contributes spectrum and carries a part of the investment costs of the network. The core network and service platforms are not shared, i.e. owned and operated independently.

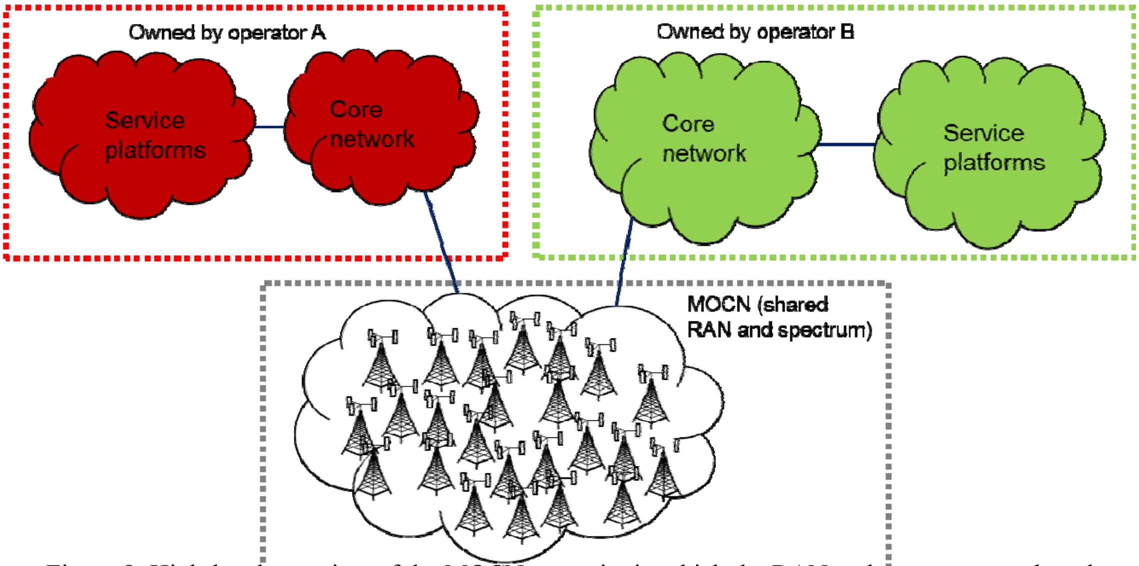

Figure 8: High-level overview of the MOCN scenario, in which the RAN and spectrum are shared

Reasons for considering the Multi-Operator Core Network sharing solution in our analysis are:

- MOCN is a full sharing solution, i.e. it combines RAN sharing with spectrum sharing, and is therefore fully within the scope of this deliverable.
- It is a credible solution as it is already fully specified in standardisation and available from a range of network providers. It appears that the solution is even already implemented in commercial network deployments such as in Hong Kong [28] and Sweden [29].
- The fact that the solution is already standardised reduces the amount of speculation required in our scenario definition about technical characteristics.

In order to focus our analysis, we have tried to reduce the degrees of freedom in our scenario specification to the minimum. We retain two degrees of freedom which have specific relevance for the study of sharing: the operating/ownership model and the pricing mechanism. Another degree of freedom, the geographic extent of sharing, leads to the definition of a separate scenario. This is explained in. Table 10.

Table 10: Degrees of freedom in our MOCN scenario

Option	**Choices**
Geographic extent of sharing	Options to include in our analysis are: a) **National sharing**, i.e. the MOCN solution is applied for the full geographic extent of the network b) **Rural sharing**, i.e. the MOCN solution is applied for "rural" areas, while the sharing operators deploy their networks independently in all other ("urban") areas. This option is elaborated as a separate scenario, described in Section 4.3.
Operating/ ownership model	Various options are possible here: a) **Joint venture** (JV), i.e. the sharing operators initiate a joint venture in which each owns a share. The joint venture builds, operates and owns the network. b) Operating/ownership split. The sharing operators define operating responsibility and ownership per part of the network. c) Third party, i.e. a third party builds, operates and owns the network and receives fees from the sharing operators for use of the network. A specific version of this operating model is described in Section 8 of the SAPHYRE Deliverable D5.3 [3], which specifies the spectrum broker as the real-time "operator" of the spectrum. Note that a third party model allows for multiple resource allocation mechanisms. As the default option we select the first option (JV).
Pricing mechanism	Various options are possible here, including: a) **Cardinal split**, i.e. the sharing parties divide network costs evenly over the partners. b) Pay-per-use, i.e. the sharing parties divide network costs in proportion to actual usage. The price of a resource is then determined with hindsight. c) More advanced models in which the price is determined by auctions or on a spot market. This corresponds to the scenarios described in Sections 8 and 9 of the SAPHYRE Deliverable D5.3 [3]. As the default option we select the first one (cardinal split). We assume the plain three player market. Although more advanced business models and even new roles may be introduced, this would not affect the total amount of equipment required and thus 'only' imply a shift of costs and benefits.

This means that for other parameters we will have to make choices. Specifically, we assume that the full spectrum is shared for the new technology that is rolled out. The reason for this is that this would be the most extreme case and therefore the most interesting both in terms of the benefits as well as concerns associated with sharing. Also, we are not aware of current features in the MOCN standard that would easily accommodate partial spectrum sharing, which raises doubts whether there are technical issues and whether it is of interest to the market. Note that while we consider full spectrum sharing for the new, LTE network, we do not consider the legacy networks (2G, 3G). These could therefore be assumed to be without sharing.

Thus, our scenario loosely corresponds to the scenario described in Chapter 6 of the SAPHYRE Deliverable D5.3 [3] with the addition of RAN sharing and the specification that the full spectrum is shared.

An implication of full sharing (RAN and spectrum sharing) is that sharing operators will in principle be using the same sites and base stations. Theoretically, it is still possible for one of the sharing operators to place a base station independently of the others. However, given the fully shared spectrum, special arrangements are required to prevent harmful interference. These arrangements could be that i) the special base station is simply fitted into the shared RAN even though only one operator financed it or ii) a special spectrum management approach is chosen where in the area of this base station only part of the spectrum is shared. Because these arrangements look rather exceptional, for sake of simplicity we assume that no dedicated base stations exist, i.e. all base stations are shared.

4.3 Rural sharing in a Multi-Operator Core Network

This scenario applies exactly the same characteristics as the "national MOCN" scenario described in the previous section in rural areas. In urban areas the sharing operators are deploying independent networks. The scenario is illustrated in Figure 9.

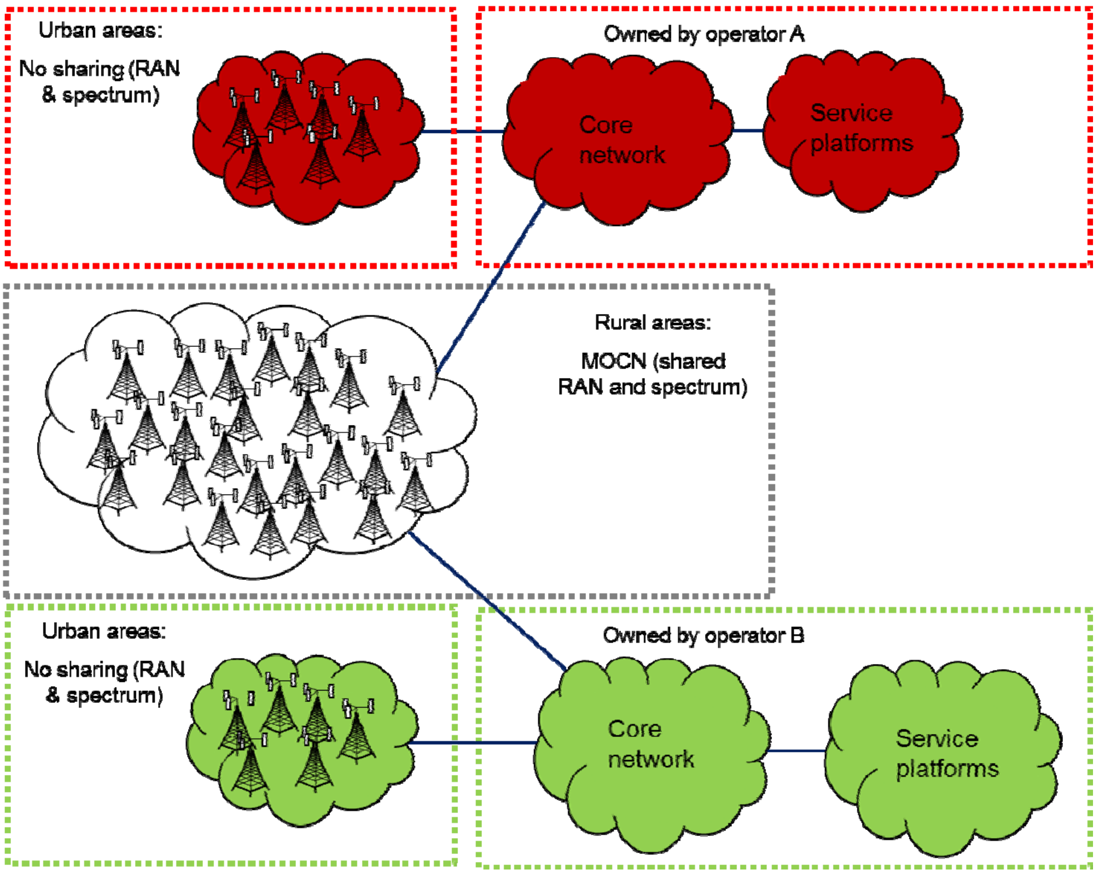

Figure 9: High-level overview of the rural MOCN scenario, in which the RAN and spectrum are shared only in rural areas

In this scenario, no sharing occurs in urban areas; the core network and service platforms are also owned and operated independently.

4.4 Sharing in a Centralised RAN

C-RAN is a novel RAN architecture, in which most of the processing functions are moved from the base station site to a central unit (CU) that serves multiple sites. The architecture has been described in the SAPHYRE Deliverable D5.4 [4]:

> *Centralised RAN was firstly defined in [30] as a novel vision for a RAN architecture where the processing traditionally performed in the base stations is moved into a central unit (CU), and connected via high-speed links to spatially distributed transmission points (TP). At the CU real-time centralisation techniques are used to enable resource virtualisation with the goal of reducing the total energy consumption and hardware usage. This vision corresponds to a novel intra-operator sharing solution. As a matter of fact the BBU in the pool are shared between different sites (and eventually different RAT), allowing dynamic loading as a function of the user distribution and traffic volume.*
>
> *The benefits of this vision are clear: an operator could use an intelligent network deployment, by dynamically assigning one of more transmission points to some processing resources in the central unit, as a function of the load. Moreover, the site-footprint would be reduced. Cooperative MultiPoint (CoMP) techniques could be used to coordinate the transmissions from/to different TP, in order to improve the user experience.*
>
> *On the downside, Centralised RAN has some technical challenges that still require some major efforts to be solved. For example, the need for a real-time base band processing could limit the dimension of the coordinated area. The availability of dark fibre is a requirement that could limit Centralised RAN based deployments to only in some specific regions.*

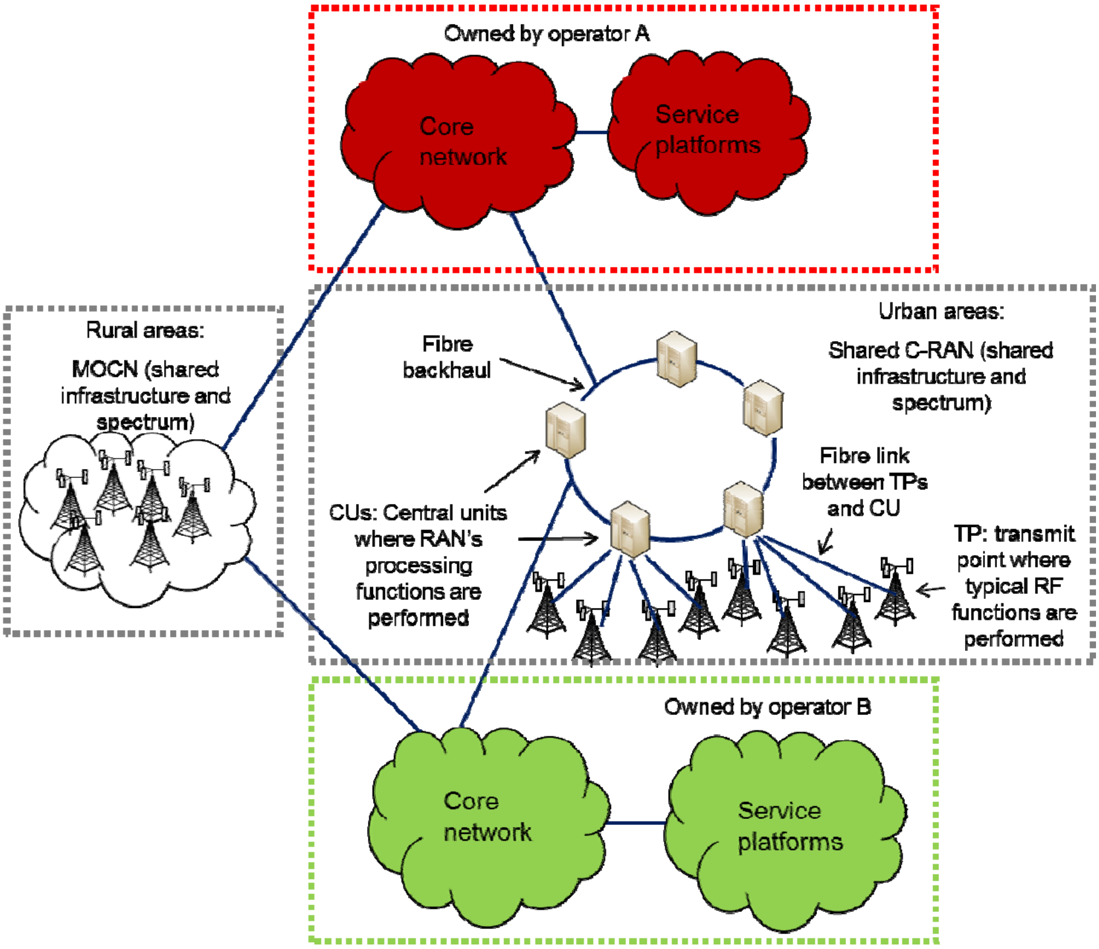

Figure 10: High-level overview of the shared C-RAN scenario in which the RAN and spectrum are shared

In this scenario each operator contributes spectrum and carries a part of the investment costs of the network. In areas with high traffic load (typically urban areas) the C-RAN architecture is deployed. Other areas are served over the MOCN scenario as described in Section 4.2. The core network and service platforms are not shared, i.e. owned and operated independently.

For the analysis in this document, we assume that the C-RAN architecture is deployed in areas with high traffic load (typically urban areas). For other areas, where the C-RAN architecture may not be economically attractive due to the high costs associated with fibre deployments over such large areas, we assume that a classical RAN architecture is used. This architecture is called "distributed" in the above mentioned SAPHYRE Deliverable D5.4. In those areas, we assume that the operators are still sharing their network and spectrum, effectively using the same MOCN concept as described in the previous section.

4.5 Not selected: relaying nodes and CoMP

In order to focus our analysis, we have decided to limit our analysis to a maximum of three technical concepts. This means that not all of the technical concepts could be studied. Specifically, we will not consider:

1. Relaying nodes. In the SAPHYRE Deliverable D5.1b [1] we decided that the scenario in which relaying nodes and spectrum are shared would be of lower priority for the following reasons:

   First of all, SC1b does not provide the cost-saving potential of sharing as it only shares the network elements that are most low-cost. Base stations constitute a much larger part of the overall network CAPEX than relaying nodes. At the same time SC1b does have the same or similar challenges arising from sharing as SC1a, like technical complexity and lack of QoS differentiation. Based on these considerations we decided to give a low priority to this scenario.

   System level simulation results on simplified relaying scenarios with shared relays are available from WP4. However, they are not yet mature enough to perform a solid analysis. This forms an additional reason for not considering the shared relaying nodes in our analysis.

2. CoMP. We do not consider CoMP for the following reasons:

   a) We anticipate that the introducing CoMP in a MOCN scenario does not introduce additional sharing issues or benefits (it only introduces an efficiency gain).

   b) CoMP is now being drafted in 3GPP standardisation. What we would need for the inclusion of CoMP into this deliverable is multi-operator network and spectrum sharing requiring two additions to the current standardisation activity: multi-operator sharing and spectrum sharing. This makes the scenario a very long-term scenario. We already consider a long-term scenario (C-RAN) which is preferred over CoMP because it has been studied explicitly in the frame of SAPHYRE [4] which provides solid basis for the analysis.

5 Evaluation of full sharing in national MOCN sharing

In this chapter we evaluate the national MOCN sharing scenario based on the criteria described in Section 3.1. As indicated in our method description (Chapter 3) we will compare the MOCN scenario with the reference, non-sharing scenario.

5.1 Dominant positions

The changes in dominant positions in the market resulting from sharing arrangements are analysed using the coalition formation model. First, the model is used to determine the sharing arrangements that the three operators prefer in the absence of regulatory intervention. Then, the HHI index in the resulting market is computed to obtain an indication of the level of concentration in the market. Figure 11 shows the results from the model. In addition to the HHI values, the figure also shows the effect of sharing on the average cost level in the market.

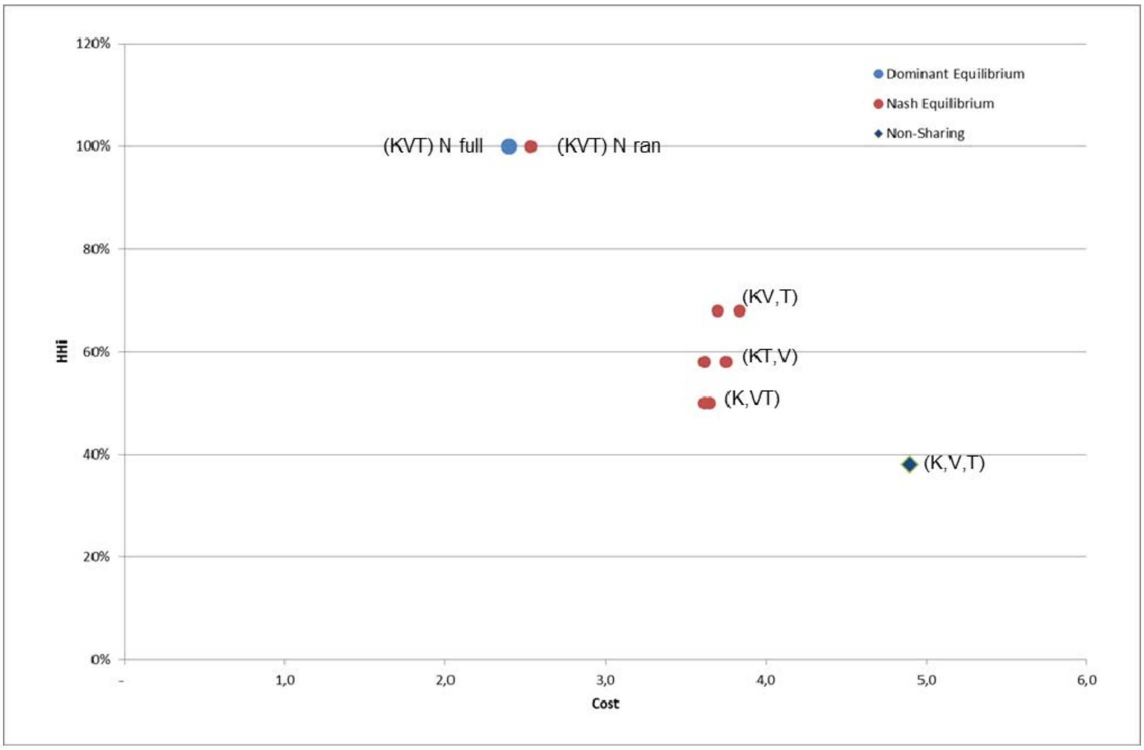

Figure 11: National MOCN sharing coalitions indicated for the three operator market

The model indicates four stable potential coalitions. (KVT) is the most comprehensive coalition with three sharing operators. This is also a dominant equilibrium, i.e. all three operators prefer it over the other stable coalitions. Then, there are three stable collations in which two of the three operators share: (K,VT), (KT,V) and (KV,T). The non-sharing situation (K,V,T) that serves as the reference scenario is also a stable coalition. For comparison, the figure also shows the stable coalitions that are indicated for RAN sharing, a more limited form of sharing in which spectrum is not shared. It is seen that the coalitions obtained with RAN sharing and full sharing are the same, with a slightly lower cost level for full sharing.

Not surprisingly, the lowest cost per subscriber is achieved in the most comprehensive sharing coalition (KVT). This coalition also has the maximum degree of concentration (and hence the maximum HHI value). The two operator sharing coalitions have lower HHI values and higher costs. In the remainder of the analysis, we restrict our analysis of the two operator sharing coalitions to (K,VT) and do not consider the (KT,V) and (KV,T) coalitions as their HHI values and costs are relatively close to those for (K,VT). Compared to the non-sharing reference case (K,V,T), all sharing coalitions lead to lower average market costs and higher HHI values. The results thus point at a trade-off between the degree of market concentration that is accepted and the cost reduction that is achieved. At the level of the policy objectives (Section 3.1), this corresponds to a trade-off between *"ensuring that there is no distortion or restriction of competition in the electronic communications sector…" and "promoting efficient investment and innovation in new and enhanced infrastructures …"*.
Note that the (K,VT) coalition and also the non-sharing reference scenario (K,V,T) show HHI values well above the 25% and should therefore be considered as concentrated. This is an intrinsic characteristic of a (wholesale) market with two or three operators. Still, it is relevant to see that the increase of the HHI value when moving from (K,V,T) with HHI = 38% to (K,VT) with HHI = 50% is relatively small compared to the further increase caused by the move to (KVT) with HHI at its maximum value of 100%.

5.2 Barriers to entry

The coalition formation model is also used to analyse changes in barriers to entry. The aim is to predict the effect of sharing in the three operator market on the entry barrier experienced by a fourth, new entrant operator. As a measure for the entry barrier, we use the costs per subscriber per year of the new entrant relative to the average cost per subscriber per year of the three existing operators. This measure captures an important effect of sharing among existing operators on new entrant, as the sharing increases the economies of scale advantage that existing operators already enjoy. We use the two stable coalitions in the three operator market from the previous section as starting points for the analysis: (KVT) and (K,VT). The reference scenario is again the non-sharing situation, in which the new entrant joins a market with three existing, non-sharing operators. Figure 12 shows the results for the entry barrier, together with the average cost in the market. The model indicates a dozen stable coalitions, some of them relating to other starting points than the two that we focus on in our analysis.

Starting from the comprehensive sharing coalition (KVT), the (nKVT) coalition can be reached in which the new entrant joins the existing coalition and a four way sharing arrangement is achieved. This coalition is a dominant equilibrium, i.e. all four operators prefer it over the other stable coalitions, again in the absence of regulatory intervention. The (n,KVT) coalition is not stable. In this coalition, the new entrant faces a formidable entry barrier as he does not share that cost benefit enjoyed by all of his competitors. As a result, the new entrant prefers not to invest, i.e. (x,KVT), over the option to invest while competing with a three way sharing coalition (n,KVT).

The (nKVT) coalition brings a relatively low entry barrier and the lowest average market costs. The entry barrier is low as the new entrant can enjoy the same economies of scale in network infrastructure as the existing operators that he joins in the sharing arrangement.

Obviously, this coalition inherits the maximum degree of market concentration from the comprehensive sharing coalition (KVT) in the three operator market.

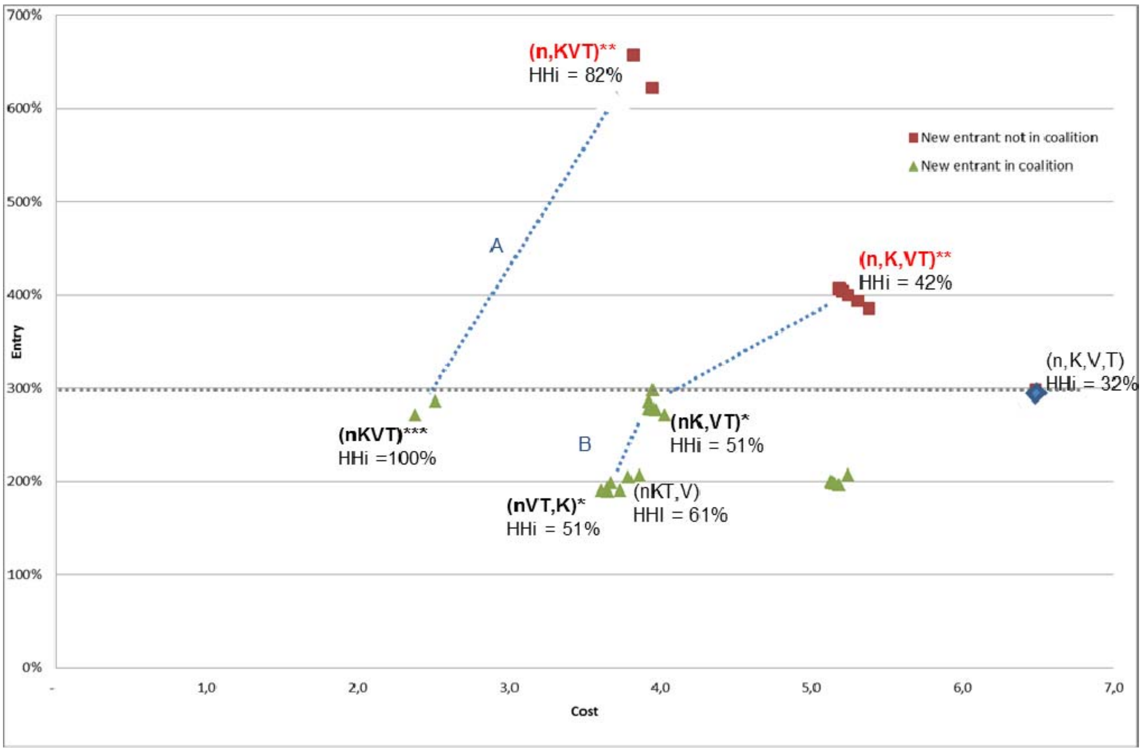

Figure 12: National MOCN sharing coalitions indicated for a new entrant in the market with three existing operators. The y-axis displays the entry barrier measure as defined in the text: costs per subscriber per year of the new entrant relative to the average cost per subscriber per year of the three existing operators. *** coalition is a dominant equilibrium, ** coalition is not stable (new entrant prefers not to invest), * stable equilibrium, **…A** coalitions derived from (KVT), **…B** coalitions derived from (K,VT)

Starting from the (K,VT) coalition, the model indicates three stable coalitions: (nVT,K), (nK,VT) and (nKT,V). The (n,K,VT) coalition is not stable: the new entrant prefers not to invest if he is not in a position to join a sharing arrangement. The three stable coalitions have much smaller HHI values than the comprehensive sharing coalition, but they still point at a large degree of concentration in the four operator market.

The non-sharing reference scenario (n,K,V,T) has an entry barrier for the new entrant of 300% and an average market cost of 6.50 Euro per subscriber per year. As expected, all sharing scenarios lead to lower average market costs, thus contributing to the policy goal of *"promoting efficient investment and innovation in new and enhanced infra-structures ..."*. Furthermore, it is seen that in order to come to an entry barrier below the non-sharing value of 300%, it is required that the new entrant is able to enter an existing sharing coalition. Stated otherwise, sharing will lead to a higher entry barrier if the new entrant is not in a position to join an existing coalition. The figure also shows that if the new entrant joins an existing coalition, his entry barrier may also be reduced substantially, e.g. from 300% to 200%, depending on the coalition he joins.

5.3 Service homogeneity

The service homogeneity increases in the national MOCN sharing scenario in comparison to non-sharing, in the following ways:

- The radio planning is shared, except for base stations that are added by individual operators. In a national MOCN scenario, such base stations are expected to be the exceptions, otherwise the advantages of MOCN are removed. In the case that the full spectrum is shared, a base station of an individual operator creates a white spot in the coverage of the partner operator networks. This practically rules out non-shared, individual-operator base stations.
- The individual operators can determine the QoS parameters for their services by choosing the parameter settings from the range available in the network. In the shared network, the quality and performance perceived by customers of one operator are influenced by the QoS policies of the other sharing operators. The coordination between operators that is needed for defining the QoS parameter settings that are available in the network may lead to comparable business rules.
- The operators can still set their own retail prices, although the underlying costs are the same for the shared portion of the network. The sharing operators may gain insight the future evolution of their competitor's cost in the sharing arrangement. Thus, the sharing brings the risk of coordination of prices and marketing strategy. It should be noted that this risk already exists independent of sharing arrangements.

Other areas are not affected by the national MOCN sharing:

- Value-added services by operators, e.g. voicemail, are generally not linked to the RAN. Homogeneity in this area is therefore not reduced. However, value-added services by operators are of decreasing importance anyway as customers increasingly use Over-The-Top (OTT) services from app stores rather than operator services.
- Certain important network innovations such as Wi-Fi off-loading can be determined by individual operators, also in case of MOCN sharing.

A key question here is to what degree the RAN – and not other assets, services or products – are used by operators to differentiate their propositions to customers. In propositions based on existing RAN technologies, the differentiation based on RAN is rather limited compared to for example other factors such as pricing or terminals. Note that a new generation of technology can increase the importance of RAN as it leads to an increased marketing attention to RAN technology. For example, the introduction of 4G in the USA has led to much marketing centred around RAN technology.

5.4 Efficient use of spectrum

Spectral efficiency gains occur mainly in urban areas, where spectrum is relatively scarce due to the relatively large demand for capacity. This gain results from the "trunking gain", i.e. the fact that an increase in spectral resources yields an above-proportional increase in the corresponding traffic handling capacity. Spectral efficiency gains of 10% could provide 10% increase in bandwidth, or a 10% smaller investment in

RAN infrastructure in urban areas. Note that the mentioned figure of 10% is assumed as an input scenario variable for analysis. Currently a study on quantifying this aspect is ongoing within the SAPHYRE project.

In rural areas, the networks are dimensioned for coverage and therefore the efficiency gain is near-zero; for LTE, increased availability of spectrum does not significantly increase cell coverage.

5.5 Cost efficiency

For the RAN, the cost efficiency gain is significant, mostly due to site count reduction. The biggest reduction is achieved by sharing infrastructure (as a reference, in the example market around 1800 sites (coverage and capacity) were required). Spectrum sharing introduces further modest cost reductions due to the increased spectrum efficiency. It is important to note here that the operators incur many other costs than those associated with the RAN: core networks, IT systems, applications and service provisioning, customer support, billing etc. The effect of the RAN cost reduction on the total costs that the operators face is therefore substantially smaller.

5.6 Innovation in networks

Innovation in radio networks may be stimulated by MOCN as the introduction of innovations is less expensive as the costs are shared. Furthermore, the prospects of reaching a critical mass of end users are better, which is crucial for the availability of a variety of suitable handsets.

Innovation in networks may be limited by MOCN sharing in the following ways:

- The incentive to innovate is smaller, as the innovation does not offer a clear differentiator from the sharing partner, but only from the remaining other operators.
- The innovation requires a coordination between sharing partners. This is feasible if the technology roadmaps of the sharing partners happen to be aligned, but it is prohibitive if there are discrepancies between roadmaps. For large innovations, such as the move from 3G to 4G, the sharing coalitions are reconsidered anyway, as can be seen from the history of evolving coalitions in Sweden [31].
- Certain smaller innovations in radio networks, such as the gradual increases in the HSPA capacity are typically introduced as features in 3GPP releases within a mobile technology generation. The initial releases may not be compatible with sharing.

5.7 Emitted power levels

There are several ways in which sharing of infrastructure and spectrum may have an impact on emitted power levels and the discussions surrounding this topic. On the one hand, it may help to reduce reluctance among the public:

- Having less base station sites makes a new technology more acceptable. In this way the site reduction enabled by MOCN sharing contributes positively.

- Power limits are typically set as overall limits for all operators. Coordination among operators enables individual operators to adapt their local individual power limits to the actual power use by the other operators. More coordination of spectrum use among operators enables them to optimise their power use. This means that more traffic can be served while power limits are respected. Network sharing already enables more coordination of spectrum use than non-sharing. Full sharing (including spectrum sharing) enables maximum spectrum use coordination.
- The spectral efficiency gain obtained with MOCN helps to get more performance with the same emitted power.

On the other hand there is also a way in which sharing of infrastructure and spectrum may lead to increased emitted power levels. Site sharing could bring higher peaks in emission, as traffic – which requires transmit power – of multiple operators is handled over a single site. In this way, the implementation of MOCN sharing may be limited by radiation limits. Note that these limits are not the same across regions; even within Western Europe some countries deviate from EU recommendations and impose a more stringent radiation limit regime (for an overview see e.g. [32]).

6 Evaluation of full sharing in rural MOCN

In this chapter we evaluate the rural MOCN scenario based on the criteria described in Section 3.1. The focus in this chapter is on the elements in the analysis that work out differently for rural sharing than for the national sharing analysed in the previous chapter.

6.1 Dominant positions

The changes in dominant positions caused by rural MOCN sharing have been analysed using the same approach as for the national MOCN sharing (Section 5.1). The results are shown in Figure 13. The HHI values in the figure deserve a further explanation. With a combination of sharing in rural areas and no sharing in urban areas, it is difficult to capture the level of concentration in the national market in a single measure. The HHI values in the figure are based on the market shares in rural areas which are affected by sharing. As a result, the values emphasise the concentration in rural areas that results from sharing. In urban areas, the operators still compete based on their own networks. The effects of this urban competition can also spread to the rural areas, for example through the national product offerings and price plans that operators typically have. The values in the figure therefore tend to overestimate the effect of sharing on the concentration in the national market. This should be kept in mind in the interpretation of the values. A different HHI value is obtained if the urban market shares are used. These market shares are not affected by rural sharing and give a constant HHI value of 38%.

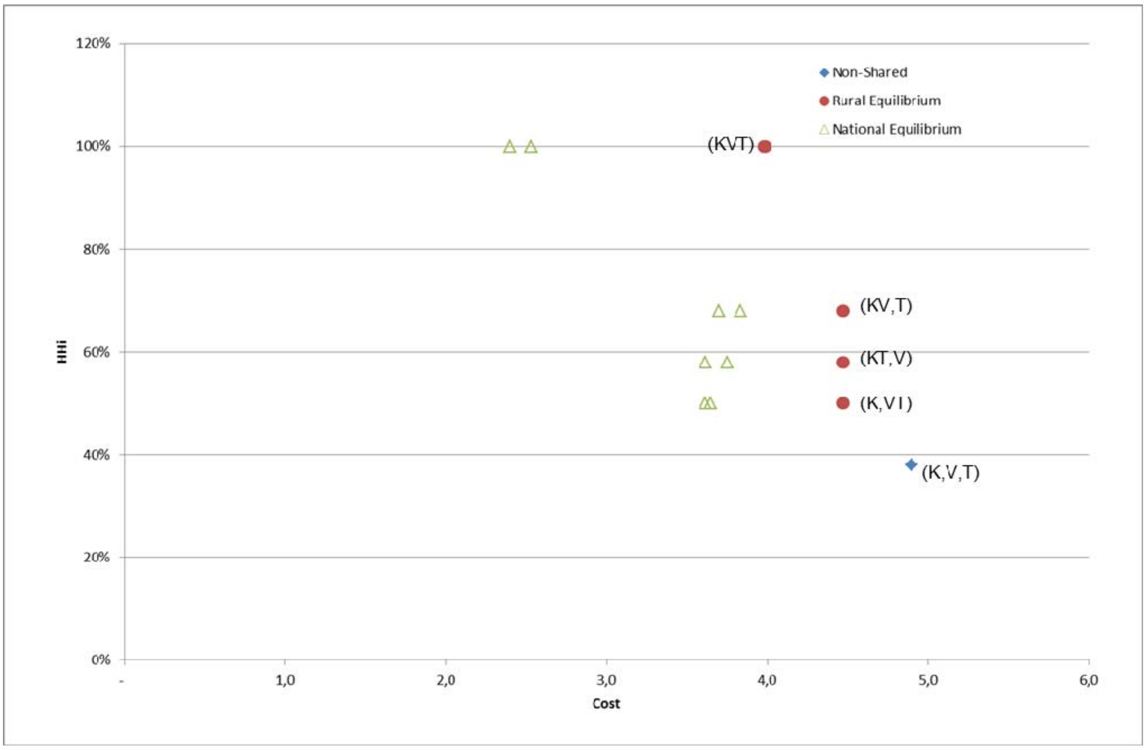

Figure 13: Rural MOCN sharing coalitions indicated in the three operator market (for comparison, the national MOCN sharing coalitions from Figure 11 are also shown)

A first observation is that, as expected, the cost reductions obtained with rural sharing arrangements are smaller than those for national sharing. It is therefore interesting to see that the coalition formation model, that is largely driven by absolute and relative cost reductions, indicates the same stable coalitions as for national sharing. Again, the (KVT) coalition is dominant. The overall picture that emerges is that rural sharing curbs the effects of sharing: both the benefits, such as lower cost levels, and the drawbacks, such as more concentration. (As noted earlier, the HHI values in the figure overestimate the concentration in the market, except for the non-sharing (K,V,T) coalition.)

6.2 Barriers to entry

Also for the entry barriers, the effects of rural sharing are (much) smaller than those of national sharing. This is readily seen in Figure 14: the box with label "C" contains the indicated coalitions in the four operator market. Figure 15 shows the precise locations of the coalitions within the box. The picture is qualitatively the same as for national sharing, but the differences in entry barrier and costs are much smaller. It is interesting to see that entry barriers of 330% and 370%, i.e. not much higher than the non-sharing value of 300%, already lead the new entrant to a decision not to invest if he is not in a position to join an existing sharing arrangement.

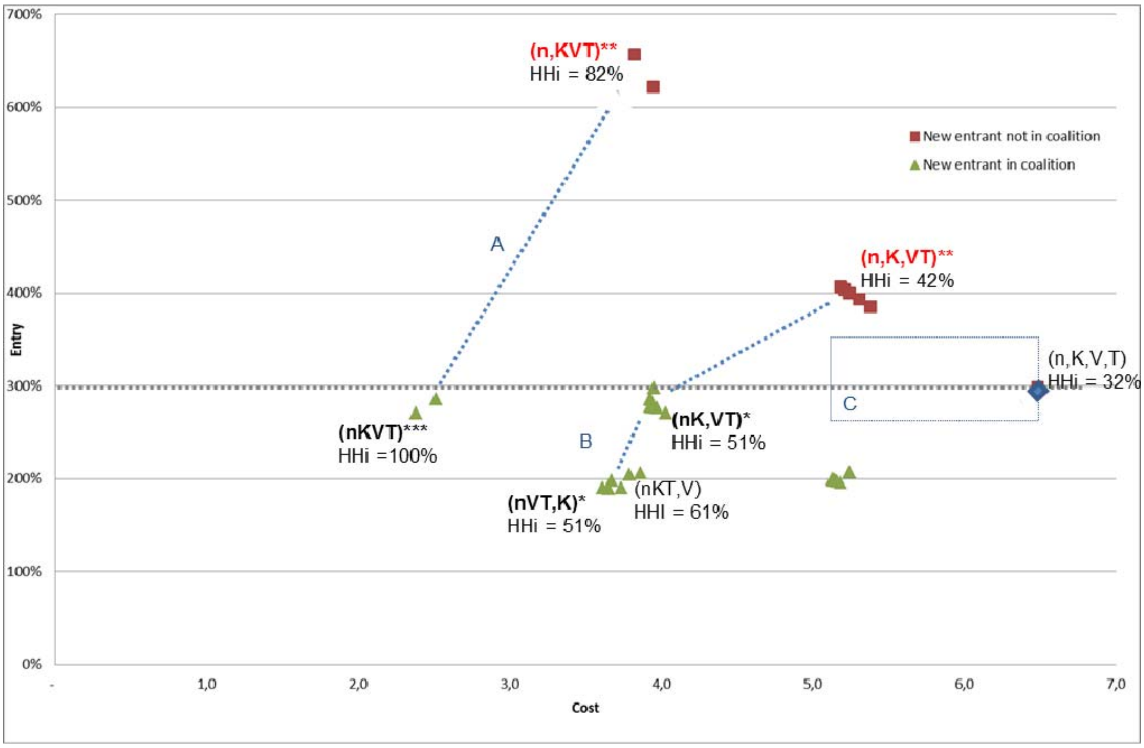

Figure 14: Rural MOCN sharing coalitions indicated for a new entrant in the market with three existing operators: the position of box "C" containing coalitions relative to national MOCN sharing coalitions. *** coalition is a dominant equilibrium, ** coalition is not stable (new entrant prefers not to invest), * stable equilibrium

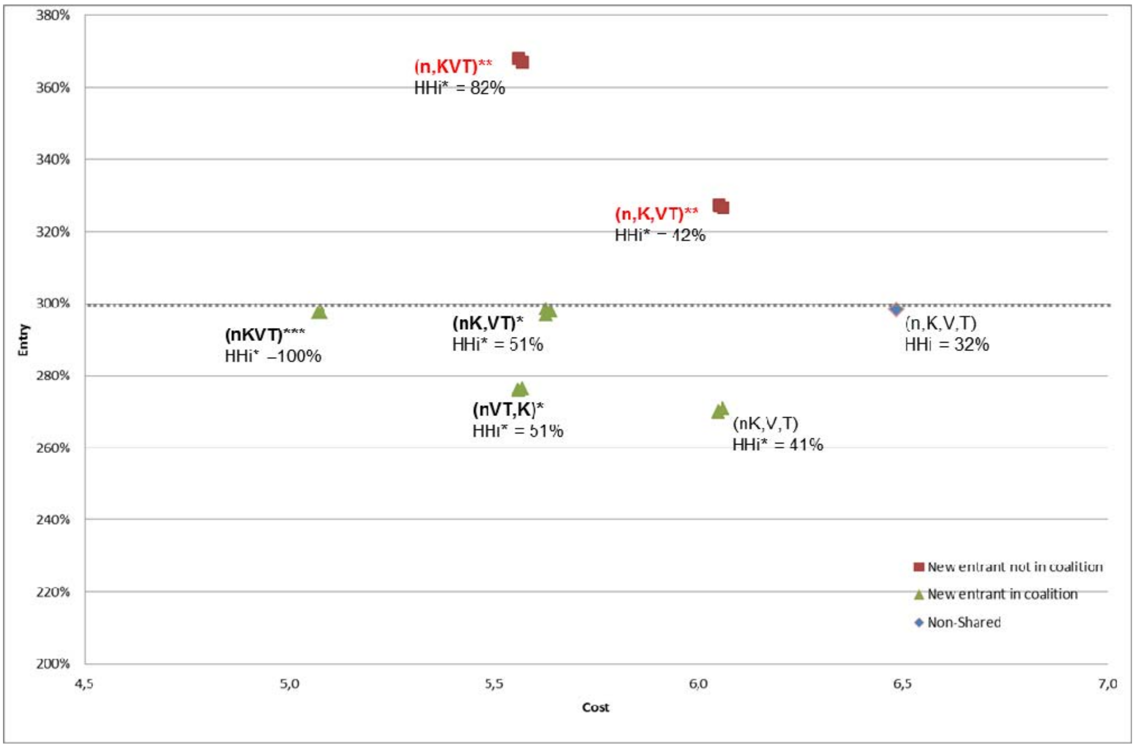

Figure 15: Rural MOCN sharing coalitions indicated for a new entrant in the market with three existing operators: detailed positions of coalitions within box “C” from Figure 14. *** coalition is a dominant equilibrium, ** coalition is not stable (new entrant prefers not to invest), * stable equilibrium

6.3 Service homogeneity

Compared to non-sharing, rural MOCN sharing leads to more homogeneity in services.

- The radio planning is shared in rural areas, except for base stations added by individual operators. Just as in the national MOCN scenario, such base stations are expected to be the exceptions in rural areas, otherwise the advantages of MOCN are removed. In urban areas, radio planning remains completely independent.
- In rural areas, the quality and performance perceived by customers of one operator are influenced by the QoS policies of the other sharing operators. The coordination between operators that is needed for defining the QoS parameter settings that are available in the network may lead to comparable business rules. Typically, the QoS policies employed by operators are focused on prioritisation of subscribers or services. Such prioritisation only has effect in busy or congested cells which are predominantly found in urban areas. The coverage cells in rural areas will seldom be congested and therefore, priorisation will have little effect there. As a result, we expect the level of dependence between operators in the area of QoS differentiation in rural MOCN to be significantly lower than in national MOCN.
- The operators can obviously still set their own retail prices, although the underlying costs are the same for the shared portion of the network. Typically, the operators use national price plans. Through these national price plans, the

effects of competition in urban areas where operators often start the roll-out of with networks upgrades spread to the rural areas.

- The insights that an operator has into his sharing partner's cost base is also limited as the sharing is only done in rural areas. Thus, only part of the RAN cost base is known. Furthermore, the insight into the partner's network technology roadmap is limited because the operators typically start their network upgrades in urban areas. When the partner wants to upgrade in rural areas as well, the upgrade is already functional in urban areas and known to the sharing partner. Therefore, rural sharing brings only modest scope for (passive) coordination of prices and marketing strategy.

6.4 Efficient use of spectrum

In rural areas, the networks are dimensioned for coverage and therefore the efficiency gain is near-zero. In addition, spectrum sharing does not significantly increase cell coverage and therefore has no effect on the number of cells that need to be built.

6.5 Cost efficiency

Rural sharing brings a cost efficiency gain. In the computation for the Netherlands, with relatively few rural areas, the cost efficiency gain is rather modest. In other countries with lower population densities and more rural areas, the cost efficiency gain is expected to be higher, although not as high as in the national sharing case.

Another factor limiting the cost reduction is that with rural sharing, each operator has two networks that need to be managed: the rural network that he manages in collaboration with his sharing partner and his own urban network.

6.6 Innovation in networks

When operators introduce network innovations in the non-shared urban areas first, the effect of rural MOCN sharing on innovation in networks is small. In essence, the sharing partners can independently introduce their own innovations including:

- Innovations that happen not to be on the sharing partners roadmap. Note that there is no need for exchange of information on the technology roadmaps for the urban networks of the sharing partners. Therefore, the sharing partners are not aware (and also should not be aware) of the other partner's roadmap.
- Innovations that are not suitable for sharing yet in the initial releases of 3GPP standards or vendor roadmaps.

In rural RAN sharing the incentive to innovate is larger than in national RAN sharing, as the innovation at least initially offers a clear differentiator from the sharing partner in urban areas. The issue of alignment of the RAN technology roadmaps becomes relevant when the further roll-out to the rural areas is planned. By that time, the benefits of the innovation for network capacity and retail service offerings has become clear. Innovations that have proven to be successful in urban areas are likely to be on the roadmaps of both (or more) sharing partners.

6.7 Emitted power levels

As in the case of national sharing the site count reduction enabled by MOCN sharing can make the roll-out of the network more acceptable to the public. In the area of emitted power levels rural MOCN sharing is similar to national MOCN sharing.

7 Evaluation of full sharing in C-RAN

In this chapter we evaluate the C-RAN scenario based on the criteria described in Section 3.1.

In the SAPHYRE Deliverable D5.4 [4] cost savings for an urban C-RAN deployment have been computed in a worst case and best case. These normalised cost savings are indicated in the table below.

Table 11: Normalised cost savings for C-RAN as derived in the SAPHYRE Deliverable D5.4 [4]

		Normalised CAPEX	**Normalised OPEX**
Worst case (Figure 1 in [4])	distributed ("classical")	59	63
	C-RAN	60	64
	relative fraction C-RAN vs. classical	102%	102%
Best case (Figure 2 in [4])	distributed ("classical")	28	68
	C-RAN	21	47
	relative fraction C-RAN vs. classical	75%	69%
Best guess	relative fraction C-RAN vs. classical	88%	85%

Thus, the C-RAN costs lie in the range of 75–102% (CAPEX) and 69–102% (OPEX). Note that this is based on an analysis of a network consisting of 271 base stations connected to a single central unit. We are assuming that urban areas are covered by {coverage_sites} + {market_share} × {capacity_sites} = 212 + {market_share} × 318 base stations. Thus, the number of base stations does not deviate too much from the number that is used in [4]. However, the number of central units will typically be higher than 1 in our study, because the distance between base stations and the central unit is limited to a few tens of kilometres (20–40 km as a fundamental maximum according to [30]) and we analyse an entire country consisting of multiple geographically separated urban areas. Given that a central unit typically costs as much as three sites (as assumed in [4]) we assume that per central unit 1% of the costs should be added. Thus, assuming that 10 urban areas are to be covered, 10% needs to be added to the C-RAN costs in the table above. This leads to a range of 85–112% CAPEX and 79–112% OPEX.

7.1 Dominant positions

Although the C-RAN sharing scenario is different from the MOCN sharing scenario discussed in Chapters 5 and 6, we can use the model-based analysis presented for MOCN and extrapolate to C-RAN. The main changes that C-RAN introduces are:

- The C-RAN concept is applied in urban areas, presumably leading to cost savings with respect to a "classical" RAN. As described above, the relative costs of C-RAN lie in the range of 85–112% CAPEX and 79–112% OPEX. If we would take the average of these range bounds, we end up with relatively minor cost savings (2% CAPEX, 5% OPEX reduction).

- C-RAN may introduce more degrees of freedom for sharing operators, as will be highlighted in Section 7.3. Thus, the “homogeneity markup” will be lower for C-RAN. Note however that this reduction is limited because the C-RAN concept is introduced only in an urban environment.

Thus, the changes to the analysis in Chapters 5 and 6 are of a second order, and will not qualitatively change the observations.

What may however change is that a C-RAN may create a natural opportunity for a third party operating the central unit. We can see a similarity with the business of a datacentre “hosting” party, that basically sells generic data storage, computing and networking facilities in a datacentre. The central unit is very much like a datacentre, and in the future the tasks performed in a central unit may be generalised in such a way that it may be operated relatively easily by an independent party. The introduction of such an independent third party would help to separate sensitive information of the sharing operators on traffic and capacity forecasts, roll-out plans, roadmaps, etc.

7.2 Barriers to entry

The analysis for the C-RAN scenario on the criterion of “Barriers to entry” is roughly the same as for the MOCN scenario, as network costs are not significantly changed (see above). There is one potential difference in comparison to the MOCN situation: the potentially increased opportunity to have a third party network operator that serves two or more sharing operators. We believe that having such a third party network operator, combined with the increased flexibility of having processing features centralised in the central unit can reduce obstacles to accommodate a new entrant: technical arrangements and the business model for serving multiple operators are already in place.

7.3 Service homogeneity

Homogeneity in the C-RAN scenario is increased with respect to the non-sharing case. Basically, the “service homogeneity” analysis specified for MOCN sharing in Section 5.3 can also be applied to C-RAN sharing. We must note, however, that the increase in service homogeneity for C-RAN sharing is expected to be less than in the MOCN case as C-RAN offers more degrees of freedom for operators who potentially do not need to align on decisions such as:

- The introduction of QoS differentiation by individual operators;
- The addition of capacity on a site.

Note, however, that the extent of this independence between sharing operators remains to be determined; it depends on the technical details of a fully specified C-RAN solution which are not yet available.

7.4 Efficient use of spectrum

C-RAN technology is expected to increase the spectral efficiency as a result of increased interference management possibilities arising from centralising baseband processing in a central unit. The additional spectral efficiency gain from *sharing* a C-RAN deployment is expected to be similar to the spectral efficiency gain arising in a MOCN sharing deployment. We see no reason to assume a different spectral efficiency gain for C-RAN sharing.

7.5 Cost efficiency

As specified in the introduction of this chapter the costs of a C-RAN deployment for the urban areas in our scenario are considered to lie within a range of 85–112% CAPEX and 79–112% OPEX compared with a “classical” RAN deployment. As these costs are comparable cost savings resulting from sharing are expected to be similar to the classical case used in the MOCN scenario. For rural areas the cost savings are exactly those of the MOCN rural case, as our C-RAN scenario applies MOCN sharing in rural areas.

7.6 Innovation in networks

The centralisation of baseband processing functionalities in C-RAN architectures should make it more easy for sharing operators to innovate their networks independently because upgrades to the baseband part of the RAN can be done in one location for multiple base stations at a time.

7.7 Emitted power levels

The analysis of this criterion for the MOCN scenario as presented in Section 5.7 is also applicable to the C-RAN scenario. C-RAN technology as such adds the following advantages to the points mentioned in Section 5.7:

- With C-RAN the equipment that is located on base station sites becomes smaller. This may reduce the reluctance among the general public to accept new base station sites that operators may experience in “classical” RAN deployments.
- Spectral efficiency gains introduced by C-RAN in urban areas (see Section 7.4) lead to a lower transmit power requirement for the same network performance. Thus, local power peaks are reduced.

We note that these two advantages hold for C-RAN technology in general, and not for *shared* C-RAN alone.

8 Overall assessment and discussion

8.1 Overall assessment of full sharing

From an operator's business perspective, network and spectrum sharing arrangements can clearly be attractive. Our cost computations and coalition model point at substantial cost reductions that can be reached. Such cost reductions have also been found in other analyses of sharing, e.g. [32] and [33], further studies are mentioned in [7]. The model also indicates that – with our model assumptions – purely from a cost/benefit perspective (which includes monetised competitive effects) operators indeed prefer participating in such sharing coalitions over the option to individually roll out their RAN. Model assumptions include important aspects such as the considered case (network roll-out with a new technology) and the particular parameter values chosen for parameters such as the marketing fees that should compensate a loss of differentiation in product offerings in case of network/spectrum sharing. Full network and spectrum sharing coalitions also occur in practice, for example in Sweden [34] and the UK [35].

In the absence of any regulatory intervention, the model indicates a comprehensive sharing coalition involving all operators. This aligns with the policy objective of *"promoting efficient investment and innovation in new and enhanced infrastructures"* as the sharing arrangement lowers the costs involved in the roll-out of new generations of mobile network technology. Note that the coalition formation model also includes a mark-up cost for the additional subscriber acquisition and retention effort that operators need to make in the more homogeneous product market that results from the sharing of networks. We have found that competitive effects of sharing (such as losing product differentiation based on unique network characteristics) must be substantial to exceed cost-savings associated with sharing. With our current set of assumptions the network is becoming a hygiene factor: a high-speed, excellent quality network does not bring a significant competitive advantage in the retail service market, but a sub-standard network does bring a competitive disadvantage.

The main trade-off identified in our analysis occurs when the policy objectives of *"ensuring that there is no distortion or restriction of competition in the electronic communications sector, including the transmission of content"* and *"safeguarding competition to the benefit of consumers and promoting, where appropriate, infra-structure-based competition"* are added. A very clear trade-off is seen between the concentration in the wholesale market for RAN connectivity and the average network cost per subscriber. Stated differently, infrastructure-based competition at the level of the RAN comes at a price: a higher average network cost in the market. When looking at the entry barrier, another important aspect of competition, it is seen that in the presence of sharing coalitions, a new entrant prefers not to roll-out over rolling out in direct competition with two or more sharing operators. On the other hand, if the new entrant is in a position to join an existing coalition, the entry barrier can be substantially lower. The preferred option for the new entrant is then to join an existing coalition, thus further increasing the concentration and lowering the degree of infrastructure competition in RAN.

It is important to note that the analysis of concentration is not just about the degree of concentration (measured by the HHI) but also about its consequences. Depending on the technical arrangements, the sharing operators may still be in a position to choose their own approaches for providing service quality to their customers, e.g. by choosing their own QoS parameter values from a set which the sharing partners have previously agreed upon. They may also be able to individually fine tune the coverage they offer to their customers, e.g. through Wi-Fi off-loading. Precise consequences of concentration in the wholesale network market for the level of competition in the retail market can only be determined on a case-by-case basis. This is also true for potential undesired coordination between the businesses of operators that may result from sharing. Sharing inevitably involves an exchange of information between the participating operators, but the consequences depend on the organisational arrangements. For example, in a joint venture between two operators it is inevitable that there is a direct information exchange between the operators, or at least between their wholesale network departments. In a third party arrangement, there is no need for a direct information flow between the operators, as each operator only exchanges information with third party that runs the shared network.

Another important point to note is that the cost benefits from sharing of the RAN and spectrum are rather modest compared to the overall costs for the operators. In our computations for the Netherlands, the cost reduction is of the order of Euros per subscriber per year. However, the operators also incur costs for their core networks, IT systems, applications and service provisioning, customer support, billing, network management and more. Thus, the overall costs incurred by the operators are substantially higher than the costs related to the RAN. Therefore, the impact of the cost reduction on the competition in the mobile market as a whole is smaller than the impact on the (somewhat artificial) wholesale market for RAN connectivity. This is one of the considerations for the Swedish competition authority to allow the Net4Mobility network and spectrum sharing arrangement [34].

We have assumed a 10% efficiency gain resulting from spectrum sharing in our study. This gain will be quantified in a subsequent technical analysis within SAPHYRE outside the scope of this deliverable. This gain by itself aligns with the fourth policy objective taken into account in this study, *"encouraging efficient use and ensuring the effective management of radio frequencies and numbering resources"*.

The emitted power levels in RAN must comply with the limits on maximal field strengths that are imposed by national authorities to limit the exposure of the public to electromagnetic fields. These limits also apply to shared RAN. Our analysis shows that the effects of network and spectrum sharing on the emitted power levels can only be determined on a case-by-case basis. A general observation is that fields strength limits employed in most European countries do not affect the opportunities for sharing. However, there are regions, e.g. Brussels, and countries, e.g. Switzerland, that have adopted substantially lower limits that for many sites effectively rule out site sharing and, as a result, also RAN and spectrum sharing.

Finally, sharing can also touch on discussions on the desired reliability of the mobile broadband infrastructure. Today, many vital business and societal processes are strongly dependent on mobile broadband. Sharing arrangements may reduce the level of redundancy that is offered by multiple independent RAN. On the other hand, carefully designed and dimensioned sharing arrangements can also help to increase the reliability of networks as there may be more scope to develop emergency fall-back mechanisms to ensure service continuity during network incidents.

8.2 Discussion based on what-if scenarios

As explained earlier, this study does not aim to make a judgement on whether certain sharing arrangements are acceptable or not from a regulatory perspective. This judgement is up to the regulators who are in a position to make evaluations on a case-by-case basis after studying the precise sharing arrangement and its consequences. Instead, the goal is to provide insights in the type of considerations that will play a role in a regulator's judgement and the factors that should be taken into account. With this in mind, we present a number of what-if scenarios that illustrate the trade-off and considerations that regulators can encounter when they determine their position towards proposed sharing arrangements.

What-if scenario: Regulator does not allow sharing arrangements that increase the HHI above a specific value

A regulator may want to preserve a certain degree of infrastructure competition at the RAN level by requiring that the HHI value after sharing does not exceed a specific value. Alternatively, a regulator could require a minimum number, for example two, of independent RAN networks. Our modelling results show that this approach has a number of effects:

- A cap on the entry barrier, i.e. future new entrants are protected from potentially very large entry barriers introduced by comprehensive sharing coalitions. This prevents a "no way back" situation in which a new entrant can only enter the market by joining an existing sharing arrangement.
- A cap on the cost reduction that can obtained. As a result, the average cost per subscriber in the market remains higher than the minimum level that could be achieved with more extensive sharing.
- A guaranteed scope for network-based service differentiation, as there are two or more RAN networks. Note that depending on the technical arrangements, operators sharing a RAN may already be able to differentiate in QoS or coverage.
- A path-dependency, as technically and organisationally equivalent sharing arrangements proposed at different times may be subject to different decisions. There is a first-mover advantage: the first sharing coalition has the best chances to be accepted by the regulator. This effect may already occur today [36].

What-if scenario: Regulator declares ex ante that sharing by new entrants will be allowed

A regulator may decide to promote market entry by declaring ex ante, e.g. before a spectrum auction, that he will allow a new entrant to engage in a sharing agreement with an existing operators. This ex ante declaration brings:

- A more predictable regulatory environment for the new entrant. It also brings more predictability for the existing operators. At the same time, it leaves their commercial considerations in the decision whether to share with the new entrant or not untouched.
- Promotion of market entry, potentially at the cost of infrastructure-based competition at the RAN level.

What-if scenario: Regulator requires that sharing arrangements are open to future new entrants

In a further step, a regulator could make it a requirement for sharing arrangements between existing operators that a future new entrant must be allowed to join the sharing. This requirement leads to:

- More predictability in both the regulatory and the business environment for the new entrant.
- Adoption of the existing conditions for sharing by the new entrant. If the new entrant is allowed to demand different technical or commercial conditions then this may lead to a very deep involvement of the regulator in the technical, financial and process arrangements in the sharing. In a first step, the regulator can require the new entrant and the existing operators in the sharing to seriously negotiate on the conditions of the intended sharing arrangement. If the negotiations fail then the regulator would be forced to become more intrusive in the operators' business and determine the technical, financial and process conditions for the sharing. This would be a difficult task, as there are many technical options for sharing. In other areas where a regulator can set conditions after negotiations between market parties prove to be unsuccessful, such as voice interconnection, the technical specifications for the coupling of networks are standardised and the regulator can focus his attention on the commercial aspects such as tariffs.
- Extensive technical and financial dependencies between the sharing operators that some of them may not want to have in the first place, making the role of the regulator very intrusive. For example, if existing parties do not trust the financial robustness of the new entrant and therefore refuse to open their sharing arrangement to that party, the regulator would have to objectively assess such refusals.
- Existing operators might refuse to invest in their networks if they have to share their networks with new entrants.
- The regulator will probably need to closely monitor the cooperation between the operators during the entire life cycle of the sharing arrangement.

What-if scenario: Regulator allows rural sharing only

A regulator may decide to limit sharing to rural areas. Compared to national sharing, rural sharing leads to:

- Smaller cost benefits. The computation for the Netherlands shows that rural sharing brings very modest cost benefits. Most other countries have a lower population density. There, the benefits of rural sharing may still be considerable.
- The effect on concentration is smaller, as the number of operators and hence the level of competition in urban areas is unchanged. The level of competition in urban areas may manifest itself in rural areas as well, as the market for mobile services is typically national and not a regional one. Note that operators typically first introduce technology upgrades in urban areas.

9 Conclusions and recommendations

9.1 Coalition formation model and evaluation criteria

The coalition formation model promises to be a useful tool to evaluate the implications of sharing for the mobile market structure by considering the interdependent strategic alternatives for multiple MNO. It provides the information required to go beyond the well-known qualitative trade-off, such as the one between competition and short/mid-term cost efficiency. In particular, the model sheds light on:

- The preferences that operators have for different sharing coalitions by distinguishing between unstable coalitions, stable coalitions and the dominant coalition (if there is one);
- The effect on entry barriers and the willingness of a new entrant to invest in RAN.

These outputs of the model are relevant for both the operators' business perspectives on sharing and for the regulator's perspective. The key inputs to the model are costs: network CAPEX and OPEX but also the costs incurred for subscriber retention to compensate for a decreased ability to technically differentiate the services provided.

To complete the cost-driven picture provided by the model, its outcomes have to be complemented by a qualitative assessment of other aspects, such as the effects of sharing on the homogeneity of the retail offerings, its effect on innovation in networks, and the spectral efficiency gain that is obtained. A proper evaluation of these aspects requires sufficient knowledge of the technical and organisational approaches in proposed sharing arrangements. Typically, operators provide this information when they notify their proposed arrangement to the concerned regulators.

9.2 Business and regulatory evaluation of sharing

The judgement on whether certain sharing arrangements are acceptable or not is up to regulators who are in a position make evaluations on a case-by-case basis after studying the precise sharing arrangement proposed by operators and its consequences. To obtain an insight in the type of considerations that will play a role in a regulator's judgement and the factors that should be taken into account, we have analysed three full sharing scenarios. In our analysis, we have addressed, either quantitatively or qualitatively, the evaluation criteria that we have determined to be relevant from a business or regulatory perspective.

The quantitative model outcomes show that – with our model assumptions – RAN and spectrum sharing are attractive for operators. Model assumptions include important aspects such as the considered case (network roll-out with a new technology) and the particular parameter values chosen for parameters such as the marketing fees that should compensate a loss of differentiation in product offerings in case of network/ spectrum sharing. The cost reductions that can be obtained with sharing lead existing operators to prefer comprehensive sharing arrangements. The cost reductions align well with the policy objective of efficient investment and innovation in networks. However, the sharing arrangements do not align with key elements of the policy objective to promote competition. Sharing leads to more concentration in the wholesale market for RAN connectivity and thereby reduces the level of infrastructure-based competition. Increased concentration on the wholesale market does not necessarily lead to a similar concentration and interdependency between operators on the retail market, as the sharing operators may still have various technical options to differentiate their retail offerings. An assessment of the consequences of the concentration in the wholesale market for the retail market requires a rather detailed analysis of the precise technical and organisational conditions in the proposed sharing arrangement. This is also true for the assessment of the opportunities that the sharing operators have to independently introduce innovations in their networks.

For the entry barrier, another important element related to the policy objective to promote competition, sharing arrangements can work out both positively and negatively. On the one hand, sharing can substantially increase the entry barrier in terms of the relative cost disadvantage that a new entrant faces. On the other hand, if a new entrant is in a position to join an existing sharing coalition, it can reduce the entry barrier.

In the three scenarios we analysed, we found that RAN and spectrum sharing are not expected to significantly affect the emitted power. As a result, the regulations governing the maximum emitted power levels play a relatively small role in the overall assessment of network and spectrum sharing. Site sharing, a sharing arrangement that typically precedes RAN and spectrum sharing, can be affected by power level regulations though.

9.3 Recommendation: use coalition formation model in combination with qualitative criteria

The coalition formation model can be of value as a common sharing assessment method in support of the discussion between operators involved in a sharing initiative and the regulator about its regulatory acceptance. It would provide the opportunity to both sides to objectify this discussion to a certain extent, or even to provide boundary values that should not be exceeded from a regulatory perspective. This would improve mutual understanding of the analyses (operators versus regulator) because they communicate in the same language. We would like to mention BULRIC as an example of a model approach that can be deployed by both regulator and operators in parallel to support their discussions (in the case of BULRIC on quantifying network costs).

Furthermore, such a model may help operators to consider strategic options in sharing. It would improve the understanding of the perspective of other operators (competitors and potential partners) involved in the same market.

Therefore, our recommendation to parties involved in the development and assessment of sharing arrangements, in particular operators and regulators, is to use a coalition formation model in their assessments. The model provides quantitative insights in preferred sharing coalitions and effects of sharing on cost levels and entry barriers that complement the qualitative assessment on other criteria. As explained earlier, every sharing arrangement must be judged on its own merits and therefore every arrangement deserves its own independent analysis.

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