SAPHYRE

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Reference scenarios for resource sharing (final)
D5.1c

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Authors:	Federico Boccardi, Osman Aydin (ALUD), Thom Janssen (TNO), Rafał Pisz (WRC)
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Abstract

This document contains a framework for SAPHYRE research scenarios on RAN and spectrum sharing and a selection of three research scenarios relevant from technical, business and regulatory perspectives.

Keywords

Network sharing, RAN sharing, infrastructure sharing, spectrum sharing, scenarios, reference scenarios, LTE, 3G, 4G, mobile networks, licensed spectrum.

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Abbreviations

3GPP	3rd Generation Partnership Project
CAPEX	Capital Expenditure
CoMP	Coordinated Multipoint
DECT	Digital Enhanced Cordless Telecommunications
ICIC	Inter-Cell Interference Cancellation
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
MNO	Mobile Network Operator
MVNO	Mobile Virtual Network Operator
MU-MIMO	Multi User MIMO
OPEX	Operational Expenditure
RAN	Radio Access Network
RAT	Radio Access Technology
RN	Relay Node
SC#	Scenario Category (number)
SLA	Service Level Agreement
SON	Self-Organising Networks
SWOT	Strengths, Weaknesses, Opportunities, and Threats
QoS	Quality of Service
RF	Radio Frequency
UE	User Equipment
WP#	Work Package (number)
X2	Logical Interface between enhanced node B (eNB) in LTE

1 Executive summary

To date, sharing has been an important practice in the deployment of mobile networks, in fact already since the early days. A brief state-of-the-art study showed that there are several cases found where full Radio Access Network (RAN) sharing is applied, operated by joint ventures which were erected by the parent companies. SAPHYRE aims to explore this phenomenon in a structured and fundamental way, to accomplish a broader understanding of the potential gains of sharing and to explore more innovative ways of sharing. A more fundamental exploration requires studying regulatory, business modelling and technical aspects of sharing.

An earlier SAPHYRE report already presented ten initial candidate scenarios. This report presents updated versions of those scenarios, updated with insights obtained primarily from interaction with the External Advisory Board as well as considerations and analysis within the project team. The report also describes the selection of three research scenarios out of these initial candidates, and presents the technical, business and regulatory criteria with which the selection was executed. The resulting three scenarios are:

1. Full sharing, i.e. sharing of network and spectrum;
2. Spectrum sharing, i.e. inter-operator spectrum sharing with separate network infrastructure;
3. Network sharing, i.e. network infrastructure sharing with and without shared relaying nodes.

These three scenarios will be studied in subsequent project work. For instance, WP5 will study business and regulatory aspects of these three research scenarios.

2 Introduction

SAPHYRE [2] aims at demonstrating how spectrum/infrastructure sharing in wireless networks improves spectral efficiency, enhances coverage, increases user satisfaction, maintains QoS (Quality of Service) performance, leads to increased revenues for operators, and decreases capital and operating expenditures. Apart from the development of enabling technology for resource sharing, SAPHYRE's goal is to identify working business models for operators and to give recommendations for regulatory measures required to make sharing feasible.

In order to study regulatory, business modelling and technical aspects of sharing, WP5 identified a number of candidate sharing scenarios. In Deliverable D5.1.a [3] ten candidate scenarios were identified and described.

D5.1.b builds on the findings described in D5.1.a [3] and finalises the choice of the scenarios selected for further studies. To do so, the first step (described in Section 3 and Section 4) has been to reduce the number of candidate scenarios by merging some of them. This merge has been performed by taking into account the input from external entities (mainly the External Advisory Board), other work packages within SAPHYRE and by having further analysis within WP5. The second step (described in Section 5) has been to define selection criteria. WP5 agreed on considering seven key aspects, ranging from some market-related, some related to the technology/cost benefit and some others related to the innovation speed. Finally, we applied the selection criteria to the candidate sharing scenarios, and gave the motivations for the score. This selection assessment has been described in Section 6.

The content of this document as from version D5.1b was used for the Deliverables D5.3, D5.4 and D5.5 [9]–[11].

3 Scenario framework

3.1 Scenario categories

Mobile network resource sharing may take different forms, depending on technical and business aspects of the sharing and its market driver. Network resource sharing may have serious impact on the competition, technical differentiation and future of the mobile market itself.

It is important for network resource sharing exploration to define and analyse as many attractive and reasonable scenarios from business perspective as possible. At the same time it is important to focus on some key sharing scenarios, in a structured way.

At the top level, three principal scenario categories can be identified based on RAN and spectrum[1] sharing as the two basic degrees of freedom:

- RAN sharing, spectrum sharing;
- no RAN sharing, spectrum sharing;
- RAN sharing, no spectrum sharing.

All categories will be elaborated and covered by this document in Section 4. For each category, important example scenarios will be presented which are described at reasonable high level. A more detailed level, which is beyond the scope of this document, is the description of use cases for each scenario. This will be tackled by the individual SAPHYRE work packages, which will define their own use cases, governed by the research questions at hand. The aspect of operator and user data security which is applicable for all sharing scenarios is to be technically solved and agreed between the sharing partners to secure data security and privacy concerns. This issue will not be discussed further in this document.

3.2 Reference scenario

3.2.1 Description

SAPHYRE will study the benefits of network/spectrum sharing, and especially innovative ways of sharing. In order to do that, a “sharing” case under study will need to be compared with a reference case (e.g. non-sharing or an existing sharing concept). The reference case should be as much as possible uniform for *all* comparisons in *all* of SAPHYRE’s work packages.

As reference scenario we chose the non-sharing case, which includes all forms of “mainstream” passive sharing (i.e. antenna sharing, cabinet sharing, mast sharing), as they are applied in the majority of cellular networks throughout Europe.

Location-based sharing, especially tower sharing, is the most used practice since it is widely accepted by European regulators. Tower sharing has minimal impact on

[1] In this document we indicate “spectrum” as licensed spectrum if not specified further.

operators' independence; most of the limitations are present at the stage of network planning or expansion. However, properly designed mobile networks, with the concept of location sharing taken into account at the design stage, will reduce those limitations to a very minimal level. An extension of the tower sharing is antenna system sharing, where two or more operators share the same antennas (single or multiport), feeder cables and other passive elements. Key limitation of this sharing scenario is the passive element, which means that in most of the cases sharing needs to end before the signal from the antenna will reaches the radio cabinet. This type of sharing may have significant impact on network coverage (same antenna beam wide and tilt), quality, capacity and some impact on technical differentiation of the operators. A special case of antenna sharing widely used is microcell sharing, where operators use one microcell antenna system with separate radio cabinets connected at the bottom end of the system. This solution is often the only chance for all operators in the market to be present in some popular hotspots like stadiums, train stations, airports or shopping centres. Some of the construction developers or building owners build this kind of installations on their own, to lease microcell installation to all possible operators in the market.

Another sharing scenario, which is widely used currently, includes RF wideband repeaters. Repeaters amplify the required bandwidth according to agreements between operators. It is a very popular solution to extend coverage in places where the installation of a regular site is not reasonable from a business perspective or very difficult because of technical reasons (e.g. trains). However RF repeaters are active elements and their usage might be restricted by market regulations.

Passive sharing is present in most of the European networks due to different reasons , e.g. site acquisition problems/savings, availability of new site locations, local authorities' requirements, site construction savings etc. Site sharing between operators might be based on cashless site swap or based on pricing agreed in a dedicated sharing contract. Nowadays, pure non shared networks are very rare nowadays; however this kind of scenario gives the best possible independence to the operator.

3.2.2 Roles

The main roles in this scenario are:

- Network operator, which possesses and manages the network and the spectrum;
- End-users, who use the mobile communication service.

4 Candidate sharing scenarios

This section is organised as follows. Firstly, in Section 4.1 we describe how some of the scenarios given in D5.1a [3] have been merged. Secondly we update the scenario description accordingly. In particular, in Section 4.2 we present the case of RAN and spectrum sharing, in Section 4.3 we present the case of spectrum sharing only and in Section 4.4 we treat the case of RAN sharing.

4.1 Scenario merging

After consultation of external parties, most prominently the External Advisory Board, and discussions within SAPHYRE, we merged some of the sharing scenarios given in D5.1a [3] as described in the following.

- Scenarios SC2a (inter-operator cooperative spectrum sharing with legacy networks), SC2b (cooperative spectrum sharing in an additional dedicated band) and SC2c (spectrum trading with separate networks) have been merged. because they have quite a lot of similarities and therefore can be jointly studied.
- Scenarios SC3b (no spectrum sharing, RAN sharing, relaying nodes optional – non shared) SC3c (no spectrum sharing, full RAN share) have been merged as the only difference between the scenarios is that in SC3b the relaying nodes are non-shared, whereas in SC3c they are shared between the operators. Therefore, these two scenarios can be jointly studied.

4.2 Scenario category SC1: RAN sharing, spectrum sharing

In scenario category SC1 both RAN and spectrum sharing are implemented (cf. Figure 1 for a visual example in the case of two operators involved).

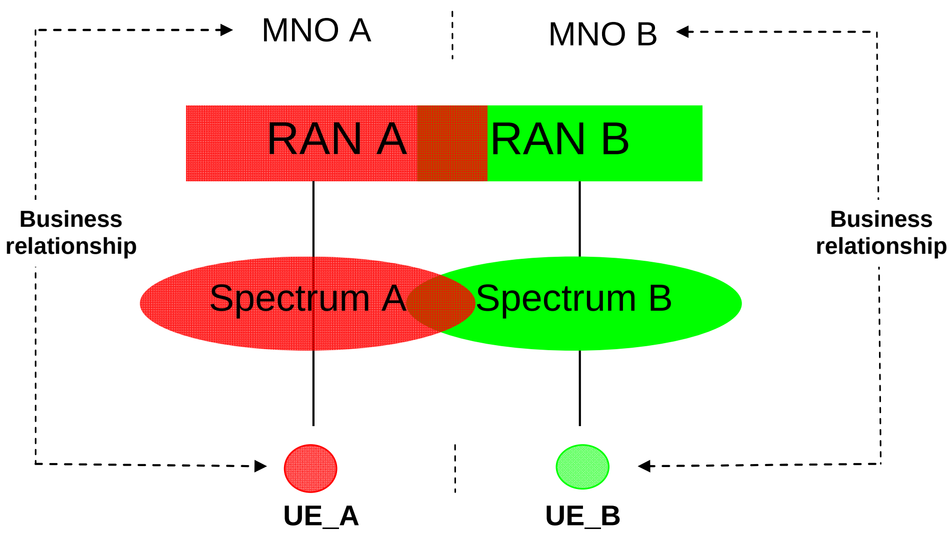

Figure 1: Scenario category SC1

Different scenarios can be filed under such category. Among them, the intra-operator sharing can be considered as a special case while inter-operator sharing can be considered as the default case.

4.2.1 Scenario SC1a: Full sharing

Network and spectrum are shared by multiple operators, who provide and sell services to end-users. The participating operators can operate on a basis of equality.

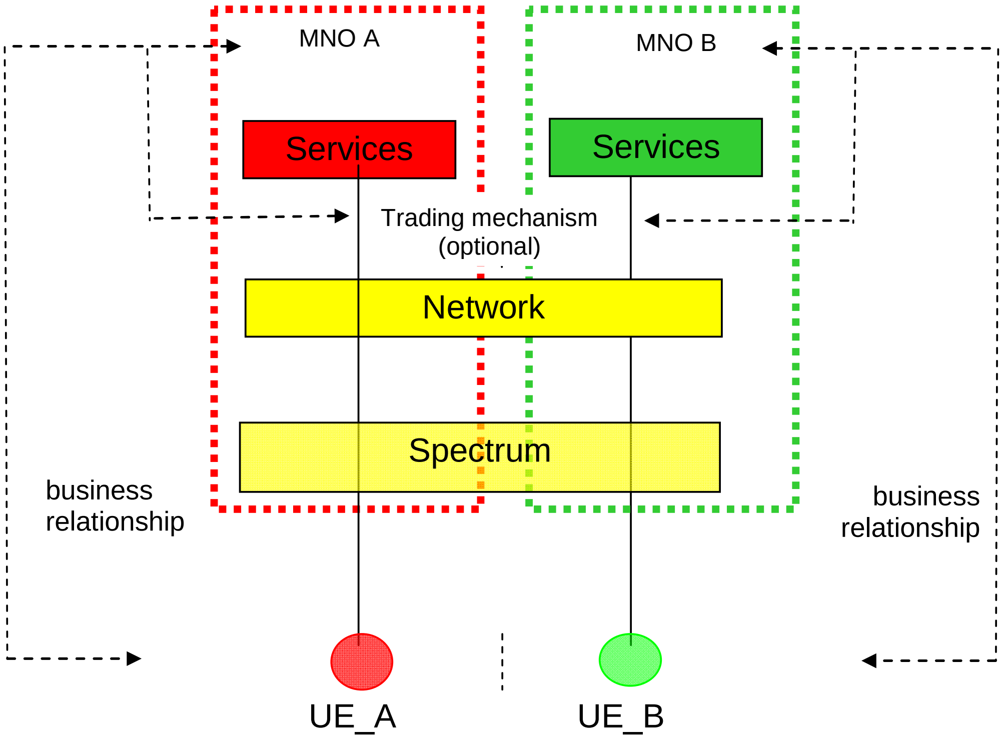

Figure 2: Scenario SC1a

4.2.1.1 Roles

The main roles in this scenario are:

- Network operator operates and manages the network and the spectrum; it sells capacity to participating operators, optionally through a trading mechanism (broker).
- [Optional] Broker (handling trading mechanism) is an intermediary between the parties involved in the capacity distribution: the buying parties (sharing operators) on one side and the selling party (network operator) on the other side.
- Sharing operators (A and B) buy capacity from the network operator and re-sell this to end-users.
- End-users who are using the mobile communication service.

4.2.1.2 Sharing mechanism

The sharing can occur with or without prioritisation. In case of non-prioritisation, operators A and B have equal access rights to the network/spectrum resources. In case of prioritisation, they have prioritised access to a specific part of the network/spectrum resources. The prioritisation can be set dynamically or statically.

If the operators share on a dynamic basis (parameters for dynamic scheduling can base on radio network characteristics like load, QoS, UE mobility, UE priority), there is a trading mechanism where capacity on the access network is sold to the highest bidding operator. In practice, the operators can use a flexible percentage of spectrum and network resources. The trading mechanism is used to extend or decrease this percentage. The timescale of trading can be determined as part of the study in SAPHYRE.

Alternatively, the sharing can be done on a static basis, within their contracts, as a pre-specified capacity that the operators may use. In practice, this could mean they have a certain fixed percentage of minimum spectrum and network resources at their disposal. Extending or decreasing this percentage would require a change of the contract and can therefore not be done in “real-time”.

4.2.2 Scenario SC1b: Relaying node sharing

Operators share the spectrum and the relaying nodes, in a cooperative way. Therefore, in Figure 3 below XX and YY describes parts spectrum which are exclusive control of a specific operator, whereas spectrum XY and YX is provided for sharing in a shared relay node.

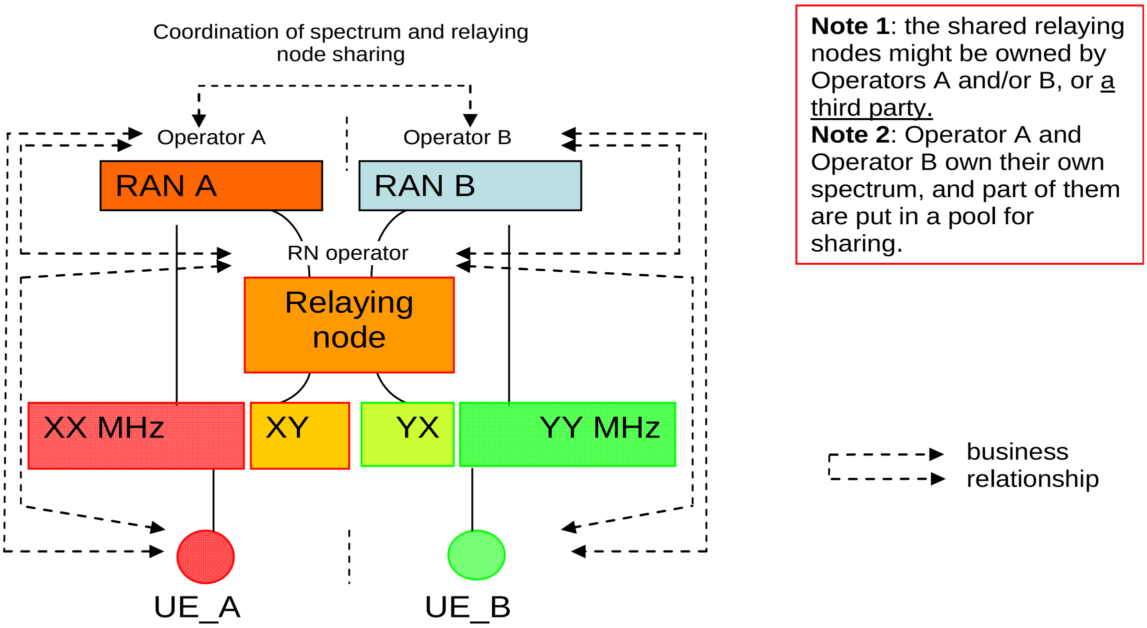

Figure 3: Scenario SC1b

4.2.2.1 Details

Operators have their own separate networks and users, except for the relaying nodes. The relaying nodes could be a part of the network infrastructure deployed by either one of the operators or a third party (deployed relaying). Another way of relaying is to use some user terminals (UEs) as relaying nodes, which work as normal terminals if the relaying functionalities are not activated (UE relaying). The main aim of the relaying nodes is to improve the coverage and the capacity of the networks at a lower deployment cost.

In this scenario, we assume that all the passive and active components in the relaying nodes (including sites, antenna, power supply, cooling, etc.) are shared instead of part of them. The spectrum is shared by separating signals from different operators in one or more of the following domains: frequency, time, space, or code, and thus coordination between operators is expected.

Direct communication between users served by the same operator is possible, in the case of L3 relaying.

4.2.2.2 Roles

The main roles in this scenario are:

- RAN operators, who manage and operate their networks. They can be the service providers to the end-users, although this can also be arranged through another retail organisation or even mobile virtual network operators (MVNO). The operators share part of their spectrum.
- [Optional] Spectrum sharing intermediary party that serves as an intermediary between the sharing operators.
- The relaying node (RN) operator is the owner and operator of the relaying node. This party has to coordinate his spectrum use with the RAN operators, for which some financial compensation is expected. Also, roaming agreements and arrangements between the relaying node operator and the RAN operators are likely.
- [Optional] End-users can participate as relaying nodes for other end-users, which would lower their subscription fee.
- End-users who are using the mobile communication service.

4.2.3 Scenario SC1c: Intra-operator sharing

In this scenario an operator can manage the assigned spectrum resources dynamically and in a fully flexible manner.

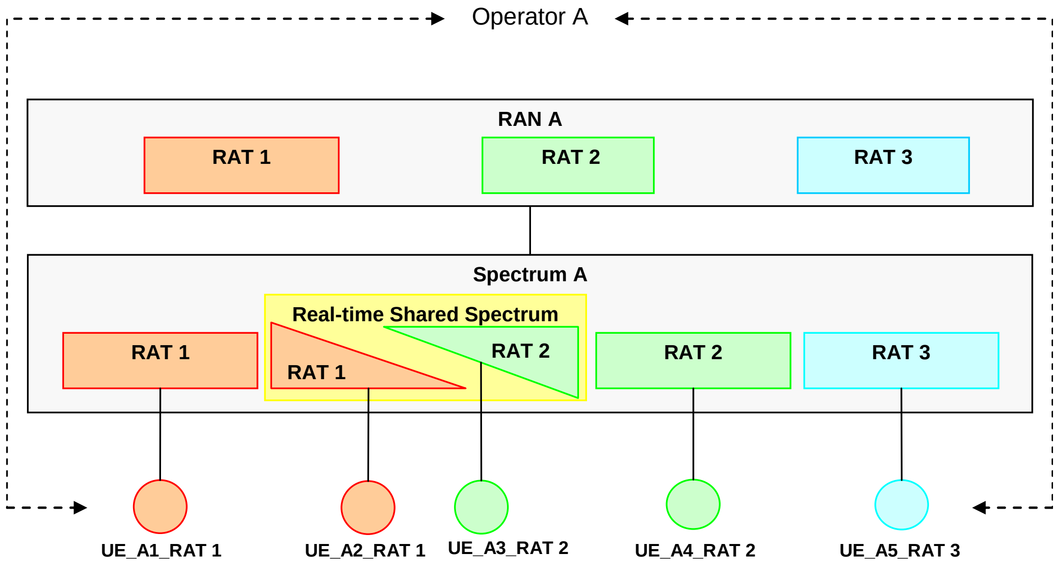

Figure 4: Scenario SC1c

4.2.3.1 Details

Nowadays and even more in the future, many operators have to manage different heterogeneous radio resources and different radio access technologies for the provisioning of different services to their users. The operation of different radio access technologies within one frequency band is now allowed by regulators in many mobile frequency bands, due to the technology neutral basis on which licenses are given. For example the European Union published a directive [8] for its member states, that "… all types of technology used for electronic communications services may be used in the radio frequency bands, declared available for electronic communications services …"

The goals of this scenario are the study and the design of a radio system with L1, L2 and L3 mechanisms capable of adapting the configuration of the networks (e.g. based on the types of traffic) in order to maximise their overall capacity, while taking into account different service requirements within different areas. With respect to the inter-operators scenarios, the advantage of the intra-operator case can be seen as a lower coordination effort due to less external signalling needs.

4.2.3.2 Roles

The main roles in this scenario are:

- Network operator operates and manages the network and uses licensed spectrum, operating different radio access technologies within one specific frequency band.
- End-users are using the mobile communication service.

4.3 Scenario category SC2: no RAN sharing, spectrum sharing

4.3.1 Introduction

In scenario category SC2 only spectrum sharing is implemented, while *no* RAN sharing exists.

Taking into account the business relations between mobile network operators (MNO) and regulatory body, which are the main stakeholders participating in the spectrum sharing: Three types of spectrum allocation can be identified in the case of spectrum sharing:

- Intra-operator sharing, i.e. spectrum allocation type where each MNO shares the acquired spectrum resources between different access technologies, thus breaking the fixed assignment of a radio access technology to spectrum resources
- Cooperative sharing, i.e. a spectrum allocation type where two or more MNOs share the spectrum that was licensed to them in the traditional way,
- Spot – market[2] scenario, i.e. a spectrum allocation type where the regulatory body does not assign spectral resources to MNOs exclusively for long period of time (current model) but allows sharing between MNOs and charges for the used quanta of spectrum.

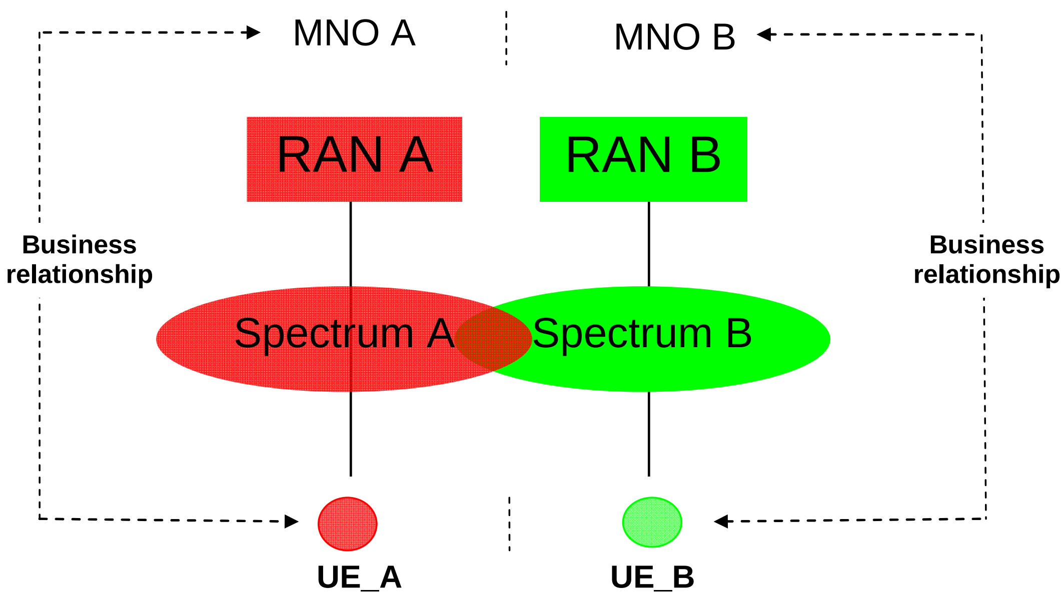

Figure 5: Scenario category SC2

[2] The *spot market* is a public market, in which financial instruments or commodities are traded for immediate delivery. It contrasts with a futures market in which delivery is due at a later date. (Wikipedia)

4.3.2 Main challenges

The main challenge is to provide fair spectrum resource distribution to the sharing partners based on agreed measurable resource units. In both technical and business domain, more specifically for the spectrum resource scheduling in the network and for the accounting of the distributed resources among operators a predefined scale unit is to be defined.

The principle could be applied for the cooperative and spot market:

- How to define unit of spectrum (both dimensions: time/information unit and frequency range)?
- How to assign a spectrum unit to the MNO?
- How to measure consumption of spectrum units?
- How to define a Service Level Agreement (SLA) between the spectrum users and the regulator?
- How to decide about resources assignment in case of resources bottlenecks?

4.3.3 Scenario SC2abc: Inter-operator spectrum sharing in existing/additional band with or without spectrum broker

In this scenario each operator involved can share a certain frequency spectrum in addition to its exclusively used band. The shared frequency spectrum could either be:

- aggregated from the existing frequency spectrum owned by the operators, or
- provided additionally for sharing purposes.

Cooperative spectrum sharing describes the case how in real-time frequency resource requests from the operator owning the resource and the operator joining the resource are controlled and scheduled dynamically. Different access policies are possible, e.g. a “cooperative” user would aim maximising the total throughput, even if this choice would imply a reduction of its own throughput in favour of the other player.. As the most likely option, each operator maintains the paternity for its own channel by carefully defining access priorities to the shared spectrum. In this scenario, the sharing occurs in a legacy situation: the decision to share spectrum is taken at a moment when the operators already have active networks in the frequency band that is shared.

Additional spectrum sharing describes an agreement between operators for sharing a spectrum. The shared frequency band is an additional spectrum that no operator involved in the spectrum sharing process was licensed to use before the sharing agreement was signed. As such, the spectrum sharing occurs in a *“green-field”* situation where no legacy network was active locally in the shared spectrum band.

Alternatively, the additional spectrum can be an unlicensed spectrum or a spectrum with minimal regulatory requirements. Examples for that can be found in UK and Netherlands. Here, the national regulatory bodies liberalised the use of former DECT Guard Band, which is no longer needed to prevent interference between GSM and DECT. The use of this new available resource can be nationally regulated in terms of licensing and technical use. In Netherlands a “light licensing” is applied, so the operators in that former DECT spectrum have to register their base stations and the spectrum is to be operated with low-power usage. In UK more than 10 operators won the license to operate in this spectrum and have to negotiate their cooperative interference prevention mechanism [7].

Furthermore the distribution of the shared resources could be done by a real-time trading mechanism in which the access to the shared spectrum channels at a particular location is sold to the highest bidding operator. This would imply the introduction of a “spectrum broker” which in fact could be an additional party beside the MNOs. Such trading mechanism requires dynamic distribution of spectrum access rights, for which technical mechanisms are not expected to become available soon. The scenario is therefore considered to be a long-term research scenario, but it is already considered by other SAPHYRE work packages.

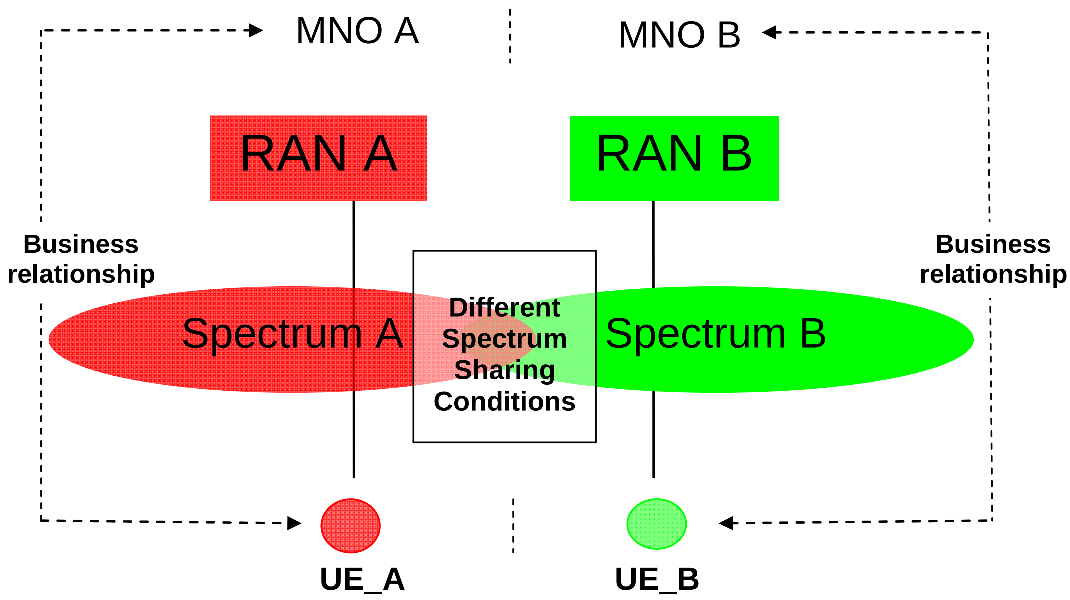

Figure 6: Scenario SC2abc with different spectrum sharing conditions

4.3.3.1 Details

Different implementations of this example scenario can be envisaged. Among others, the following two implementations are of interest:

- MU-MIMO (Multi User – Multiple Input Multiple Output) in a single-site configuration;
- MU-MIMO in a CoMP (Coordinated Multipoint) configuration;

where all the resources assigned by the scheduler to a certain UE might either follow the same transmission scheme (simplest case) or not.

In the single-site configuration, MU-MIMO is served by a single site (so joint processing among different sites is not permitted), while inter-site interference is mitigated thanks to intra-operator and inter-operator Inter-cell Interference Coordination (ICIC).

On the contrary, in a CoMP configuration, MU-MIMO can be served by multiple sites (i.e. joint processing is permitted) and that might happen within the same operator or between different operators. As a result, inter-site interference is mitigated mainly on the physical layer, even though it may also benefit from both intra-operator and inter-operator ICIC. Of course, in this case significant bandwidth availability and low latencies are required for information exchange between operators.

An option to be applied to the suggested configurations (further investigations might come to the conclusion that it is a necessary choice more than just an option) is the case of inter-operator handover (e.g. national roaming) where users belonging to different operators involved in the sharing process could be served on the same frequency band. Thus, the mechanism of inter-operator handover might be mixed to the sharing mechanism described so far in order to increase the potential benefits coming from this scenario example.

4.3.3.2 Prioritisation

A reduced level of control would be an important drawback of spectrum sharing for operators, which can be counteracted by prioritisation. Therefore, it is likely that in the case of legacy networks, where operators share frequencies that are in use by an existing network with existing users, operators opt for prioritised access in order to keep the existing end-user experience beyond the sharing introduction.

Without any lack of generality, in a two-operator scenario where operator “A” has been granted the license for selling services on the frequency channel “a” and operator “B” for frequency channel “b”, operator A shares one part of its own channel “a” to operator B and operator B does the same with one part of its own channel “b” (disjoint from channel “a”). In that way:

- Users belonging to operator A can use both “a” and the shared part of “b” but they have priority over users belonging to B when using “a”;
- Users belonging to operator B can use both “b” and the shared part of “a” but they have priority over users belonging to A when using “b”.

4.3.3.3 Roles

The main roles in this scenario are:

- Network operators (A and B) operate and manage the network and the exclusively owned spectrum; jointly manage or shared spectrum, optionally through a trading mechanism (broker).
- [Optional] Broker is an intermediary between the parties involved in the capacity distribution: the buying parties (sharing operators) on one side and the selling party (regulatory or Broker acting on its own risk) on the other side.
- End-users who are using the mobile communication service.

4.3.4 Scenario SC2d: Femto-cell operator uses spectrum of a macro cell operator

The situation this scenario refers to is the following. There is a macro network, consisting mostly of outdoor base stations operated by operator A in the spectrum portion licensed to A. Then part of this spectrum is shared with another party, operator B, under the condition that operator B employs only low-power base stations, i.e. femto-cells, in order to avoid harmful interference to A's macro network.

Alternatively, an additional spectrum used by the operator B can be an unlicensed spectrum or a spectrum with minimal regulatory requirements. Especially this kind of spectrum regulations and their use fits the requirement of femto-cells which can be operated with low power thus creating limited and reduced interference area. An example for this kind of regulation is the DECT spectrum regulation which can be found in UK and Netherlands. Their national regulatory bodies opened the use of former DECT Guard Band, which is no more needed to prevent interference between GSM and DECT (for further details see Section 4.3.3).

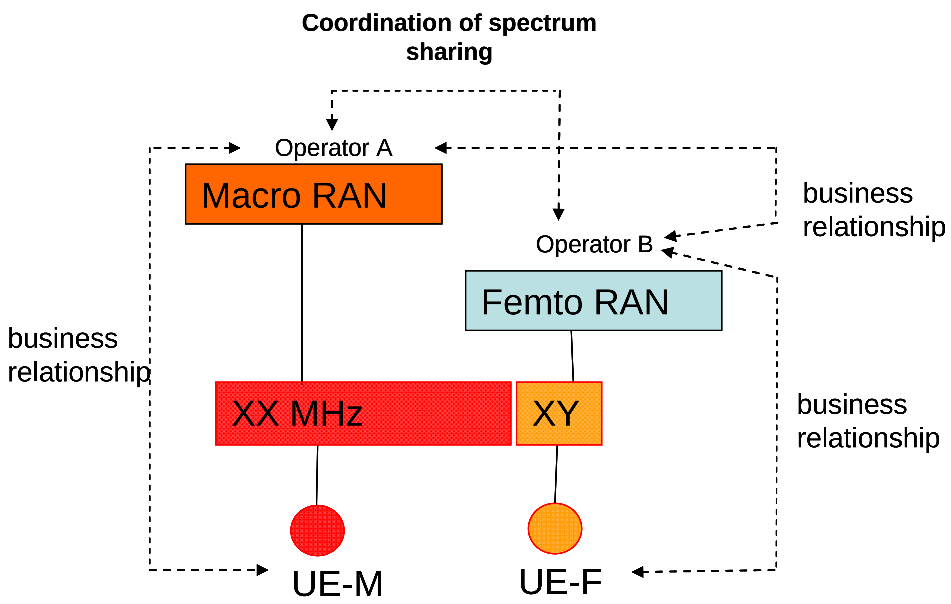

Figure 7: Scenario SC2d

4.3.4.1 Details

Given a network situation as described above in the scenario description, the operator A sub-leases the shared spectrum to operator B, gaining extra revenue. Obviously, there are severe technical challenges with this scenario, such as:

- Substantial coordination of spectrum resources is required to limit the interference [5] between macro and femto-cell networks (or advanced SON/ cognitive radio capabilities should be installed);
- Should seamless handovers be required between the femto-cell operators and operator A, the operators must implement roaming interfaces.

However, from a business modelling and regulatory perspective we think that this may be an interesting scenario as it creates room for an additional role in the market and leads to increased competition and possibly more value for the end-user. Combining this scenario with the MVNO option leads to an interesting alternative arrangement in which a Mobile Shared Spectrum Enabler takes care of all the spectrum (including coordination) and infrastructure responsibilities of the femto cell operator (operator B). The latter then acts as an MVNO.

4.3.4.2 Roles

The main roles in this scenario are:

- Macro network operator – operates and manages the network and uses licensed spectrum.
- Femto network operator – operates and manages network consisting of low power base stations using spectrum licensed to macro network operator.
- [Optional] Broker is an intermediary between the parties involved in the capacity distribution: the macro network operator on one side and the Femto network operator on the other side.
- End-users who are using the mobile communication service.

4.4 Scenario category SC3: RAN sharing, no spectrum sharing

In scenario category SC3 only RAN sharing is implemented, while no spectrum sharing exists (see Figure 8 for a visual example in the case of two operators involved).

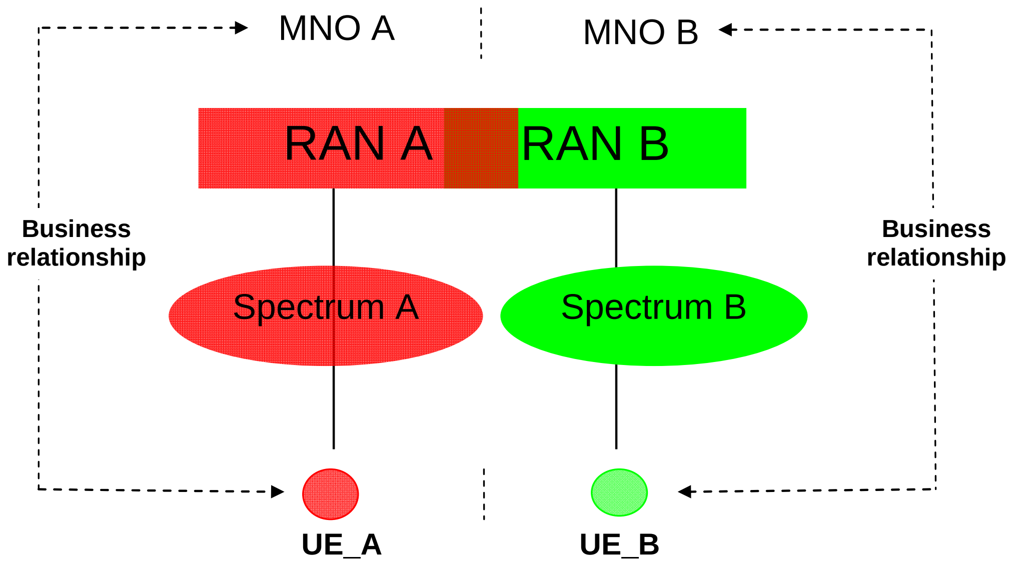

Figure 8: Scenario category SC3

The network sharing portion can range up to 100%.

Different inter-operator sharing scenarios can be filed under such category.

4.4.1 Scenario SC3a: No spectrum sharing, shared relaying nodes, otherwise no RAN sharing

Two or more network operators share relaying nodes, however no further RAN elements are shared. It means infrastructure is shared only in areas where relaying nodes are present. Operators manage spectrum and services independently, but coordinate with the relaying node operator.

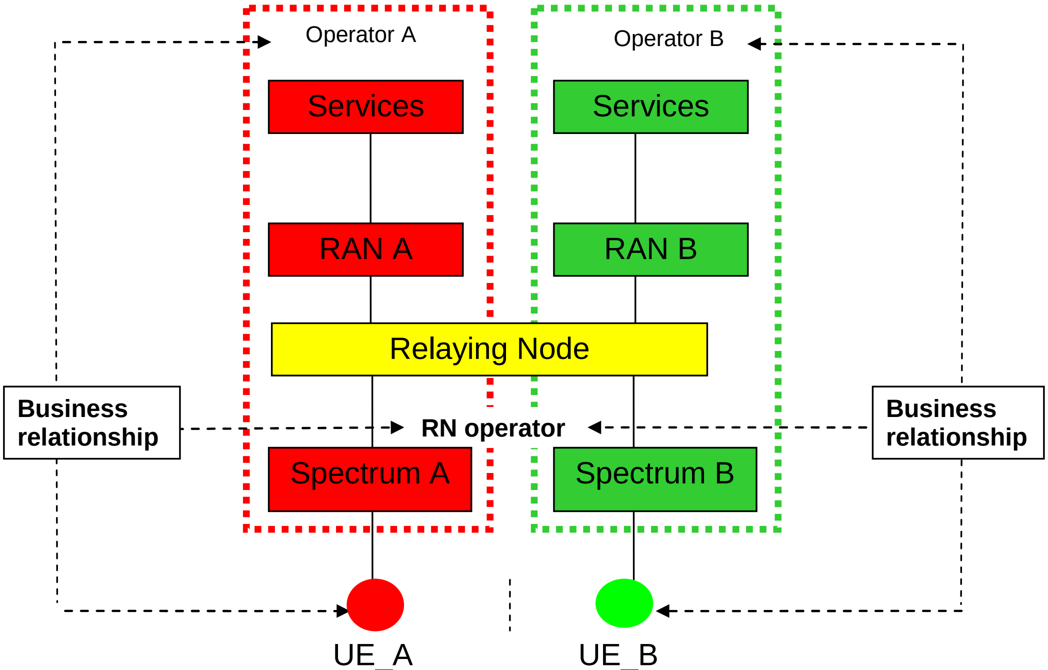

Figure 9: Scenario SC3a

4.4.1.1 Details

Spectrum and RAN network is not shared by any of the operators involved. Infrastructure sharing takes place only in the relaying domain. Relaying nodes might be managed jointly by operators or a third party called RN operator (might require enhanced network planning). The general concept is similar to the one already in use with wideband RF repeaters (cf. Section 3). Sharing takes place, where relaying nodes deployment is possible and reasonable, for example coverage gaps or capacity bottlenecks. The market maintains high technical differentiation and high competition at the same time. Sharing is used to improve network coverage, quality and capacity for all operators involved. Operators manage spectrum and services independently, network operations management is independent. There is likely to be a need for coordination between RN operator and operators A and B, ranging from non-real-time coordination to determine locations of relaying nodes to real-time coordination to facilitate L3 relaying.

4.4.1.2 Roles

The main roles in this scenario are:

- RAN infrastructure operators manage and operate their networks and services. They can be the service providers to the end-users , or wholesale operators used by MVNOs. The RAN operators use their infrastructure and spectrum independently. Some infrastructure interaction is needed for relaying nodes operations.
- RN infrastructure operator, which is the owner and operator of the relaying nodes. This party deploys and operates relaying nodes based on agreements with RAN operators and end-users. RAN operators gain benefits from shared relaying nodes equipment, however spectrum at the relaying node is not shared. RN operator may operate in areas where RAN operators usually have no interest in being present due to low return ratio. RN operators may decide independently where to deploy relaying nodes.

4.4.2 Scenario SC3bc: RAN sharing with and without shared relaying nodes

Two or more network operators share the RAN network. Relaying nodes are optional and may be shared or deployed independently by each operator. RAN infrastructure sharing is possible in up to 100 % of the time. Non-shared relaying nodes may be used for coverage and quality differentiation or other business related aspects. Operators manage spectrum independently, services are partially dependent.

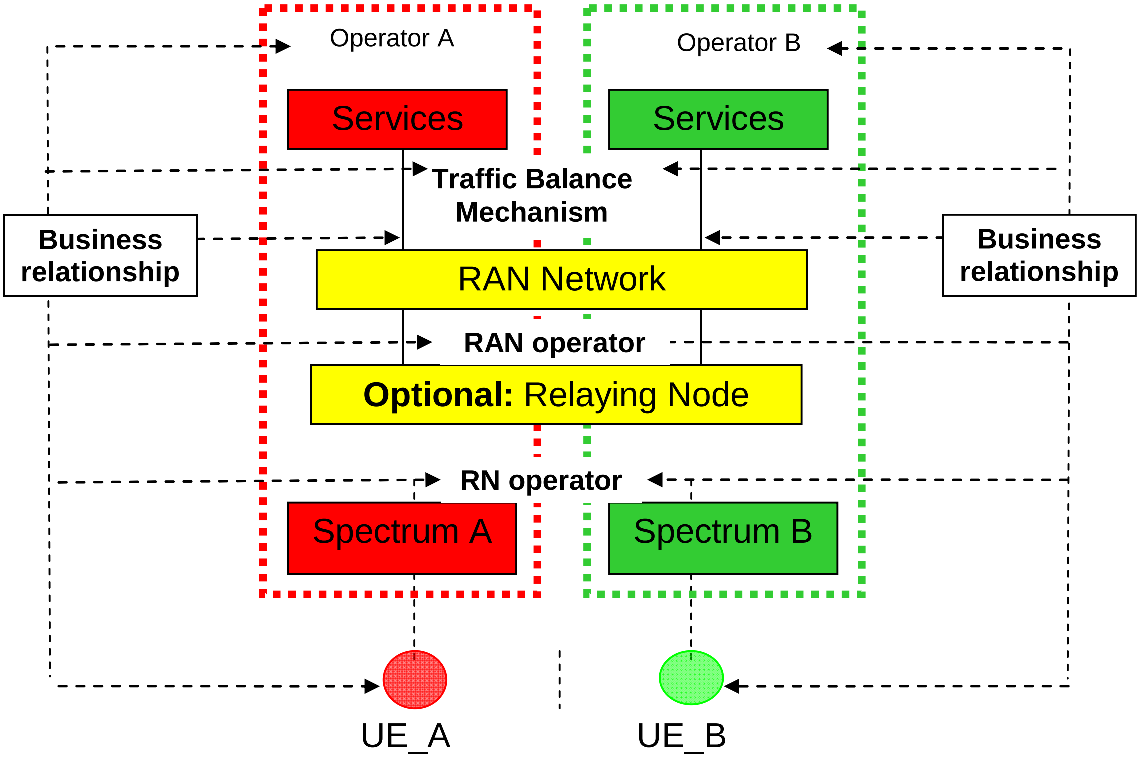

Figure 10: Scenario SC3bc

4.4.2.1 Details

The RAN network is shared by two or more operators, the spectrum is managed indepen-dently, and the relaying nodes are optional and may be shared or deployed independently for each operator (might require enhanced network planning). Infrastructure sharing takes place at the level of RAN elements; however some parts of the RAN infrastructure, inside the radio cabinets, may not be shared i.e. power amplifiers or baseband units. The shared RAN might be operated jointly by operator A and B or by a third party called RAN operator. The level of technical differentiation is medium to low, with medium competition at the same time. Technical differentiation may be realised by technology, band/carrier separation, software parameterisation, active capacity management or deployment of relaying nodes. An active capacity management is a part of a traffic balance mechanism, which ensures an appropriate capacity balance and the control of shared RAN resources like transmitted power or baseband capacity. The traffic balance mechanism may be controlled by the RAN operator, operators A&B or a third party, which will be responsible for hardware resources of shared RAN. Independent deployment of relaying nodes is an important technical differentiation element for this scenario. Both operators may use relaying nodes based on their very own purpose. Independently deployed relaying nodes give operators some level of network control at the same time with all benefits coming from a shared RAN network. This type of sharing is mostly used to reduce cost of network operations and to improve network capacity for all the involved parties. Operators manage spectrum and services independently; network operations management may be joined. Business relationship and dependency is on medium level.

4.4.2.2 Roles

The main roles in this scenario are:

- Two or more RAN infrastructure operators manage and operate jointly their shared network. They can be independent service providers to the end-users, or wholesale operators used by MVNOs. RAN infrastructure is shared, but spectrum and services are operated independently. RAN may be operated by one of the legacy operators or jointly.
- (Optional) 3rd party which operates RAN infrastructure.
- (Optional) RN infrastructure operator is the owner and operator of the relaying nodes. This party deploy and operate non-shared relaying nodes based on agreements with service operator and end-users. Function might be held by service operator. RN operator may operate in areas where other RAN operators usually have no interest being present due to low return ratio. Relaying nodes deployments may increase technical differentiation for one of the service operators.

5 Scenario selection: criteria description

To assess the candidate scenarios from a 360 degrees perspective, we consider seven key aspects, resulting from our brainstorming and SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis, related to tree main evaluation domains: impact on market, impact on usage of resources and total costs of network ownership both CAPEX (Capital Expenditure) and OPEX (Operational Expenditure) and impact on innovation implementation. We assessed each sharing scenario described in Section 3 for each of these seven key aspects, using a binary score ("YES", "NO") and giving the motivations for the score.

These seven key aspects are described in the following.

Impact on market

1. Market entry barriers:

   The main question we try to answer here is if sharing has an influence on the market entry barriers.

2. Dominant positions:

   The problem we consider here is the risk of monopoly situations. In other words, it must be assessed scenario-by-scenario if sharing could lead to a higher possibility for a coordinated behaviour of the parties that share network or spectrum resources. For example, if two major operators decided to share the network, smaller operators may not be able to match the offer from a technological or pricing perspective.

3. Homogeneity in offerings:

   The main problem considered in this section is if sharing could lead to an increased homogeneity in the product offerings.

   Regulators are already concerned with the possibility that RAN-sharing could provide the basis for information to flow between the sharing operators. This could facilitate the coordination of their businesses and affect competition in other downstream markets [1]. From a technology point-of-view, sharing the same RAN could lead to a similar offer in terms of QoS. As a matter of fact, it might be difficult to allow different operators sharing the same RAN to use different QoS parameters (for example related to scheduling). This is one of the reasons for which in developed countries RAN sharing is usually limited to rural areas, where the profit margins are lower and there is not much space for service differentiation. Moreover, RAN sharing implies that operators are using the same deployment paradigm. One trade-off solution would be to agree to share an underlying macro RAN whereas allowing the deployment of non-shared small cells.

Impact on usage of resources and total cost of ownership

4. Spectrum efficiency:

   The main aspect covered here is whether sharing can lead to a higher spectral efficiency for the mobile market as a whole. The importance of this aspect is due to the fact that today spectrum is a scarce resource and sharing has been indicated as a possible solution to increase the spectral-efficiency [2].

   In order to assess the potential of the different sharing scenarios for improving the spectral efficiency, we reviewed different types of enabling techniques. On the other hand, we observed that some sharing scenarios have higher potential gains than others.

5. Cost efficiency:

   The aspect covered in this section is to assess the different scenarios from the point-of-view of cost reduction, where by cost reduction we include CAPEX and OPEX.

   We note that in general cost efficiency is probably the main motivation for sharing. On the other hand, we observed that different sharing scenarios can have a different impact on cost efficiency. Therefore we believe this is a key aspect to consider for selecting the sharing scenarios where to focus for further studies.

Impact on innovation implementation

6. Innovation in networks:

   The aspect covered here is the assessment of the influence of sharing on the speed of roll-out of new generations of networks. We study this aspect from a non financial perspective, as this has been already covered under key aspect 5).

   For example network sharing could reduce the speed of infrastructure upgrade, in case of discrepancies between the technology roadmaps of the different operators sharing the same mobile networks.

7. Availability of technical solutions:

   We observed that some sharing scenarios would require more efforts for an industrialisation of the techniques enabling to achieve the gains foreseen in the academic studies.

   For example, spectrum sharing without RAN sharing would involve the availability of efficient distributed algorithms for assigning spectrum resources and of the corresponding standard enablers. Due to this, spectrum sharing with RAN sharing seems to be a more robust candidate for achieving higher spectral efficiencies via sharing in a short to medium time frame.

6 Scenario selection: assessment

6.1 SC1a (Full sharing)

1. Entry barriers:

Question	Does SC1a have an influence on the entry barriers?
Score	YES
Comment	SC1a has a clear influence on the entry barriers. The most common understanding is that full sharing reduces the entry barriers. On the other hand, there could be some (non common) cases where SC1 would lead to higher entry barriers as sharing partners could jointly achieve de facto monopoly position by having a significantly large portion of the available spectrum. In such a situation, new entrants may not be able to acquire sufficient spectrum to allow for fair competition. They would be forced to join with other operators, which would hamper their independence and commercial strength.

2. Dominant positions:

Question	Is there any risk of monopoly situations? In other words, does sharing lead to more potential for coordinated behaviour of the parties that share network or spectrum resources?
Score	YES
Comment	An example is the case of two strong operators sharing spectrum and infrastructure. They could be able to offer the latest technology and at the same time keep CAPEX and OPEX low. This would lead to a clear case of dominant position.

3. Homogeneity in offerings:

Question	Does SC1a lead to a change in the homogeneity of product offerings (as multiple parties share a number of crucial resources)?
Score	YES
Comment	Full sharing would lead to a more homogeneity of the offer. As emphasised is Section 5, full sharing could provide the basis for information to flow between the sharing operators and lead to a similar offer in terms of QoS.

4. Spectrum efficiency:

Question	Does SC1a lead to a higher spectral efficiency for the mobile market as a whole?
Score	YES
Comment	Full sharing clearly leads to a higher spectral efficiency. The possibility of implementing *centralised* spectrum allocation/ optimisation algorithms in the shared RAN is an important enabler for efficient spectrum sharing.

5. Cost efficiency:

Question	Does SC1a lead to a lower CAPEX+OPEX?
Score	YES
Comment	SC1a is the best sharing scenario in terms of CAPEX and OPEX reduction. Operators could decide to lease the spectrum from a third individual (spectrum broker). In this case no CAPEX would be required for spectrum, but a higher OPEX should be considered to lease the spectrum from the spectrum broker.

6. Innovation in networks:

Question	Does sharing influence the speed of roll-out of new generations of networks?
Score	YES
Comment	Full sharing implies that there is a higher degree of standardisation, which makes it -technically- easier to replace components. However, the decision can no longer be made by one party independently, as all others have to agree – because of shared sites. This opens up the opportunity for strategic behaviours. For example one of the operators sharing the network could oppose network updates.

7. Availability of technical solution:

Question	Is the solution close to be found for the major technical challenges?
Score	YES
Comment	The solution to enable this scenario can be based on a centralised architecture and we foresee its availability in a short/medium term.

6.2 SC1b (Relay sharing and spectrum sharing)

We think SC1b will not be very popular 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.

1. Entry barriers:

Question	Does SC1b have an influence on the entry barriers?
Score	YES
Comment	Relaying nodes could be used to extend the coverage and reach the minimum level of coverage required by the regulator. However, relay sharing is not expected to be of strategic importance (see the general comment) and therefore the impact on entry barriers is low.

2. Dominant positions:

Question	Is there any risk of monopoly situations? In other words, does sharing lead to more potential for a coordinated behaviour of the parties that share network or spectrum resources?
Score	NO
Comment	Even though there is still some potential risk due to the fact that the two operators are sharing the spectrum. On the other hand compared to Sc1a this risk is low and for this reason we decided to score this as indicated above.

3. Homogeneity in offerings:

Question	Does SC1b lead to a change in homogeneity in the product offerings, as multiple parties share a number of crucial resources?
Score	YES
Comment	If implemented, from a technical point-of-view this solution would lead to a QoS homogeneity in the areas covered by relays.

4. Spectrum efficiency:

Question	Does SC1b lead to a higher spectral efficiency for the mobile market as a whole?
Score	YES
Comment	In WP2/WP3 it is claimed that in many cases spectrum efficiency increases when spectrum is shared for relays. This means “YES” in this case.

5. Cost efficiency:

Question	Does SC1b lead to a lower CAPEX+OPEX?
Score	YES
Comment	As explained above this case does not seem very appealing. On the other hand in general it could lead to a CAPEX/OPEX saving, even if this saving does not seem to be relevant with respect to the other sharing scenarios.

6. Innovation in networks:

Question	Does SC1b influence the speed of roll-out of new generations of networks?
Score	NO
Comment	We consider as a baseline the non-shared relay case. The question is not whether *relays* help network roll-out but whether *sharing the relays* helps network roll-out. Given the general remark about SC1b, the answer is as above.

7. Availability of technical solution:

Question	Is the solution close to be found for the major technical challenges?
Score	YES/NO
Comment	As a function of the type of solution. An example of a solution already in the market is analogue relays. Type-I relays have been just standardised in LTE Rel-10. On the other hand more sophisticated (and performing) relays solutions based on cooperation techniques are still under discussion in the scientific community.

6.3 SC1c (Intra-operator sharing)

1. Entry barriers:

Question	Does SC1c have an influence on the entry barriers?
Score	NO
Comment	This scenario does not limit the expenses needed to start the MNO's activity.

2. Dominant positions:

Question	Is there any risk of monopoly situations? In other words, does SC1c lead to more potential for a coordinated behaviour of the parties that share network or spectrum resources?
Score	NO
Comment	Intra-operator sharing does not have a big influence on monopoly risk.

3. Homogeneity in offerings:

Question	Does SC1c lead to a change in homogeneity in the product offerings, as multiple parties share a number of crucial resources?
Score	NO
Comment	Intra-operator sharing does not lead to a change in homogeneity.

4. Spectrum efficiency:

Question	Does SC1c lead to a higher spectral efficiency for the mobile market as a whole?
Score	YES
Comment	Intra-operator sharing (i.e. dynamic allocation of technologies to frequency channels) allows for a more efficient spectrum allocation to end-users. In an extreme example, the situation where 100% of the users in a particular cell are GSM-only and 100% of users in another cell are 3G-only might in theory be accommodated, whereas in the non-shared case this would lead to blocking of either of the groups. We emphasise that a change in the current regulation to allow this mechanism is critical.

5. Cost efficiency:

Question	Does SC1b lead to a lower CAPEX+OPEX?
Score	YES
Comment	Intra-operator sharing can lead to a lower CAPEX (sharing of cooling units, base band units, mast, antennas …) and a lower OPEX (common maintenance tools, dynamic use of different technologies). Regulators play an important role to enable spectrum sharing between different technologies.

6. Innovation in networks:

Question	Does SC1c influence the speed of roll-out of new generations of networks?
Score	YES
Comment	A lower CAPEX can lead to a faster deployment of new networks. Moreover, an operator could use spectrum refarming.

7. Availability of technical solution:

Question	Is the solution close to be found for the major technical challenges?
Score	YES
Comment	Solutions to allow intra-operator sharing rely on centralised algorithm architecture and common hardware between different technologies. Availability is foreseen in a short to medium time-range.

6.4 SC2abc (Inter-operator spectrum sharing in existing/additional band)

1. Entry barriers:

Question	Does SC2abc have an influence on the entry barriers?
Score	NO/YES
Comment	In this case the investment needed to start the activity could be reduced but it depends on the regulatory policy (e.g. higher pricing for shared spectrum resources). Also, in principle the entry barrier is reduced because a new entrant can obtain spectrum access even if no new spectrum is made available, through a spectrum sharing deal with an existing player.

2. Dominant positions:

Question	Is there any risk of monopoly situations? In other words, does SC2abc lead to more potential for a coordinated behaviour of the parties that share network or spectrum resources?
Score	YES
Comment	Depending on the prior distribution of spectrum, perhaps some players can enhance their position strategically.

3. Homogeneity in offerings:

Question	Does SC2abc lead to a change in the homogeneity of the product offerings, as multiple parties share a number of crucial resources?
Score	NO
Comment	Where spectrum is shared, service homogeneity is likely to be increased. However, there is only a limited potential for change in homogeneity in this scenario (far smaller than with RAN sharing and full sharing).

4. Spectrum efficiency:

Question	Does SC2abc lead to a higher spectral efficiency for the mobile market as a whole?

Score	NO/YES
Comment	The “NO” depends on the fact that a distributed processing is used, so performance could get worse due to the interference. Realistic algorithms to solve this problem are not available at the moment. The “YES” depends on a long-term availability of efficient distributed algorithms, which are under study in WP2 and WP3, see Deliverable D3.1a [6].

5. Cost efficiency:

Question	Does SC2abc lead to a lower CAPEX+OPEX?
Score	YES
Comment	Spectrum sharing can lead to a lower CAPEX/OPEX. For example it could allow a higher spectral efficiency without the need of a network update.

6. Innovation in networks:

Question	Does SC2abc influence the speed of roll-out of new generations of networks?
Score	NO/YES
Comment	NO (no spectrum trader): due to the fact that each of the two operators would own its own chunk of spectrum, we do not think that SC2abc would have an influence on the speed of roll-out of new generation networks. YES (with spectrum trader): the operators could rent the spectrum from the spectrum broker → lower CAPEX.

7. Availability of technical solution:

Question	Is the solution close to be found for the major technical challenges?
Score	NO
Comment	SC2abc relies on distributed techniques: at the moment we detect problems due to convergence, problems due to the need of information exchange, restrictions due to bandwidth for information exchange, restrictions due to latency for information exchange. Moreover, this scenario requires interface extensions for existing standards e.g. X2 in 3GPP LTE.

6.5 SC2d (Femto operator uses macro operator's spectrum)

1. Entry barriers:

Question	Does SC2d have an influence on the entry barriers?
Score	YES
Comment	This scenario opens the market for local operators without spectrum ownership and dedicated services focussing on specific local needs.

2. Dominant positions:

Question	Is there any risk of monopoly situations? In other words, does SC2d lead to more potential for a coordinated behaviour of the parties that share network or spectrum resources?
Score	NO
Comment	With a femto-cell operator there is no monopoly risk because (a) there can be multiple femto-cell operators and (b) femto-cell operators are not obliged to provide coverage through the femto-cell operator as they have the option to rely on their own network

3. Homogeneity in offerings:

Question	Does SC2d lead to a change in the homogeneity of product offerings, as multiple parties share a number of crucial resources?
Score	YES
Comment	SC2d may lead to more interesting services – more heterogeneity.

4. Spectrum efficiency:

Question	Does SC2d lead to a higher spectral efficiency for the mobile market as a whole?
Score	NO
Comment	Baseline: we consider the case with no sharing, where the macro operator owns the all spectrum and also deploy femto-cells. In this case the spectrum usage is more optimised.

5. Cost efficiency:

Question	Does SC2d lead to a lower CAPEX+OPEX?
Score	YES
Comment	Similar to SC2c

6. Innovation in networks:

Question	Does SC2d influence the speed of roll-out of new generations of networks?
Score	NO
Comment	In baseline case (macro operator owns all spectrum and also deploys femto-cells), the macro operator could use co-channel deployment of the femto-cells to roll-out the network.

7. Availability of technical solution:

Question	Is the solution close to be found for the major technical challenges?
Score	NO
Comment	Similar to SC2abc

6.6 SC3a (Only relaying nodes are shared)

A comment similar to the one in Section 6.2 about SC1b applies here.

1. Entry barriers:

Question	Does SC3a have an influence on the entry barriers?
Score	YES
Comment	As the relying nodes do not impact on the cost structure at high level, SC3a has a low impact on the entry barriers.

2. Dominant positions:

Question	Is there any risk of monopoly situations? In other words, does SC3a lead to more potential for a coordinated behaviour of the parties that share network or spectrum resources?
Score	NO
Comment	See the general comment about SC1b in Section 6.2.

3. Homogeneity in offerings:

Question	Does SC3a lead to a change in the homogeneity of product offerings, as multiple parties share a number of crucial resources?
Score	YES
Comment	At locations where relaying nodes are shared, service homogeneity is likely to be increased

4. Spectrum efficiency:

Question	Does SC3a lead to a higher spectral efficiency for the mobile market as a whole?
Score	NO
Comment	No major improvements in spectral efficiency.

5. Cost efficiency:

Question	Does SC3a lead to a lower CAPEX+OPEX?
Score	YES
Comment	The same comment made for SC1b applies. We foresee a cost reduction, but this cost reduction is marginal compared for example to SC3bc.

6. Innovation in networks:

Question	Does SC3a influence the speed of roll-out of new generations of networks?
Score	NO
Comment	As relaying nodes cost is lower than macros', we expect that if an operator can afford deploying macros, it should be able also to deploy relaying nodes.

7. Availability of technical solution:

Question	Is the solution close to be found for the major technical challenges?
Score	YES
Comment	It can be derived as a sub case of SC1a.

6.7 SC3bc (RAN sharing with and without shared relaying nodes)

1. Entry barriers:

Question	Does SC3bc have an influence on the entry barriers?
Score	YES
Comment	RAN sharing has clearly an impact on the entry barriers. The general understanding is that RAN sharing should reduce the entry barriers.

2. Dominant positions:

Question	Is there any risk of monopoly situations? In other words, does SC3bc lead to more potential for a coordinated behaviour of the parties that share network or spectrum resources?
Score	YES
Comment	Similarly to SC1a, two strong operators sharing RAN could be able to offer the latest technology, and at the same time keep CAPEX and OPEX low.

3. Homogeneity in offerings:

Question	Does SC3bc lead to a change in the homogeneity of product offerings, as multiple parties share a number of crucial resources?
Score	YES
Comment	At locations where network elements are shared, service homogeneity is likely to be increased.

4. Spectrum efficiency:

Question	Does SC3bc lead to a higher spectral efficiency for the mobile market as a whole?
Score	NO
Comment	Same comment as SC3a.

5. Cost efficiency:

Question	Does SC3bc lead to a lower CAPEX+OPEX?
Score	YES
Comment	Clearly, RAN sharing leads to a lower CAPEX and OPEX.

6. Innovation in networks:

Question	Does SC3bc influence the speed of roll-out of new generations of networks?
Score	YES
Comment	Infrastructure sharing allows a reduced initial CAPEX for the operators, so in general we expect RAN sharing to speed-up the network deployment. On the other hand, the same comments made for SC1a applies, for possible “veto” behaviours.

7. Availability of technical solution:

Question	Is the solution close to be found for the major technical challenges?
Score	YES
Comment	Same as SC3a.

6.8 Outcome of scenario selection

The selection assessment is summarised in the following overview. For the selection we have adopted the requirement that further studies should address one scenario for each category. The bottom row shows with a bold marking which of the scenarios has the highest score within the three different scenario categories SC1, SC2 and SC3. The three bold marked scenarios will be further analysed within SAPHYRE WP5 work with dedicated business model studies.

Scenario **Key aspect**	**SC1a**	**SC1b**	**SC1c**	**SC2abc**	**SC2d**	**SC3a**	**SC3b**
1. Entry barriers	YES	YES	NO	NO/YES	YES	YES	YES
2. Dominant positions	YES	NO	NO	YES	NO	NO	YES
3. Homogeneity in offerings	YES	YES	NO	NO	YES	YES	YES
4. Spectrum efficiency	YES	YES	YES	NO/YES	NO	NO	NO
5. Cost efficiency	YES	YES	YES	YES	YES	YES	YES
6. Innovation in networks	YES	NO	YES	NO/YES	NO	NO	YES
7. Availability of technical solution	YES	YES/NO	YES	NO	NO	YES	YES
TOTAL # of YES	**7**	4/5	4	**2/5**	3	4	**6**

Table 1: Outcome of scenario selection

7 Conclusions

To date, sharing has been an important practice in the deployment of mobile networks, in fact already since the early days. A brief state-of-the-art study showed that there are several cases found where full Radio Access Network (RAN) sharing is applied, operated by joint ventures which were erected by the parent companies. SAPHYRE aims to explore the phenomenon in a structured and more fundamental way, to accomplish a broader understanding of the potential gains of sharing and to explore more innovative ways of sharing. A more fundamental exploration requires studying regulatory, business modelling and technical aspects of sharing.

An earlier SAPHYRE report already presented ten initial candidate scenarios. This report presents updated versions of these scenarios, updated with insights obtained primarily from interaction with the External Advisory Board as well as considerations and analysis within the project team. The reports also describes the selection of three research scenarios out of these initial candidates, and presents the technical, business and regulatory criteria with which the selection was executed:

1. Impact on entry barriers;
2. Risk of dominant positions;
3. Change in homogeneity in offerings;
4. Spectrum efficiency increase;
5. Cost efficiency;
6. Innovation in networks;
7. Availability of technical solution.

The three scenarios resulting from the selection assessment are:

1. SC1a: Full sharing, i.e. sharing of network and spectrum;
2. SC2abc: Spectrum sharing, i.e. inter-operator spectrum sharing with separate network infrastructure;
3. SC3bc: Network sharing, i.e. network infrastructure sharing with and without shared relaying nodes.

These three scenarios will be studied in subsequent project work. For instance, WP5 will study business and regulatory aspects of these three research scenarios.

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