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SON for future Networks

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Abstract: In this deliverable, future networking scenarios, including further advancements of LTE, 5G systems, and future deployment scenarios are considered and the need of SON functionalities for four selected use cases are investigated. The four selected use cases are Cognitive Policy-based SON management, Device-to-Device Communications, Nomadic networks and License Assisted Access for LTE. For these use cases research activities and conceptual solutions targeting the simplification of the management of these networks have been identified.

Keywords: Device-to-Device, Cognitive PBSM, LAA_LTE, Nomadic Networks

Executive Summary

In this deliverable, exemplary future networking scenarios, including further advancements of LTE, 5G systems and future deployment scenarios are considered by a set of studies. Since these features are far beyond the time-line of the main SEMAFOUR research areas, this deliverable does not provide fully worked out solutions or simulation results. Instead, it provides an initial study, detailing the set of selected areas and potential for future research. The studies describe possible new SON functionalities for future networks based on the SEMFOUR results. Four use cases have been selected for further studies: Cognitive Policy-Based SON Management (Cognitive PBSM), Device-to-Device (D2D) Communication, Nomadic Networks and License Assisted Access for LTE (LAA-LTE). For these use cases, research activities and conceptual solutions targeting the simplification of the management of these networks have been identified and described.

The study on Cognitive PBSM elaborates on the potential of learning mechanisms in the context of Policy-Based SON Management and Cognitive Radio. The results of this study reveal that cognitive components are crucial for future mobile radio systems. Cognition enables the mobile network to adapt to varying conditions that naturally change, not only over time, but also in space. This and the fact that the overall requirements in terms of traffic demand by the users varies as well, makes a learning component important in order to detect and react on changes that happen in the network. The study on D2D communication reveals that SON functions could play an important role in the autonomous management of D2D communications while following a central management approach. The functions tackling the mode selection and resource allocation/interference management would support the requirements for multi-mode communication in cellular networks, thus making the benefits of D2D tangible. In the study on nomadic networks we concentrate on the problems that occur when nomadic nodes and users move out of each other's vicinity. The focus is on a SON function for a bus scenario where a nomadic node is mounted on a bus to provide better coverage to users on the bus. Among the main findings of the study on LAA-LTE channel selection SON algorithms are i) selection algorithm based on detection of the interference type (LTE or Wi-Fi) to improve co-existence between LTE and Wi-Fi, ii) potential improvements by using standardized UE measurements on the LAA carrier and iii) a set of potential parameters for the distributed channel selection SON function.

The results of all four studies show a large potential for benefit in future mobile network performance and as such appear excellent candidates for future research. These areas could be used as a starting point for follow-up projects to SEMAFOUR.

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List of Acronyms and Abbreviation

3GPP	3rd Generation Partnership Project
5G	5^{th} Generation mobile wireless communications system
AC	Access Controller (WLAN)
AP	Access Point
ARS	Active Road Safety
CEM	Customer Experience Management
CEPT	Conférence Européenne des Administrations des Postes et des Télécommunications
CM	Configuration Measurements
CQI	Channel Quality Indicator
CR	Cognitive Radio
CRC	Cognitive Radio Cycle
CRS	Cognitive Radio System
CSAT	Carrier Sensing adaptive Transmission
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
D2D	Device-to-Device Communication
DNS	Domain Name Server
E-UTRAN	Evolved UTRAN
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FM	Fault Measurements
GPS	Global positioning System
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
ISM	Industrial, Scientific and Medical
ITU	International Telecommunications Union
KPI	Key Performance Indicator
LAA-LTE	Licence Assisted Access LTE
LAC	Load-aware Channel
LBT	Listen before Talk
LTE	Long Term Evolution
LTE-A	Long Term Evolution – Advanced
LTE-U	LTE in unlicensed spectrum
MAC	Media-Access-Control
MDP	Markov decision Process
MDT	Minimization of Drive Tests
ML	Machine Learning
MRVH	Modified Relative Velocity Aided Handoff
MTC	Machine-Type Communication
MQA	Mobile QoS Agents
M2M	Machine-to-Machine
NUOC	Non-Utilized Outage Capacity
OFDMA	Orthoginal Frequency Division Multiple Access
OMC	Operations and Maintenance Center
PBSM	Policy-Based SON Management
PAPR	Peak-to-Average Power Ratio
PM	Performance Measurements
ProSe	Proximity Services

PS	Public Safety
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RRM	Radio Resource Management
RF	Radio Frequency
RLF	Radio Link Failure
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSS	Radio Signal Strength
RSSI	Radio Signal Strength Indicator
RVAH	Relative Velociyt Aided Handoff
SA	System Aspects
SC-FDMA	Single Carrier Frequncy Divison Access
SeNB	Serving eNodeB
SINR	Signal-to-Interference-and-Noise-Ratio
SON	Self-Organising Network
SSID	Service Set Identifier
STA	Station
TETRA	Terrestrial Trunked Radio
UE	User Equipment
URL	Uniform resource Locator
V2I	Vehicle-to-Infratsructure Communication
V2V	Vehicle-to-Vehicle Communication
V2X	Vehicle-to-X Communication
WG	Working Group
WLAN	Wireless Local Area Network

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1 Introduction

Network management of both evolved LTE and future 5G infrastructure will be characterized by a high degree of automation and cognition, which is required to continuously tune the network to the current communication demands, and to concurrently improve the efficiency in the use of resources. The degree of automation and cognition most probably will be even higher when compared to the situation in today's networks. This goes along with the introduction of new features into the networks, like device-to-device communication (D2D), nomadic networks, ultra-densification (using large numbers of millimeter-wave-based small cells) or the combined access in licensed and unlicensed bands. Here, D2D is considered in the large sense including also Vehicle-to-Vehicle (V2V) communication. This will require the development of a significant number of new SON functions.

In this deliverable exemplary future networking scenarios, including further advancements of LTE and 5G systems, and future deployment scenarios are considered by a set of studies. Since these features are far beyond the time-line of the main SEMAFOUR research areas, the deliverable does not provide fully worked out solutions or simulation results. Instead, it details the areas and potential for research on new SON functionalities for future networks based on SEMFOUR results.

The approach taken by SEMAFOUR to select appropriate future use cases was as follows. First a call for interest on *Use Cases for SON on future Networks* has been issued within the consortium. Based on the expressed interest, the importance of the use cases and the resources available the following four use cases have been selected for further studies:

- Cognitive Policy-Based SON Management (Cognitive PBSM)
- Device-to-Device Communication
- Nomadic Networks
- License Assisted Access for LTE

For these use cases, research activities and conceptual solutions targeting the simplification of the management of these networks have been identified and described. The description of the four use cases have the nature of a study item and do not provide simulation results of the proposed solutions. The latter will be subject to potential follow-on projects.

Each of the four mentioned uses cases is treated in a separate chapter, the content of which follows the generic structure:

x.1 Introduction
x.2 Background on the specific Use Case
x.3 Approach for SON in future Networks
x.4 Conclusions

Chapter 6 of the document includes the overall conclusions and an outlook to future activities based on the findings in this deliverable.

2 Cognitive Policy-Based SON Management

2.1 Introduction

When Joe Mitola III presented the concept of Cognitive Radio (CR) on the 20th of May, 1999, at a seminar at KTH (The Royal Institute of Technology, Sweden) as the main theme of his PhD thesis [1], he marked the dawn of the "cognitive era" in wireless communications. Shortly afterwards, came the first publication ([2] followed by the PhD dissertation of Mitola on CR [3]). The definition of CR is expressed by Mitola in his PhD thesis, as follows:

"The term cognitive radio identifies the point at which wireless personal digital assistants (PDAs) and the related networks are <u>sufficiently computationally intelligent</u> about radio resources and related computer-to-computer communications:

(a) to detect user communications needs as a function of use context, and

(b) to provide radio resources and wireless services most appropriate to those needs."

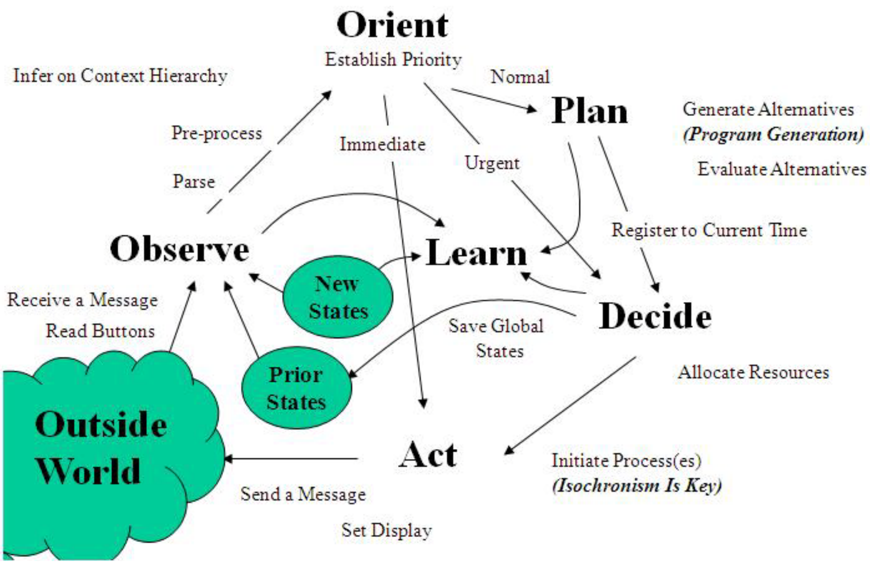

Figure 2.2.1 Cognitive radio cycle as introduced by Joseph Mitola III [1]

Mitola defines 9 levels of cognition capability, with level 0 having no cognition capability and level 8 being able to propose and negotiate totally new protocols (also known as Full CR) as well as the "Cognitive Radio Cycle" (CRC) shown in Figure 2.2.1. Such cycle is triggered after so-called *stimuli* are dispatched by the outside world (i.e. the mobile network system in this scope of study). The stimuli reach the cycle by the *observer*. After that an *orientation* phase is started by determining the priority associated with the stimuli, followed by a *plan* phase. The different plans will be evaluated in the *decide* phase. At last *acting* enforces the actions to the outside world. In the middle is a *learning* phase which builds upon the observations and decisions.

Cognitive radio was for a while related to cognitive terminals in an opportunistic spectrum access context. The extension of the cognition capability to the network level came later. A more general term was used in the definition given by the International Telecommunications Union (ITU). In the ITU-R Report SM.2152, a cognitive radio system is defined as follows [4]:

"Cognitive radio system (CRS): A radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained."

Almost in parallel with the cognitive radio concept, "Autonomic Computing" [5] was introduced by IBM to cope with increasing complexity of software systems. Autonomic Self-x capability is based on an analogy with the autonomic nervous system governing "low level vital functions as heart rate and body temperature". However CR is inspired by conscious brain, and by its capability of reasoning and learning from experience for adapting decisions to new contexts. A cognitive system is then a system which is autonomic and intelligent.

In a SON enabled network, cognitive capability can be introduced in several levels:

1. At the level of each SON function by introducing in the SON algorithm itself, the learning capability. The SON algorithm is then capable of adapting its internal parameters to enhance its decisions based on the feedback of the network.
2. At the SON management level, namely by rendering the PBSM cognitive. E.g. by learning the effects of SON function on the network or to predict changes in terms of performance by introducing certain SON function configurations. The PBSM will then enhance its different levels of decisions by learning from the impact of the past decisions on the network.

In this chapter, we focus on Cognitive PBSM and show the main challenges that we see for rendering the SEMAFOUR PBSM system cognitive, namely, the environment awareness and the learning capabilities. Only the management level will be addressed since the work on integrated SON management in the SEMAFOUR framework is not focusing on individual SON functions either.

2.2 Basic learning techniques

A cognitive PBSM will rely on several learning algorithms as explained later. This section is a short introduction to learning techniques [6].

Machine learning is a branch of artificial intelligence that designs algorithms allowing the machine/system behaviour to evolve based on example data or past behaviour. The three basic classes of machine learning algorithms are:

- **Unsupervised learning** aims at finding the underlying structure of unlabelled data. In this family of algorithm the clustering techniques that define a set of similar groups or classes of objects can be found. The k-mean clustering or the classical k-nearest neighbour belongs to this family of algorithms. It is important to notice that the definition of the distance between the elements is crucial in these algorithms. Blind signal separation is another category of unsupervised learning algorithms where the objective is to separate a set of signals from a set of mixed signals without any knowledge on the sources or the mixing process. An example for this category is the principal component analysis.
- **Supervised learning** learns a function from labelled training data. For each sample, an output data is associated. The supervised learning algorithms aim at generalizing from the training data to the unseen data to predict the output data associated to an unseen object. Regression algorithms such as linear or logistic regressions are in this class of algorithms. In this case the output data is supposed to be continuous. Classification of data applies if the output is discrete, where artificial neural networks, decision tree learning or naïve Bayes classifier techniques can be found.
- **Reinforcement learning** is widely used in Cognitive Radio area. The aim of reinforcement learning is to enhance the decision of the learner based on the feedback of the environment to the past decision through the maximisation of a certain cumulated reward. Indeed, the feedback of the environment is given to the learner as a reward which will guide the learner for his next decision. Reinforcement learning algorithms are then particularly adapted to online learning problems as this technique is meant to adapt the decisions to the variations of the environment. Among the reinforcement learning techniques Q-Learning and Markov Decision Process (MDP) algorithms can be found. In both Q-learning and MDP the objective is to learn the optimal policy, which consists in finding for each state, the most appropriate action in a way that the cumulative reward starting from this state is maximized. In Q-learning

the model is unknown, whereas in MDP the model is known (rewards, transitions probability between states).

2.3 Approach for SON in Future Networks

In this section the main approaches for SON solutions in future networks regarding learning capabilities for the Policy-Based SON Management (PBSM) framework will be presented. At first a brief overview of the current architecture of the PBSM framework is given in Section 2.3.1. After that three different starting points for learning, i.e. cognitive mechanisms, in the PBSM framework will be presented in the following subsections that have been identified as potential candidates where learning would lead to an improvement of the PBSM framework. Besides this, Section 2.3.2 deals with the knowledge acquisition and data management that is needed to get meaningful results in general.

2.3.1 Starting Points for Learning in the PBSM Framework

The PBSM architecture that builds the foundation for this work has been described in full detail in [7]. Figure 2.2.2 represented a simplified view on the building blocks of such architecture. The basic idea of PBSM is to give the network operator the ability to formulate KPI targets or even (high-level) goals which will be translated into a machine-readable language. This language can be used in combination with input models, e.g. descriptions of the mobile network and the effects of SON functions on the network performance, in order to generate rules that will be triggered if certain events and conditions in the network are fulfilled. The triggered rules include SON function configuration values that will cause the desired network behaviour.

Buildings blocks that are likely to be updated or improved during run-time by a potential learning capability are marked in pink. The points to include a learning component in the PBSM framework are represented as feedback-loops (i.e. which is the main requirement for a cognitive or learning system) and labelled with an explanation mark.

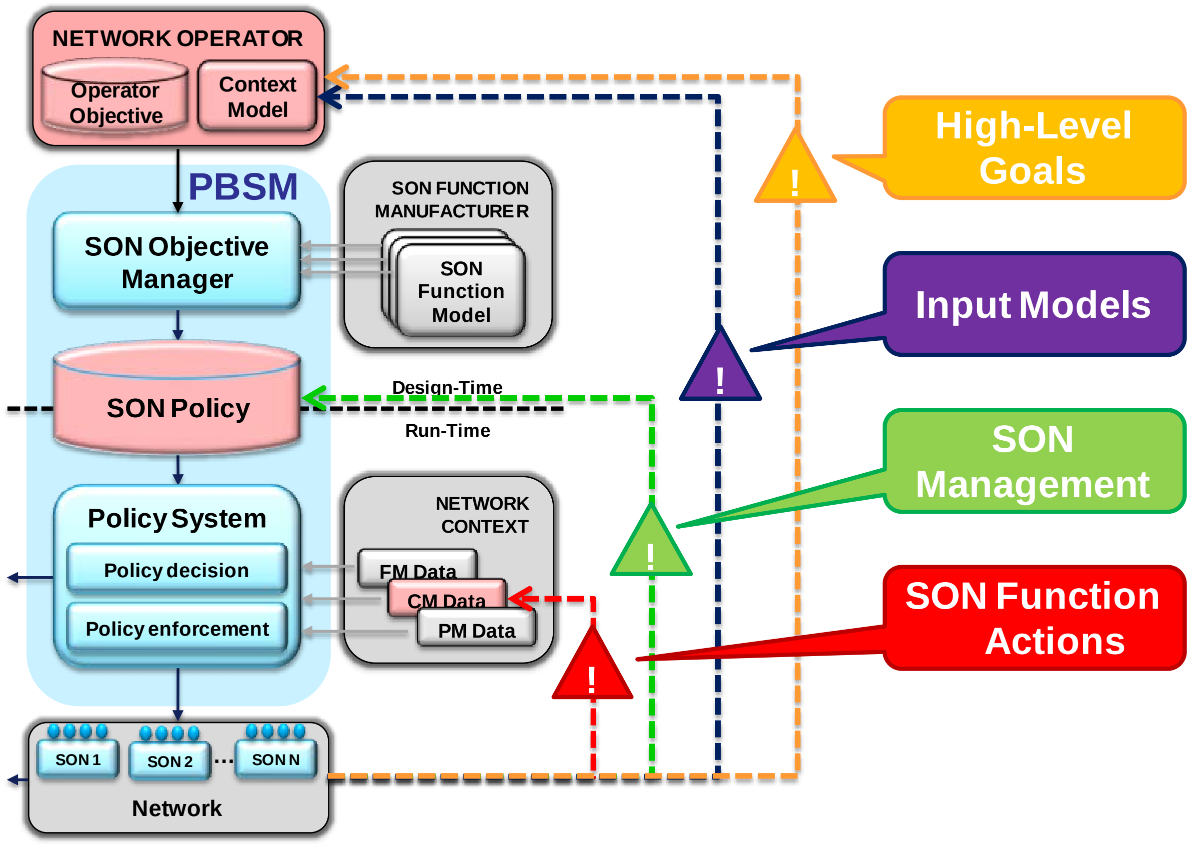

Figure 2.2.2: Simplified buildings blocks of the PBSM architecture

Four potential and promising starting points have been identified that would improve the mechanisms and the performance of the PBSM framework over time. These starting points are:

1. **Identification of SON actions in the network system:**

   The SON functions are the means to achieve the KPI targets by changing the SON configuration parameter values in a way that such targets can be achieved. Simulation results have shown that, in specific network conditions (e.g. different cell types, location, mobility profiles, etc.), not all SON actions, i.e. changing the (radio) parameters, are beneficial for a radio system [8]. By keeping track of the executed SON actions and learning the effects on the system the operation in a SON-enabled network could be improved. Examples for that could be to inform SON Coordination about the new insights or to learn “bad” SON configurations and prevent them in the future.

2. **Improving the input models needed for PBSM:**

   The PBSM system is only as good as the quality of the input to that system, i.e. the SON function models or context model. The consequence is that the input models should be accurate as possible. Hence, an improvement over time of such models would be of high importance.

3. **(Re-)Defining SON management/PBSM actions:**

   In the current implementation of PBSM the SON configurations will be changed based on the rules in the SON Policy repository. After that no means of tracking the achievements of KPI targets or the performance of SON functions with the adjusted configuration is done. Evaluating the past performance may cause a redefining of policies that lead to a better result.

4. **Transformation of High-Level Operator Goals:**

   High level operator goals can be related to operator profit augmentation, end user Quality of experience enhancement or operational cost reduction. The first task of PBSM is to translate these high level goals into technical objectives. Technical objectives can then be expressed in terms of radio KPIs that can be fulfilled by the SON functions. Machine learning could improve the transformation process itself over time.

Starting Point / Application area	
Potential type of Machine Learning (ML) algorithm	Supervised, unsupervised or reinforced learning (see Section 2.2 for further information)
Time scale	Short, medium or long scale ranging from days to months
Data needed	Performance-, Configuration- and/or Fault-Measurements (PM, CM and/or FM)
Improvements through learning	Components (SON Policy repository, transformation entities, etc.), models (context and/or objective models) or mechanisms in the PBSM framework that will be improved
Cognitive cycle	The basic phases in the cognitive cycle:
Observe	What should be observed?
Orient	What should the observations be compared to?
Learn	Which behaviour/pattern/actions can be learned from the observations?
Decide	What is to be decided?
Act	What are the actions that will be executed in the mobile network?

Table 2.2-1: Evaluation template

Each point will be described and evaluated based on a template given in Table 2.2-1. The different tables will explain the scope of the learning/CR component that could be introduced and give concrete example how a cognitive cycle could look like. In addition estimation on the time scale, which data has to be collected and what kind of improvement can be expected by learning, will be provided.

2.3.1.1 Identification of SON actions in the network system

The PBSM derives rules for a SON enabled mobile network that trigger SON function configurations if certain events and conditions are fulfilled. These SON functions are then supposed to run in the network and change SON specific (radio) parameter based on algorithms that work with the configured settings. A first starting point were learning in a mobile network could be beneficial is to observe the SON actions in the network and try to map such actions to the current network behaviour/performance.

Starting Point / Application area	SON actions
Potential type of ML algorithm	Supervised learning (generalizing from old measurements, i.e. training data, to up-coming SON actions to predict the output of a SON action)
Time scale	Short term (hours – days) (measurements from network elements on which a specific SON instance is running on)
Data needed	PM, CM, FM data
Improvements through learning	SON function configurations, SON policies
Cognitive cycle	
Observe	PM, CM, FM data from respective cells with active SON function
Orient	Investigate correlation between faults, bad network behaviour or network degradation and SON function actions (parameter changes)
Learn	Compare old SON actions with network behaviour
Decide	Were the actions by a specific SON function useful or did they harm the network?
Act	Change SON function configurations, “instruct” SONCO to allow/disallow specific SON configurations, forbid SON function (at certain times), change SON Policies (remove SON configurations)

Table 2.2-2: Evaluation table for the identification of SON actions in the network system

The main improvement for the mobile network system would be to learn “bad” SON function configuration settings. Such information could prevent the system running into an undesired network state.

2.3.1.2 Improving input models needed for PBSM

PBSM relies on several input models. One of them is called “Context Model” which has the purpose to describe the system and provides cell class definitions [9]. Based on such definitions the operator is able to formulate KPI targets for cells that belong to a specific cell class. Now, if the classification of such cells is wrong in the first place, targets may not be reachable at all. This shortcoming can be solved by monitoring the cell class behaviour and identifying cells that may be classified in the wrong cell class and correct the classification or the class definition itself.

Starting Point / Application area	Input Models

Potential type of ML algorithm	Unsupervised learning (i.e. finding the underlying structure of unlabelled cells)
Time scale	Medium-term (weeks to months) (collecting cell KPI measurements over a adequate amount of time in order to feed the learning algorithm)
Data needed	PM data
Improvements through learning	Cell classes, context and cell class definition
Cognitive cycle	
Observe	PM data from all cells within one class or in an area of the mobile network
Orient	Evaluate statistical measures such as mean, variance, correlation, etc. to improve cell classification
Learn	Cell class behaviour/performance
Decide	Is the classification of a certain cell correct or would a different classification fit better?
Act	Change cell class or (re-) define class definition

Table 2.2-3: Evaluation table for improving input models needed for PBSM

It is important that an initial cell class definition is available and in use. With the available statistical tools and a significant amount of KPI measurements an unsupervised learning algorithm should be able to identify, measure and if necessary adjust the affiliation of cells to certain cell classes.

2.3.1.3 (Re-)Defining SON management/PBSM actions

As already stated in Section 2.3.1.1, SON functions will be configured based on rules. Such rules are part of the SON Policy Repository (cf. Figure 2.2.2). With no feedback-loop that is going from the network back to the Policy system a validation of the applied rules is not possible. To overcome such shortcoming the creation of SON Policies can be subject to a learning objective.

Starting Point / Application area	**SON Management**
Potential type of ML algorithm	Reinforcement learning (enhance the decision of the SON management system based on the feedback of the environment to the past decision)
Time scale	Medium-term (weeks, months) (measurements needed are not often reported)
Data needed	PM and CM data
Improvements through learning	SON Policies, High-Level Operator Goals
Cognitive cycle	
Observe	PM and CM data from network, operator targets/goals
Orient	Analyse performance and compare with operator targets for the given KPI target values
Learn	Achievement of KPI target values, SON settings (SCV sets)
Decide	Could the KPI targets or the (high-level) operator goals be reached?
Act	Mark inefficient SON Policies and/or change the SON Policy creation, i.e. the rules which led to the policy in the first place

Table 2.2-4: Evaluation table for (re-)defining SON management/PBSM action

Collecting data from the past enables a comparison of the network performance (on area, cell or cell class level) with the given targets and thus an evaluation on the created and triggered policies of the PBSM system.

2.3.1.4 Transformation of High-Level Operator Goals

Enhancing through learning the transformation procedure that translates semantic goals into quantitative objectives presents the following two challenges:

1. Understanding and interpretation of the high level goals that can be expressed in human language.
2. Define the technical objectives that correspond to these high level goals by
   a. Defining the relevant targeted KPIs or metrics that reflect the high level goals. For instance, the profit of the operator can be expressed as a function of a capacity metric depending of the type of service and the pricing strategy. The quality of experience is a subjective indication on the user satisfaction. It can be expressed based on QoS indicators. An example of operational cost that can be reduced by acting on the radio network through SON features is the energy consumption.
   b. Defining the good target values (e.g. thresholds) for the list of technical objectives (e.g. enhancing the average user throughput, access probability,…): these targets should correspond to the expectation of the higher level (i.e. the high level operator goals). In other terms, if the technical objectives are fulfilled, this should guarantee the fulfilment of the high level operator goals. This step is then crucial and very tricky for the following reason: a performance degradation of the end user quality of service for example does not depend only on the radio network segment. End-to-end performance should be considered. In order to give a reachable target for the SON system, the contribution of the radio network segment to the overall performance should be somehow isolated.

Starting Point / Application area	Transformation of High-Level Operator Goals
Potential type of ML algorithm	Reinforcement learning (enhance the decision of the SON management system based on the feedback of the environment to the past decision)
Time scale	Long-term (months) (measurements needed are not often reported, collection and KPI derivation are difficult)
Data needed	PM and CM data
Improvements through learning	High-Level Operator Goals, transformation processes
Cognitive cycle	
Observe	Degree of fulfilment of the high level goals
Orient	How far off is the “degree of fulfilment”
Learn	KPI weightings and transformation rules used
Decide	Adjust KPI weightings and/or transformation rules
Act	Change transformation process, adjust High-Level Goal mapping, reconfigure KPI weightings

Table 2.2-5: Evaluation table for the transformation of High-Level Operator Goals

A cognitive approach would be the same as usual: first a “reward” has to be defined that corresponds to the feedback of the environment to the action overtaken by the learner. In this case, it would correspond to an evaluation of the degree of fulfilment of the high level goals. Then, a reinforcement learning algorithm tries to enhance this reward.

SON functions act on the radio access segment of the network, whereas the high level goals are evaluated as the feedback of the whole network. The evaluation of the level of fulfilment of the operator goals, can be expressed as a “satisfaction” metric provided by the operator in an open loop or computed automatically based on some QoE metrics (on the basis of traces corresponding to representative panel of users for example).

The transformation procedure associates a set of actions/conditions on certain radio KPIs (for instance: the average bit rate should be higher than X %) to the high level goals. The relative weights of the KPIs are also an important parameter: does the operator give a higher priority to service accessibility (coverage, minimum bit rate) or does he prefer maximizing the overall throughput of a cell for instance. In order to enhance the transformation procedure, a learning algorithm (see Figure 2.2.3) can play on the target values and relative weights of these different KPIs, for instance, setting more ambitious targets for certain KPIs.

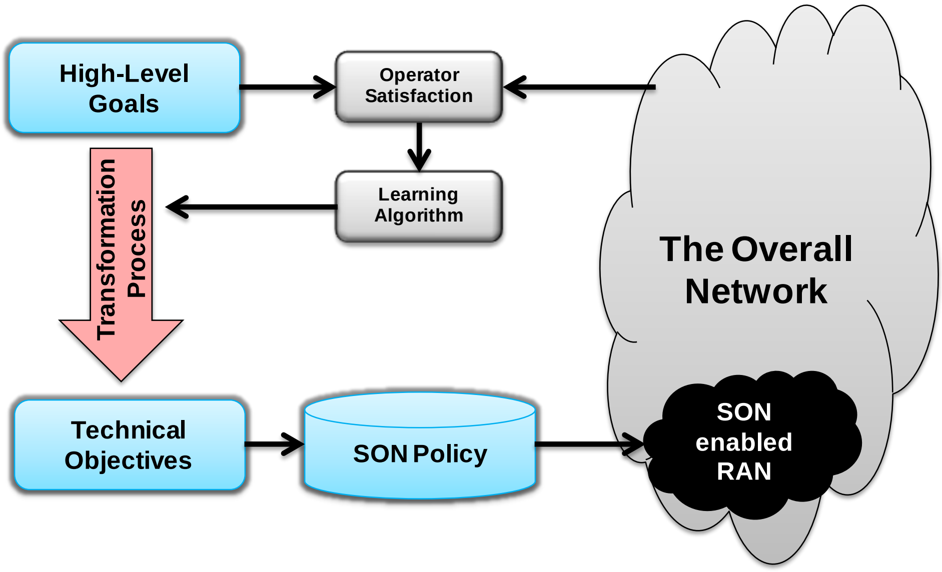

Figure 2.2.3: The transformation process in the context of learning

2.3.2 Knowledge acquisition and data management

Environment awareness (the “Observe” step in the cognitive cycle, cf. Figure 2.2.1) is the awareness of the environment of the “decision maker” which is not limited to radio environment. All the information on the network configuration, the knowledge of SON functions behaviour (e.g. SON function models) as well as potential external reconfigurations, any hardware constraints, the distribution and the variation (spatial and temporal as well) of traffic demands…*etc.* are part of the environment awareness. Depending on the considered cognitive loop, the environment response to a given decision can be related to metrics defining the end-user Quality of Service (QoS) or to radio quality indicators. In this paragraph, we identify some of challenging research axes to be further investigated.

The crucial step for designing any cognitive PBSM component is to be capable of defining properly the learning problem, where the system moves from a state to another as a consequence of a decision or an action taken by the learner. The algorithm is capable of learning only if the behaviour of the system in a given state is predictable. A system state comprises for example the type of environment (urban, rural…etc.), the traffic demand for each traffic class (voice, mobile internet or streaming), its spatial distribution as well as its temporal evolution. In the SEMAFOUR PBSM framework, a policy is defined for each class of cells. This cell classification contains both the environment characteristics and the type of traffic. By defining a policy for a given class of cells we expect that the reaction of this class of cells to that policy is predictable, and it is supposed that any cell belonging to a given class will behave in the same manner. Observing the reactions of the different classes of cells to the corresponding policies allows to judge whether the definition of classes is relevant. The classification of cells should be performed during design time, but a runtime algorithm can correct the attribution of a given cell to a defined class based on the network feedback. A further step could be the online redefinition of the classes based on the observation of their behaviour, moving slowly to a more pertinent classification.

If we focus now on the high level operator goals, assessing the performance of the network w.r.to these goals is not obvious. In particular, monitoring the end-user quality of experience is a complex task. Today, the Quality of Service can be evaluated from network captures (Operations and Maintenance Center ([OMC) data or probes) and measurement campaigns (drive test, walk test). The first component has the advantage of being fully automated and offers a view in real time of the network performance. The second component allows pushing the investigation to pinpoint areas of poor quality and guide corrective actions. But this solution doesn't indicate the real user experience often referred to as Quality of Experience (QoE) without being restrictive in terms of spatial and temporal coverage. In order to collect the QoS and QoE indicators as experienced by the end user in statistically significant manner, two options are possible today: Mobile QoS Agents (MQA) or Minimization of Drive Tests. An MQA is a piece of software embedded and running on a standard mobile terminal for the purpose of measuring service quality. This can effectively turn thousands of commercial mobile phones into service quality probing stations. MDT is a feature specified by 3GPP since Release 9, as an automated solution involving User Equipments (UE) to reduce the operator costs for network optimization and drive tests. In both cases, quality indicators are reported to the network together with geo-location information to allow a finer monitoring of the QoS.

Collecting statistically significant feedback on the quality of user experience is one important step; the second step is to understand the collected information. First, the amount of data to be processed is becoming more and more huge, which brings us to the "big data" challenge: how to extract knowledge from a huge amount of data.

Besides, the diversity of services and user profiles result in a variety of different metrics reflecting user expectations. Monitoring the end-user perceived quality of service raises the following questions:

a. How to quantify the "good experience feeling" of a user?
b. What is the contribution of the radio access segment to this quality of service among other possible causes?

For instance, the quality of a voice service can be estimated based on customer complaints, surveys or instrumental measurements. The major problems are known: premature unwanted call release, echo, no sound in either transmission direction, noises of different types, low speech level, clipping or cuts in the heard speech and sound. However, it is not easy to link these perceived degradations to technical causes, neither to isolate the contribution of the radio access network.

Considering mobile internet (web sites and video browsing on internet, when accessed through mobile packet networks), the quality of service experienced by the end-user can be can be evaluated through two main criteria: service access and browsing speed. Again, relating these criteria to a radio cause in not straightforward. For instance, the following failures result in the same feeling of "no connection" for the user:

a. Problem when registering to the mobile packet switched network i.e. registration procedure failure.
b. Problem to get the IP connectivity i.e. bearer establishment procedure failure.
c. Problem to resolve Uniform Resource Locator (URL) when trying to contact websites i.e. Domain Name Server (DNS) procedure failure.
d. Problem to reach external servers (routing issues).

Only the second problem can be related to a bad radio quality.

To conclude, there is still a lot of effort to be spent on the knowledge acquisition or the 'observe' step of the cognitive cycle(s). At the radio network level, the definition of the system state which is related, but not limited, to the classification of cells could be enhanced further using the feedback of the network. On the other side, monitoring the end-user quality of experience, which corresponds to a typical high level operator goal, is a challenging task, especially if we want also to extract or isolate the contribution of the radio network segment. In both areas, extracting useful and relevant knowledge from the huge amount of information available in the network (OMC, probes and soon MDT information, user complaints CEM (Customer Experience Management) data…) brings us to the Big data domain.

2.4 Conclusion

The study in this section elaborated on different parts for potential learning mechanisms in the context of Policy-Based SON Management and Cognitive Radio. First of all, an overview of the existing definitions regarding cognitive radio, network and cycle has been given, followed by a summary of available learning algorithms. After that four potential starting points in the PBSM framework have been presented where a closed feedback-loop, i.e. a cognitive cycle, could be beneficial. Such starting points include the observation of *SON actions*, the improvement of *Input Models*, the adjustment of *SON Management* operation during run-time and the *Transformation of High-Level Operator Goals*. Such starting points have been evaluated w.r.to the data needed, the time needed to aggregate enough network measurements and the main elements of a cognitive cycle. In addition key points regarding the *knowledge acquisition* and *data management* have been addressed. These points are strongly related to data aggregation and evaluation issues and have been worked out by synchronising with the activities of *Monitoring and Diagnostics*.

The results of this study reveal that cognitive components are crucial for a mobile radio system. Also note that first activities started in [5] include a simple learning component in the PBSM framework in order to replace SON Function Models by real network measurements over time. With cognition, other components allow adapting the mobile network to varying conditions that naturally change, not only over time, but also in space. This and the fact that the overall requirements in terms of traffic demand by the users increases as well, makes a learning component important in order to detect and react on changes that happen in the network.

2.5 References

[1] J. Mitola III. [Online]. Available: [1] http://www.imit.kth.se/info/GRU/Events/Old-Seminars/1999/19990520-13.00%3ACCSLab-Seminar.html. [Accessed 8 April 2015].

[2] J. Mitola III, "Cognitive Radio - An Integrated Agent Architecture for Software Defined Radio," Royal Institute of Technology (KTH), 2000.

[3] J. Mitola III and G. J. Maguire, "Cognitive radio: making software radios more personal," *Personal Communications, IEEE,* vol. 6, no. 4, pp. 13-18, 1999.

[4] International Telecommunication Union, *Report ITU-R SM.2152 Definitions of Software Defined Radio (SDR) and Cognitive Radio System (CRS),* 2009.

[5] J. O. Kephart and D. M. Chess, "The Vision of Autonomic computing," *Computers,* vol. 36, no. 1, 1 January 2003.

[6] R. C. Qiu, Z. Hu, H. Li and M. C. Wicks, Cognitive Radio Communications and Networking: Principles and Practice, Wiley, 2012.

[7] EU FP7 project SEMAFOUR (Self-management for unified heterogeneous radio access networks), "Deliverable 5.3, ‘Integrated SON Management – Policy Transformation and Operational SON Coordination (final results)’," February 2015.

[8] S. Hahn and T. Kürner, "Managing and Altering Mobile Radio Networks by Using SON Function Performance Models," *ISWCS 2014 - Fourth International Workshop on Self-Organizing Networks (IWSON 2014),* Spain, Barcelona, August 26th, 2014.

[9] S. Hahn, S. Lohmüller, D. Götz and T. Kürner, “Classification of Cells Based on Mobile Network Context Information for the Management of SON Systems,” *VTC-Spring, Fifth International Workshop on Self-Organizing Networks (IWSON 2015),* 2015.

3 Device-to-Device communication

3.1 Introduction

Device-to-Device (D2D) technology enables devices to communicate directly with each other without passing via the network infrastructure, or alternatively, in network assisted mode, D2D connectivity establishment is controlled by the network. While D2D technology is already well established in the market (e.g. Bluetooth), it has been introduced into the cellular context in 3GPP Release 12 for the LTE technology under the term Proximity Services (ProSe). The area of D2D is expected to take a central part in the 5G systems, encompassing other types of communicating devices, such as Machine-to-Machine (M2M) or Vehicular to Vehicular (V2V). Furthermore, D2D could play a role in future networks as a mean to achieve certain performance targets such as very low latency, e.g. for Machine Type Communication (MTC) [10].

The D2D technology further increases the network heterogeneity and its degree of distribution. It is expected to operate with a certain degree of autonomy, with self-organization capabilities. Hence D2D is expected to enlarge the Research &Development front for SON evolutions. Among the identified use cases for D2D is network enhancement, namely using D2D connections to improve the network performance in term of capacity and coverage. Network enhancement requires to identify the type of D2D connections, to optimally allocate resources to these connections and to manage interference. This is just one example where self-organization is expected to play a role in the D2D technology.

We introduce the basic classification of D2D communication (see for example [11]) that is adopted in this Chapter (see *Figure 3.1*). In *inband* category, D2D communication uses the cellular spectrum. In the *underlay* category, the D2D users share the same spectrum as the cellular users (also denoted as *Reuse* mode). If the spectrum is divided between the cellular and D2D users, the *overlay* category is used. In *outband* communication, D2D users utilize unlicensed spectrum, e.g. Industrial, Scientific and Medical (ISM) radio bands, and can be controlled by the network (*control* category) or operate autonomously (*autonomous* category).

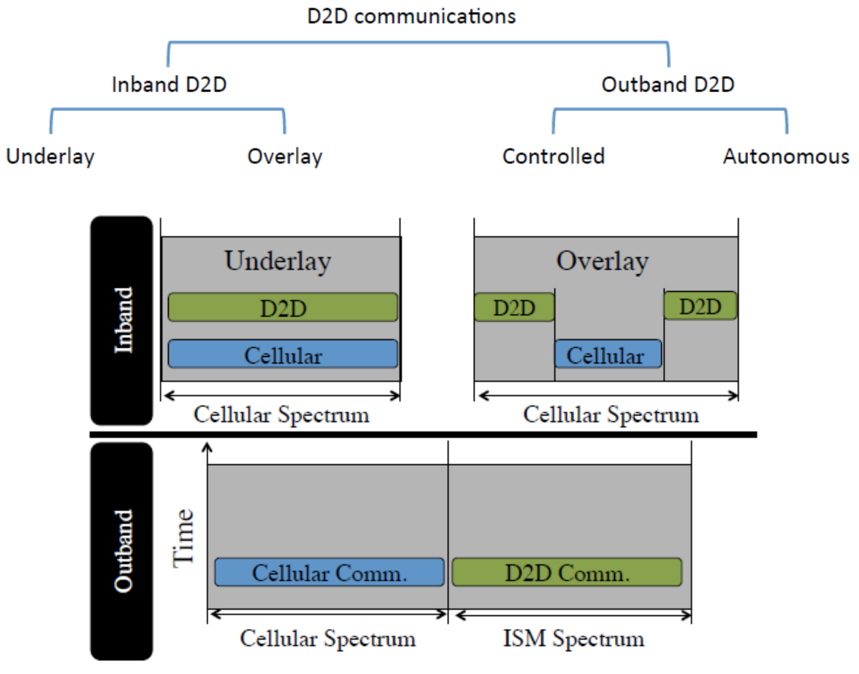

Figure 3.1: Classification of D2D communication ***[11]***.

In addition to the operation modes of D2D communication, three distinct types of operation scenarios can be distinguished (see *Figure 3.2*). When in *in-coverage (A)*, all D2D communication partners reside within the networks coverage area. When in *partial coverage (B)*, communication takes place between devices *in*- and *out of coverage*, e.g. when a device is used as a relay for coverage extension. In *Out of Coverage (C)*, the communication is performed in autonomous mode.

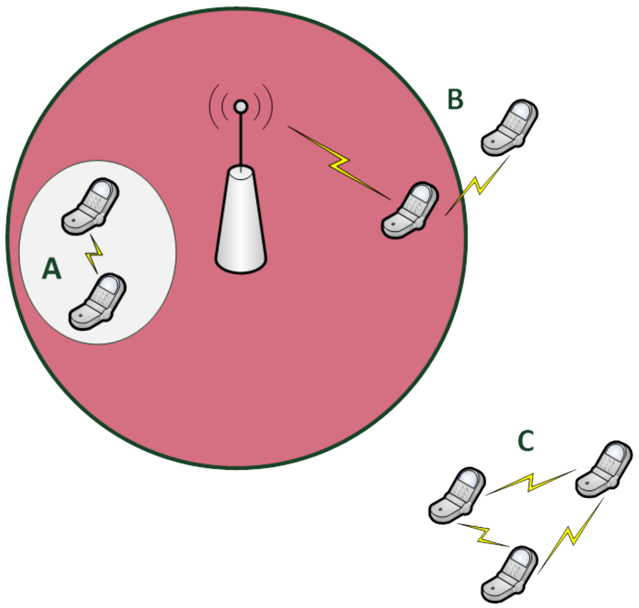

Figure 3.2: Different D2D scenarios: In Coverage (A), Partial Coverage (B), Out of Coverage (C)

This Chapter presents a short overview of D2D applications and a brief summary of the state of the art from research and standardization angle. A few requirements for implementing SON functions are listed. First ideas and discussion on SON functions for D2D, with a particular focus on the network enhancement use case are summarized.

3.2 Background on Device-to-Device communication

While D2D communications has been first standardized and developed for Bluetooth and Wi-Fi (Wi-Fi Direct) technology, its introduction in the LTE is likely to enable large scale deployment D2D with new applications and services. The main applications and services for D2D that are studied today focus on commercial applications, public safety services, M2M and Vehicle-to-X (V2X) applications.

Commercial applications

We classify commercial application services into the following three groups: (*i*) Discovery–centric services (*ii*) Communication –centric services and (*iii*) network enhancement based services. The latter can be seen as a service used by operators to enhance network performance and hence its profitability.

(i) Discovery-centric services:

Discovery-centric services are related to the capability of D2D devices to discover other devices in their proximity, (e.g. smartphones, or sensors embedded in objects within the surrounding environment, etc.). The discovery process typically involves identifying the device identifier and its capabilities in terms of the supporting services and its available data/information. Examples are guidance within buildings for public and commercial usages, or real-time public transport information; Proximity personalized services such as local advertising within malls or assistance services depending on the location of users; Social discovery of nearby persons belonging to a certain group with similar interest [11].

(ii) Communication-centric services:

Communication-centric services are driven by content sharing / exchange between D2D users, e.g. files, photos/videos, on demand proximate content such as maps or cinema program; Content Centric

Networking (CCN) for local device cashing and autonomous dissemination; Content synchronization between peripheral devices at home or at office (e.g. between smartphone, camera, PC).

(iii) Network enhancement:

Network enhancement can be viewed as a service for operator, namely the use of D2D as a mean to improve connectivity, QoS, and performance in terms of coverage and capacity. Typically, this category is divided into two sub-categories: mode selection, encompassing cellular mode (mobile-base station), D2D mode between two nearby mobiles/devices, and relay mode, where a mobile achieves connectivity to the infrastructure (e.g. Wi-Fi access point or base station) via one or more intermediate devices serving as relays or gateways. D2D and relay modes can be established by the network. When a D2D data/video or voice calls between nearby devices are established in order to decongest a cell, the term D2D offload is sometimes used. D2D coverage extension aims at enhancing coverage at cell edge or at local outage zones such as outdoor to (deep) indoor communication [11] [12] [13].

Public Safety Services

A more specialised service, relying on the combination of local and wide-area communication, is the use of cellular D2D in Public Safety (PS) services as a replacement [14] for the currently used trunked radio systems like TETRA (Terrestrial Trunked Radio System). In current 3GPP standardization activities, PS Proximity Sevices (ProSe) is primarily considered to extend the push-to-talk capabilities (transmit only when a button is pushed) of current radio systems used by PS authorities. By increasing the capacity and flexibility as well as enabling new applications, e.g. the streaming of video feeds at a disaster site for better coordination or the distribution of digital maps to improve orientation. While it also relies on mutual discovery of UEs to enable direct mode and group communication, PS ProSe need to be able to operate in no-coverage situations and without prior discovery. As this application is mostly 3GPP driven and has not been given much attention by the academic community, the current 3GPP point of view is summarized in Section 3.2.1.

M2M and V2X applications:

The direct link aspect between devices in close proximity and the resulting low latency are strong incentives to enable ProSe in M2M, especially in situations where information dissemination in direct proximity needs to be combined with wide area communication. In V2X or communication in smart electrical grids for example, ProSe offers many possibilities.

For V2X application of D2D, some work has been carried out within [15] using the combined possibilities of LTE and D2D to overcome connectivity issues with the existing 802.11p standard used for V2X. In addition, some preliminary work has been carried out in [16] to investigate the LTE D2D resource allocation with the strict latency and reliability requirements for V2X communication. The applicability of D2D in the context of smart grids is shown in [17], where the concept of data aggregation and forwarding using D2D in LTE-A is investigated.

The role of D2D in 5G networks

While D2D is considered as an add-on of the LTE technology, it is one of the pillars of future 5G systems. D2D will contribute to new applications and services (e.g. enhanced commercial services) on the one hand and to network enhancement in terms of reliability, spectrum and energy efficiency on the other hand.

From the application perspective, M2M (or MTC in METIS Horizontal Topics) and Internet of things (IoT) are expected to proliferate in both industry and the public sector. In industry, M2M targets to provide high resilience and reliable communication with very low latency. Communication between machines in a factory for example could be established by means of MTC. V2X (i.e. V2V and Vehicle-to-Infrastructure (V2I))} communication is one of the challenging areas for 5G systems for which expectations are particularly high. Certain companies in the car industry (e.g. BMW) and IT companies (mainly Google and Apple) target autonomous driving systems. From D2D perspective, enhanced proximity services are expected to develop, such as services for smart cities or mass events and other type of crowd networking.

The main reference for D2D in 5G scenarios is the METIS project where both D2D, V2X and MTC communication scenarios are described in detail [18].

3.2.1 Background of D2D Communications in 3GPP

Starting in Release 12, 3GPP considers D2D communication for the LTE standard under the term Proximity Services for the following application areas:

- commercial/social use
- network offloading
- public safety (PS).

For the above application areas, an initial feasibility study was conducted [19], followed by studies in the working groups (WG) services and systems aspects (SA2) [20], (SA3) [21] and the WG Radio Access Network (RAN1) [22].

While [19] resulted in use case and requirements specifications for the respective application areas, the focus of Release 12 subsequently shifted [23], [24] towards discovery and group communication for the PS application due to the strong interest by respective responsible governmental bodies. Thus the RAN study item [22] solely covers discovery and PS, leaving the commercial/social and offloading use cases for further study and tentatively in Release 13 [24]. The use of ProSe for V2X communication is also of high interest [25] and the respective working items could be considered for Release 14.

Based on [22], the current 3GPP working assumptions for LTE ProSe (Release 12) are:

- In FDD(Frequency Division Duplex) networks, uplink spectrum is to be used. For TDD (Time Division Duplex) networks uplink timeslots shall be used although the use of DL (Downlink) timeslots is open for further study.
- The interface for the direct UE-to-UE communication can either be WLAN direct, e.g. in unlicensed bands, or a 3GPP specific radio interface in licensed bands, and is still to be specified. The 3GPP specified interface will use SC-FDMA (Single-Carrier Frequency Division Access) a waveform due to better PAPR (Peak-to-Average Power Ratio) properties compared to OFDMA (Orthogonal Frequency Division Multiple Access) .
- UEs are not capable of full-duplex communication with either ProSe, WAN or both. TDD shall be used for multiplexing transmissions.
- The system shall support a very large number of ProSe enabled UEs.

3.3 Approach for SON in future networks

This section describes requirements for some exemplary D2D application areas, both from the application point of view as well as the resulting network related requirements. Subsequently, two exemplary SON functions, for mode selection and bandwidth allocation are illustrated.

3.3.1 Vehicle-to-X (V2X)

Communication among vehicles and/or infrastructure like road side units (V2X communication) is expected to increase road safety through cooperation and improve the overall traffic flow, e.g. by disseminating information on road hazards or traffic signal phases. Additionally V2X could be used to offer infotainment or social services to passengers. We focus on radio-related requirements for typical vehicular-specific active road safety (ARS) applications as they mostly rely on direct communication

ARS applications require reliable information like position, orientation and velocity information on participants with a high level of accuracy. The V2X radio-related requirements [26] for D2D can be summarized as follows:

- Communication range is scenario dependent (50 -250m)
- Typically frequent (10 Hz) transmissions with small payload lead to low data rates for most applications. For special applications (e.g. see-through-vehicle, where a vehicle streams the video of its dashboard camera to trailing vehicles) streaming with high data rate is required.
- For ARS related frequent transmissions, low latency (< 100ms) and reliable delivery are required. This is relaxed for messages with a purely informative character, e.g. information on upcoming traffic light phase.

This leads to the following network related requirements:

- Reliable mutual discovery of devices.
- Enable grouping mechanisms based on proximity and heading, e.g. for emergency vehicle warnings
- Support for multi-hop message propagation
- Support for direct mode broadcasting of critical safety messages, e.g. collision warnings
- Mode selection and RRM for highly varying device constellations caused by the high mobility of the users

3.3.2 Public Safety (PS)

With the worldwide proliferation of LTE and its flexible spectrum requirements, a possible adaption of LTE for public safety purposes is of general interest. Especially for first responders, an increased coverage and refined group management/communication capabilities compared to the existing systems are required. To ensure an end-user focused standardization process, several governmental bodies provided specific requirements for a PS compliant radio system [27]. These resulted in the following network related requirements for PS:

- Group communication capabilities [19] [28] [28] [28] [28]: A PS UE shall be able to communicate with multiple PS UEs simultaneously using direct mode and/or traditional cellular mode.
- Authorization for the use of PS services is required at least once for each UE.
- Network controllable, one-way or mutual discovery
- 1:1 communication
- 1:x communication, with x ranging from 1 to many.
- 1:x broadcast without prior discovery of all authorized PS UEs.
- Direct mode communication shall be possible, regardless of the UEs being in or out of coverage of one/different cellular networks [19].

3.3.3 Commercial

In order to support optimized commercial services encompassing discovery-, communication-, and network enhancement services, the communication system should provide three functions: mode selection, resource allocation and interference management, and monitoring (it is noted that this is not an exhaustive list).

Mode selection:
In the context of network assisted inband D2D, three modes are proposed: *reuse* (or underlay), *dedicated* (or overlay) and *relay* modes (the notation in [29] is adopted). Mode selection algorithms should be carefully designed since they can considerably impact QoS and cell performance, e.g. in terms of user throughput, outage or energy consumption. Both channel conditions and interference produced / experienced by D2D users should be taken into account in the mode selection. It is noted that interference can impact users in the D2D serving cell or/and its neighboring cells.
D2D communications can serve as a mean to achieve certain operator policies. Different policies can be envisaged, such as: offloading of certain services from (congested) cells in cellular mode towards D2D communication, or enhance coverage for certain type of services using relay mode selection. The design of SON functions for mode selection is among the challenges of network assisted D2D.

Resource allocation and interference management:
The performance of a cell with D2D enabled connections highly depends on the resource allocation to the D2D users (e.g. transmit power, bandwidth allocation). The allocated resources can allow the network to minimize the interference generated and experienced by D2D users. Different interference management techniques have been proposed in the literature (see different examples in the survey

paper [11]). By designing SON functions that are able to manage interference and adapt resource allocation to the dynamics of traffic variation, performance can be considerably enhanced.

Monitoring:
In network assisted D2D (but also in autonomous D2D mode), it is essential for the operator to be able to monitor the network performance for both cellular and D2D links. The monitoring should allow

- to assess QoS and performance at link-, cell-, and network level
- to detect QoS problems for all type of connections
- to assess performance of triggered policies involving D2D communication, e.g. off-loading policies, mobility policies

Based on the challenges identified for D2D communication for commercial service operation, one can derive certain system requirements. Examples of such requirements are:

- Allow eNB to request UE to check, via measurements, if potential D2D UEs are in communication range
- Allow eNB to set up a D2D session and handover to - and from such a session
- Guarantee seamless handover to and from a D2D session
- Triggering and maintaining D2D connection should be transparent to the user
- Allow eNB to set up D2D connection according to specific operator policies
- Allow eNB to dynamically adjust D2D transmitted power according to measurements reported by other devices / mobiles
- Allow eNB to dynamically adjust frequency bandwidth allocated to D2D and to cellular users
- Allow eNB to monitor interference generated by D2D links to non D2D links
- Allow eNB to monitor interference experienced by D2D links
- Allow the operator to implement policies involving SON functions for D2D communication
- Allow the operator to monitor the performance gain achieved by policies involving D2D connections

3.3.4 Illustration of SON for D2D

The heterogeneity and the additional degree of distribution introduced by the D2D technology calls for self-organizing (SON) solutions. SON solutions can be used to optimally allocate resources to D2D users and to ensure cohabitation for a mixed cellular and D2D traffic. Interference management SON functions will be of particular interest in order to protect both cellular and D2D traffic, and achieve the maximum performance gain brought about by D2D users.

We distinguish two types of SON capability:

(i) The SON function maps a state of the system to an action (e.g. admission control: accept or reject a D2D connection, increase or decrease a RRM threshold) or to a quantity / value of an allocated resource (e.g. the portion of the bandwidth allocated to a user when it is scheduled). An action can be taken by a controller based on a set of rules (e.g. fuzzy logic controller [30]), or based on a function that maps KPI values into a parameter or a resource value. An example of bandwidth allocation for inband overlay D2D is shown below.

(ii) The SON function has a learning capability, namely a cognitive SON function. The decision the SON function takes improves with time thanks to a cognitive capability that learns from experience (e.g. Reinforcement Learning, [30]).

Guidelines for two SON algorithms are described below as indication for the interest of SON for the D2D technology.

Example 1: Cellular-D2D mode selection

A mobile (UE_1 in *Figure 3.3*) is admitted into the network. The mode selection can be performed in three steps:
Step 1: UE_1 receives reference signals from the base station and reports to it the signal quality
Step 2: UE_1 receives reference signals from neighboring UEs with D2D capability (UE_2 in *Figure 3.3*) and reports the signal quality to the base station.
Step 3: Based on the signal qualities (and the associated estimated throughputs), and possibly other cell performance indicators (e.g. cell load), the base station selects cellular or D2D mode.

The problem of mode selection has been addressed by several authors (see for example [29]). From the SON perspective, the challenge is to optimize cell or network objectives, in addition to the estimated throughput achieved by each mobile. In the context of network assisted D2D, the base station can take into account KPIs such as load condition (see *Figure 3.4*) and neighboring performance indicators.

The mode selection can be extended to account for the Relay mode. Mode selection is likely to be a challenging problem also in V2X communications. The choice between V2V and V2I could depend on signal strength or user speed, and KPIs related to performance, e.g. handover related KPIs.

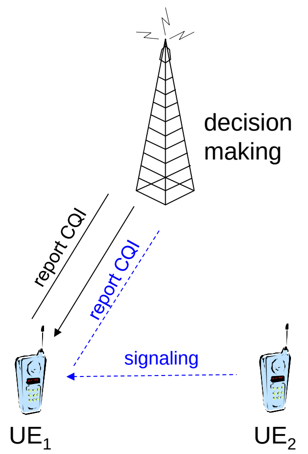

Figure 3.3: Mode selection procedure

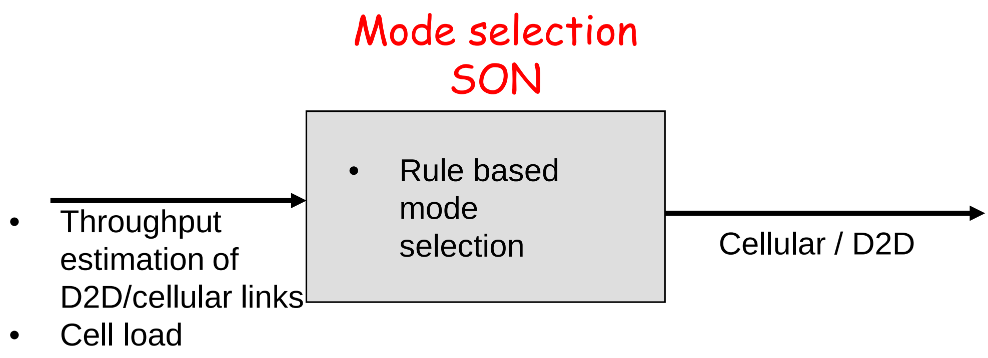

Figure 3.4: Mode selection SON

Example 2: Bandwidth allocation SON algorithm
Interference management is one of the central problems in D2D. The type of solution to manage interference and related resource allocation depends on the specific category of D2D. The example below considers the following case

- Inband – overlay D2D (cellular spectrum is divided between cellular and D2D users)

- D2D users utilize UL frequency band
- Elastic (data) traffic

The SON function dynamically determines the portion δ of the frequency bandwidth allocated to the cellular users while the remaining portion (1-δ) is allocated to the D2D users (see *Figure 3.5*). To this end, the SON function calculates the Proportional Fair (PF) utility function $U(\delta)$ which depends on the overall users throughputs. Denote by $\bar{R}_u$ the average throughput of a user u if it is allocated the entire available bandwidth. Then $U(\delta)$ is defined as

$$\boldsymbol{U_{PF}(\delta) = \sum_{u \in Cell} log(\delta \bar{R}_u) + \sum_{u \in D2D} log\big((1-\delta)\bar{R}_u\big)} \qquad (3.1)$$

where *Cell* in (1.1) stands for mobile-to-base station (cellular) communication. It is supposed here that when a user is scheduled, it is allocated the entire bandwidth. By deriving the utility with respect to δ and equating to zero one gets the value that maximizes the overall throughput

$$\delta = \frac{N_{Cell}}{N_{D2D} + N_{Cell}} \qquad (3.2)$$

Hence a closed-form function for δ is obtained, and can be applied periodically, or at arrival and departure events for example.

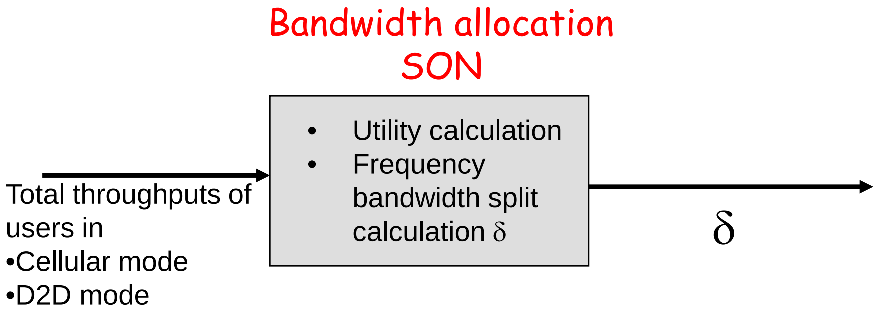

Figure 3.5: Bandwidth allocation SON algorithm

Equation (1.2) applies to elastic traffic. The extension of the solution to any traffic mix, e.g. elastic and streaming, is of interest. For other communication modes, such as inband underlay D2D, specific SON algorithms for optimized resource allocation should be designed. Interestingly, a mixed underlay/overlay approach has been proposed in [31].

3.4 Conclusion

The introduction of Device-to-Device communication into LTE offers vast possibilities to enhance the mobile communication over cellular mobile networks, from both service and performance point of view. While many different applications can be envisioned to benefit from proximity services, the accompanying challenges for mobile networks are immense.

The increasing heterogeneity of mixed cellular and D2D traffic along with an immense expected growth of devices will require new solutions for mobility management, radio resource management, interference management and energy optimization. We have presented an overview on the state of the art of D2D in LTE in academia and standardization and summarized the different network-related challenges involved for exemplary application areas like V2X, PS and application in commercial networks. Based on this, we described and outlined two possible SON features for mode selection and bandwidth allocation for joint cellular and D2D communication modes.

SON functions could play an important role in autonomously managing each of the management aspects mentioned above while following a central management approach. The functions tackling the mode selection and resource allocation/interference management would deliver key functionalities required for multi-mode communication in cellular network, thus making the benefits of D2D tangible.

3.5 References

[1] J. Mitola III. [Online]. Available: [1] http://www.imit.kth.se/info/GRU/Events/Old-Seminars/1999/19990520-13.00%3ACCSLab-Seminar.html. [Zugriff am 8 April 2015].

[2] J. Mitola III, „Cognitive Radio - An Integrated Agent Architecture for Software Defined Radio," Royal Institute of Technology (KTH), 2000.

[3] J. Mitola III und G. J. Maguire, „Cognitive radio: making software radios more personal," *Personal Communications, IEEE,* Bd. 6, Nr. 4, pp. 13-18, 1999.

[4] International Telecommunication Union, *Report ITU-R SM.2152 Definitions of Software Defined Radio (SDR) and Cognitive Radio System (CRS),* 2009.

[5] J. O. Kephart und D. M. Chess, „The Vision of Autonomic computing," *Computers,* Bd. 36, Nr. 1, 1 January 2003.

[6] R. C. Qiu, Z. Hu, H. Li und M. C. Wicks, Cognitive Radio Communications and Networking: Principles and Practice, Wiley, 2012.

[7] EU FP7 project SEMAFOUR (Self-management for unified heterogeneous radio access networks), „Deliverable 5.3, 'Integrated SON Management – Policy Transformation and Operational SON Coordination (final results)'," February 2015.

[8] S. Hahn und T. Kürner, „Managing and Altering Mobile Radio Networks by Using SON Function Performance Models," *ISWCS 2014 - Fourth International Workshop on Self-Organizing Networks (IWSON 2014),* Spain, Barcelona, August 26th, 2014.

[9] S. Hahn, S. Lohmüller, D. Götz und T. Kürner, „Cell Class Paper IWSON 2015".

[10] Z. Li, M. Moisio, M. A. Uusitalo, P. Lundén und C. Wi, „Overview on initial METIS D2D Concept," in s *5GU Conference*, Levi, Finland, 2014.

[11] A. Asad et al, „A survey on device-to-device communication in cellular networks," *Communications Surveys & Tutorials, IEEE,* Bd. 16, Nr. 4, pp. 1801-1819, 2014.

[12] K. Doppler et al, „Device-to-device communication as an underlay to LTE-advanced networks," *Communications Magazine, IEEE*, Bd. 47, pp. 42-49, 2009.

[13] D. Feng et al, „Device-to-device communications in cellular networks," *Communications Magazine, IEEE,* Bd. 52, Nr. 4, pp. 49-55, 2014.

[14] 3GPP TS 22.468 V12.1.0, Group Communication System Enablers for LTE (GCSE_LTE) (Release 12), September 2014.

[15] E. Abd-Elrahman, A. M. Said, H. Aififi und M. Marot, „A Hybrid Model to Extend Vehicular Intercommunication V2V through D2D Architecture," in s *ICNC 2015 : 2015 International Conference on Computing, Networking and Communication,* Anaheim, California.

[16] W. Sun, E. G. Ström, F. Brännström, Y. Sui und K. C. Sout, „D2D-based V2V Communications with Latency and Reliability Constraints," in s *Globecom 2014*, Austin Texas, USA, 2014.

[17] G. Rigazzi, F. Chiti, R. Fantacci und C. Carlini, „Multi-hop D2D networking and

resource management scheme for M2M communications over LTE-A systems," in s *2014 International Wireless Communications and Mobile Computing Conference (IWCMC),*, Nicosia, 2014.

[18] NGMN Alliance, „NGMN 5G White paper," 2015.

[19] 3GPP TR 22.803 V12.2.0, „Feasibility study for Proximity Services (ProSe) (Release 12)," June 2013.

[20] 3GPP TR 23.703 V12.0.0, „Study on architecture enhancements to support Proximity-based Services (ProSe) (Release 12)," February 2014.

[21] 3GPP TR 33.833 V1.0.0 , „Study on security issues to support Proximity Services (Release 12)," June 2014.

[22] 3GPP TR 36.843 V12.0.1, "Study on LTE Device to Device Proximity Services; Radio Aspects (Release 12)," March 2014.

[23] Vodafone et. al, „Agreements from TSG RAN on Work on Public Safety Related Use Cases in Release 12," 2013.

[24] M. Gundlach, „Presentation: Overview of D2D Proximity Services Standardization in 3GPP LTE," in s *European Conference on Networks and Communication (EuCNC2014) - Workshop on Radio Access and Spectrum,* Bologna, 2014.

[25] 3GPP TSG-SA WG1 Meeting #69 S1-150005, „Minutes of 3GPP TSG SA WG1 Meetings #67bis and #68," February 2015 .

[26] ETSI, „Intelligent Transportation Systems (ITS); Vehicular Communications;Basic Set of Applications; Definitions," 2009.

[27] (UK) Home Office and US Dept of Commerce, „Rationale for the Public Safety Priorities for Release 12," in s *TSG SA Meeting #61*, 2013.

[28] 3GPP TS 23.468 V12.3.0 , „Group Communication System Enablers for LTE (GCSE_LTE); Stage 2 (Release 12)," December 2014.

[29] K. Doppler et al, „Mode selection for device-to-device communication underlaying an LTE-advanced network," *Wireless Communications and Networking Conference (WCNC),* 2010.

[30] P. Munoz, R. Barco und I. de la Bandera, „Load balancing and handover joint optimization in LTE networks using Fuzzy Logic and Reinforcement Learning," *Computer Networks,* Bd. 76, pp. 112-125, 2015.

[31] X. Chen et al, „Downlink resource allocation for device-to-device communication underlaying cellular networks," *23rd International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC),* 2012.

[32] T. Toukabri, A. M. Said, E. Abd-Elrahman und H. Afifi, „Cellular Vehicular Networks (CVN): ProSe-Based ITS in Advanced 4G Networks," in s *2014 IEEE 11th International Conference on Mobile Ad Hoc and Sensor System*, 2014.

[33] R. Tanbourgi, H. Jäkel und F. Jondral, „Cooperative interference cancellation using device-to-device communications," *IEEE Communications Magazine,* Bd. 52, Nr. 6, pp. 118-124, June 2014.

4 Nomadic networks

4.1 Introduction

A nomadic network is a network in which so-called nomadic network nodes provide communication capabilities without a fixed backhaul connection. The opportunistic use of nomadic nodes is seen as a key element of future (5G) networks to allow for a dynamic and flexible network extension depending on service, capacity and coverage demands [1] [2]. This means that nomadic nodes can be switched on or off in case there is a need for extra capacity or coverage, or when there is no longer such a need (e.g., parked vehicles with on-board relay infrastructure and advanced backhaul antennas); that they can be moved to places where there is such a need (e.g., fire trucks); or that they can move through the fixed network (i.e., the mobile network) while providing service to users on board of for example a bus or train (i.e., mobile relays [3]). This implies that nomadic nodes are characterized by an inherent uncertainty with respect to their spatial and temporal availability. In this study this uncertain temporal and/or spatial availability will serve as the defining trait of a network to be called nomadic.

Potential deployment scenarios for nomadic nodes are traffic jams, where good network experience is sought by in-vehicle users stuck in the traffic jam; public transport, to serve the on-board passengers; blind spots, i.e., rural areas with sparse network infrastructure; emergency scenarios like natural disasters or terrorist attacks, after which only some infrastructure remains or after which there is network congestion due to excessive calls made in the emergency area; sporadic events like public gatherings, sport games or outdoor concerts; etc.

Various aspects that are specifically related to nomadic networks can be identified and linked to the temporal and spatial availability of nomadic nodes. For the temporal availability these are the activation and the deactivation of a nomadic node, and for the spatial availability these are the moving of a nomadic node and a user into or out of each other’s vicinity.

The aspects that are related to the activation of nomadic nodes are the decision process of whether and when to activate a nomadic node on one hand and aspects that are related to the activation itself on the other hand. Deciding whether and when to activate a nomadic node involves the identification of future increasing coverage and capacity demands in order to make sure that a nomadic node can be switched on to resolve the issue in a timely manner. Aspects that are related to the activation itself are for instance coordinating resource usage between the fixed network and the nomadic nodes in order to avoid interference; node selection, i.e., selecting the base station to which a nomadic node will be assigned; and user association, i.e., deciding which users will be assigned to which of the nomadic nodes and which to the fixed network.

Similar aspects are related to the deactivation of nomadic nodes. First there is the decision whether and when to deactivate a nomadic node. This decision process involves the identification of future decreasing coverage and capacity demands, where also energy saving opportunities can be taken into account. Once the decision to switch a nomadic node off has been made (either by the aforementioned process or by manual intervention) the deactivation process involves finding suitable handover targets for the remaining users that are connected to the nomadic node and preventing new users to still be associated with the node.

There are various ways in which a nomadic node and a user can move into each other’s vicinity. The nomadic node can for instance be mounted on a moving vehicle like a bus that moves along the street or a nomadic network can be set up by vehicles that are stuck in a traffic jam. Handover management is an important aspect in this case. It involves deciding whether and when to handover a user to the nomadic node. In case of a moving nomadic node it is very important to decide which users are allowed to connect to the nomadic nodes and which users are not. Users that are for instance outside a bus should be prevented from handing over to the nomadic node on the bus, as they will not be able to stay connected to it for a very long time. On the other hand, users that are getting on the bus should be handed over to the nomadic node in a timely manner.

Aspects that are related to a nomadic node and a user moving out of each other’s vicinity are detecting that a user and a nomadic node are actually moving away from each other and to which base station to handover a user. For instance, when a user is on a bus and connected to the nomadic node that provides connectivity to users on that bus, it is important to accurately predict the moment on which to handover the user to the fixed network as there will be a very steep decline of the received signal power once the user gets off the bus and the doors close. In order to maintain connectivity the moment of handover should be decided within a range of a couple of 100 milliseconds. It is however difficult to decide when this is going to happen as each time the bus stops and the doors open there will be a sudden increase of the signal strength of the fixed network even if the user is not getting off the bus.

In this study on nomadic networks we will in particular focus on aspects related to nomadic nodes and users moving out of each other's vicinity. In particular we will focus on the above-mentioned bus scenario in which a user that is connected to a nomadic node on the bus is getting off the bus. Opportunities for applying SON in this scenario will be discussed and a conceptual design for a SON function will be proposed.

The remainder of this chapter is structured as follows. Section 4.2 gives an overview of literature related to nomadic networks in general. Section 4.3.1 describes the specific problem that is considered in this deliverable. Section 4.3.2 explains what information can be exploited in a SON algorithm tackling the problem at hand, and in Section 4.3.3 a conceptual SON algorithm is proposed. Finally, Section 4.4 concludes this chapter.

4.2 Background on Nomadic Networks

The use of nomadic nodes as a means to provide a flexible network deployment has been considered and discussed in literature in the past years.

In [4], the performance of various relaying modes in a nomadic relay network is assessed, illustrating that deploying nomadic relays can significantly improve network performance in terms of coverage and capacity. Results of [4] show that for the purpose of coverage extension, deploying Layer-2 decode-and-forward relay nodes is a good choice for nomadic nodes, while for improving the throughput of UEs, Layer-3 decode-and-forward in-band relay nodes are preferable.

Similar as in [4], most papers discussing nomadic nodes consider the LTE relay solution developed in 3GPP [5] as the means to provide backhaul to nomadic nodes. However, also other wireless backhaul solutions recently being investigated for future heterogeneous networks, like the LTE-based backhaul concept [6], could be applied. Where LTE relay has been designed to use LTE link technology for both backhaul and access, LTE-based backhaul is access-agnostic and can be used with any access link technology. Further, backhaul links and access links typically use radio resources in separate frequency bands with LTE-based backhaul, while the (in-band) LTE relay solution shares radio resources between backhaul and access links.

In [7], coarse nomadic node selection is investigated, i.e., the selection from a set of available candidates of the best nomadic node in terms of downlink SINR on the backhaul link considering shadowing only (so considering only the long-term channel quality). The performance of the selection method is evaluated in a parking lot scenario, in order to take the uncertainty of the availability of nomadic nodes into account. In the considered scenario, nomadic nodes are mounted on vehicles and provide service when the vehicles are parked. Results show that performing coarse nomadic node selection provides significant gains on the backhaul link SINR relative to random nomadic node selection. Achieved SINR (Signal-to-Interference-and-Noise-Ratio) gains on the backhaul link are shown to translate into clear improvements in end-to-end rates. The deviation from the maximum achievable end-to-end rate gains (achieved with optimal nomadic node selection, i.e., considering both shadowing and multi-path fading) becomes negligible when the access link is the bottleneck.

In [8], an optimization problem that aims at minimizing the overall energy consumed by all active nodes is formulated for the assignment of nomadic nodes to base stations and of UEs to nomadic nodes or to base stations. Since a global optimum for the problem is out of reach, two heuristic algorithms are proposed and evaluated for energy consumption. Numerical results show that the proposed algorithms have considerable potential for energy savings compared to the closest cell selection algorithm.

4.3 Approach for SON in Future Networks

4.3.1 Problem Description

As mentioned in Section 4.1, this study will focus on aspects related to nomadic nodes and users moving out of each other's vicinity. In particular, the focus will be on a scenario where a user that is connected to a nomadic node on a public bus is getting off the bus. In such a scenario a nomadic node is mounted on the bus in order to provide service to the passengers on the bus. The metal enclosure of a bus attenuates a wireless signal considerably [9], which means that the spectral efficiency that can be achieved inside the bus will be lower and that mobile devices are required to use a higher transmit power. Providing service on a bus by deploying a nomadic node will resolve these issues. The deployment of this nomadic node however comes with problems of its own. One of these problems is determining when a user that is connected to the nomadic node on the bus has to be handed over to the fixed network outside the bus.

When a user that is connected to the nomadic node on the bus is getting of the bus, there are only a few seconds between the user getting up from his or her seat and the doors of the bus closing. During this short interval the entire handover has however to be carried out as it is no longer possible to maintain connectivity once the doors are closed and the bus continues its journey. At the same time it is also not possible to carry out the handover in advance as the bus will not have come into the range of the fixed based station yet. Therefore it is needed to accurately determine when the handover will have to occur in order to carry it out in a timely manner.

In LTE, handover decisions are usually based on RSRP (Reference Signal Received Power) and RSRQ (Reference Signal Received Quality) measurements of the surrounding eNodeBs. In the case of the aforementioned scenario it will be difficult to solely base the handover decision on these RSRP/RSRQ measurements as there will only be a small difference between the measurements obtained when the doors open and close again while the user remains seated and when the user is getting off. Our study will therefore concentrate on augmenting these RSRP/RSRQ measurements with additional information and using SON techniques to accurately predict the most optimal moment to initiate a handover to the fixed network.

In [10] and [11], an alternative solution that aims at resolving the problem of sudden changes in signal strength is proposed. This technique, called forward handover, allows the eNodeB to which a UE reconnects after a radio link failure (RLF) to obtain the UE's context and buffered packets from the eNodeB to which the user was connected before the RLF. This will allow a faster recovery of the connection. While forward handover aims at solving the problem after it has occurred, we will focus on avoiding the problem instead.

In [12], the situation that UEs are connected to a stationary mobile relay station which suddenly starts moving, without the UEs moving along, is considered. This situation largely corresponds to the focus of our study. In [12], a new handover algorithm, called Relative Velocity Aided Handoff (RVAH), is proposed. UEs are supposed to measure besides the received signal strengths from their serving and surrounding base stations also their relative velocity to these base stations. Further the algorithm defines a relative velocity threshold V_0. Normally, the traditional handover decision process based on hysteresis and time-to-trigger is used. However, in two cases this handover decision process is overruled: (i) in case the relative velocity of a UE to its serving base station is greater than the threshold V_0 and a target base station to which the relative velocity is below V_0 is available, the UE should initiate the handover procedure immediately, irrespective of the fulfillment of the hysteresis and time-to-trigger conditions; (ii) in case the relative velocity of a UE to its serving base station is below V_0, the UE should never initiate a handover to a base station to which its relative velocity is higher than V_0, again irrespective of the fulfilment of the hysteresis and time-to-trigger conditions, in order to avoid ping-pongs. As such, the RVAH algorithm aims to increase the handover success rate when the mobile relay station changes its moving pattern. In Section 4.3.2.2 we refer to a way to determine the relative velocity of a user to a base station. The RVAH algorithm will be used in Section 4.3.3 as the basis of the developed SON algorithm. For this the V_0 parameter will be tuned automatically per bus stop.

4.3.2 Opportunities for Applying SON

This section gives a description of specific information that can be collected or measured and made available to a nomadic node that is deployed on a bus. This information can then be exploited when designing a SON function that aims at optimizing the handovers of users that are leaving the bus.

4.3.2.1 Location of Bus

Through GPS (Global Positioning System) and Information Management Systems like the one provided by [13] information is available about whether a bus is moving or is at a stop, and about between which stops it is driving or at which stop it is. This information can be exploited by a SON function of the nomadic node.

First of all, it is clear that users will not be leaving or getting on the bus while it is traveling between stops. This means that handovers from users outside the bus to the nomadic node that is mounted on the bus and from users on the bus to another node can be prohibited or be performed with very conservative parameters while the bus is traveling between stops.

Furthermore, when the bus is at a bus stop a SON function could adapt the parameters of the handover algorithm depending on at which stop the bus is. As busses always follow the same trajectory after leaving a bus stop, the signal strength from the nomadic node on the bus will degrade in a similar fashion for all users that get off the bus at that bus stop. This fact could be exploited by learning the optimal setting for the handover parameters per bus stop.

4.3.2.2 Relative Velocity of Users

In [14] a method that can be applied by a UE for estimating its relative radial velocity to its serving eNodeB (SeNB) and its neighboring eNodeBs (NeNBs) is presented. This method is based on the Doppler power spectrum which is derived from the reference signals of the cell. The accuracy of the method is a trade-off between processing capabilities, time required for the velocity estimation and battery drain. Simulations in [14] show that the estimates are accurate enough for basing handover decisions on.

The RVAH algorithm that was discussed in Section 4.3.1 requires UEs to measure their relative velocity to their serving and surrounding base stations. The algorithm uses these relative velocities to decide whether an immediate handover of a user is needed or whether the normal handover triggering procedure will be used. Similar as in the RVAH algorithm, the relative velocity metric will play an important role in the SON function that we will propose in Section 4.3.3.

4.3.2.3 User Behavior and Time of Day/Day of Week

Other pieces of information that can be used to influence the handover behavior of users in the bus scenario are the bus stop where a user got on the bus, the time of the day and the day of the week, and whether it is a holiday or not. For instance, during morning rush hour, users will be more likely get off the bus at a stop in the business area of a city, while during the evening rush hour users will be more likely get off the bus in a residential area or at a train station. Although the SON algorithm that will be proposed in this chapter will not exploit this type of information, it is clear that this type of information could be useful to improve the handover decisions.

4.3.3 Conceptual SON Solution

In this section a conceptual SON solution is proposed in order to illustrate how the information that is described in Section 4.3.2 can be exploited by a SON function.

The basis of the SON function is a modified version of the RVAH algorithm (presented in Section 4.3.1 and in [12]), called the Modified Relative Velocity Aided Handoff (MRVAH) algorithm. The RVAH algorithm was modified such that it supports multiple handover targets. The MRVAH algorithm is assumed to be executed by the nomadic node on top of the ordinary handover algorithm. As such the part of the RVAH algorithm that deals with ordinary handovers is not included in the MRVAH algorithm.

A flowchart of the MRVAH algorithm is given in Figure 4.1. In this flowchart

- V_{NN} denotes the relative velocity of the UE to the nomadic node
- $V_{NT,j}$ denotes the relative velocity of the UE to neighbor node j
- V_0 denotes the relative velocity threshold applied by the MRVAH algorithm

Further, the MRVAH algorithm maintains a set H with which it keeps track of which UEs were handed over by it (so not by the ordinary handover algorithm) from the nomadic node to another cell. This information will later be used by the proposed SON function to tune the V_0 parameter.

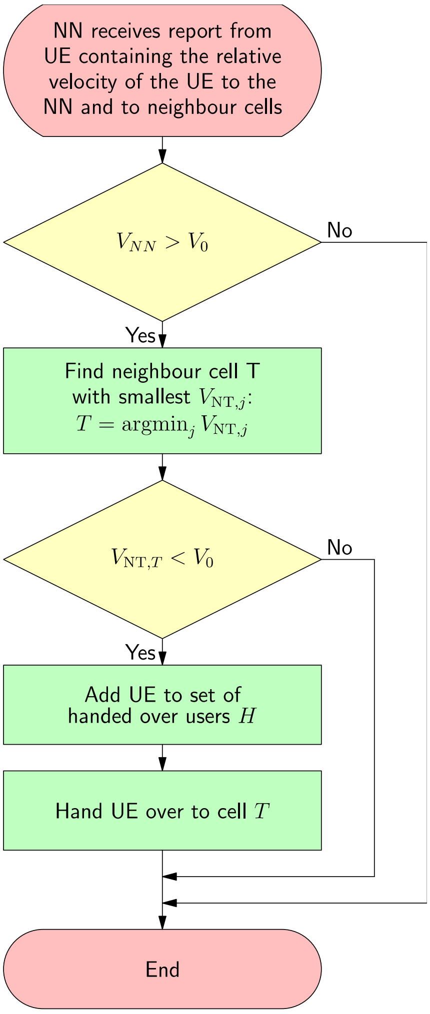

Figure 4.1: A flowchart describing the Modified RVAH algorithm.

In Figure 4.2, a general timeline of the events of interest that occur to a bus along its trajectory is shown. At each bus stop the same sequence of events occur:

1. The bus comes closer than a certain distance (*x* metres) from the bus stop.
2. The bus stops at the bus stop and its doors open, allowing users to leave and enter the bus.
3. The doors of the bus close again and the bus leaves the stop.
4. The bus has moved further than a certain distance (*y* metres) from the bus stop.

This pattern repeats itself at each bus stop that is visited by the bus.

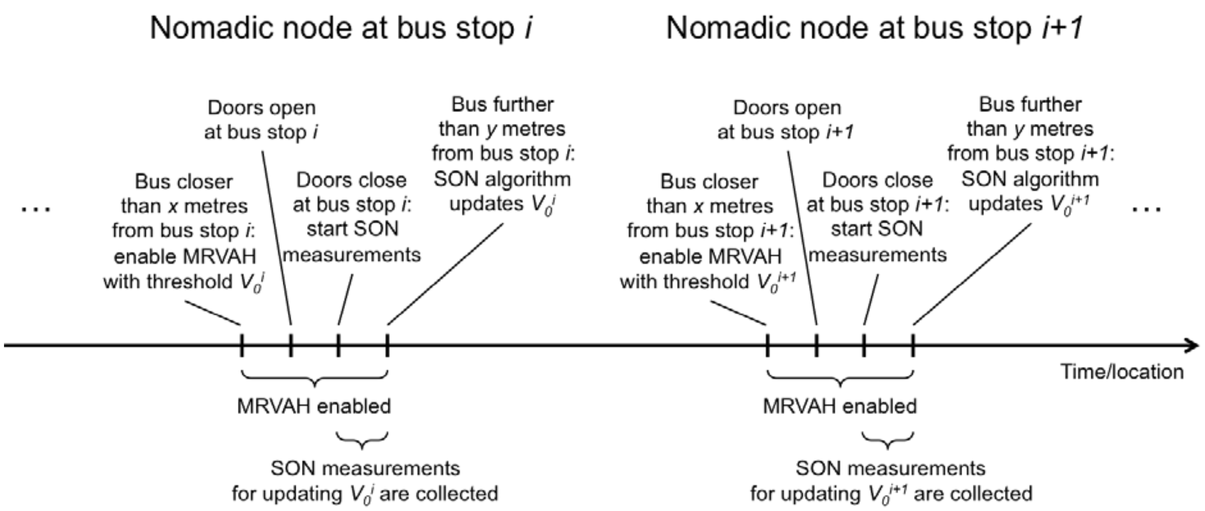

Figure 4.2: A timeline showing the events that occur to the bus along its trajectory and the corresponding actions taken by the SON algorithm.

Based on its location (see Section 4.3.2.1), it can be deduced when the bus comes closer than *x* meters from the bus stop and when it has again moved more than *y* meters away from it. Consequently it is also known when the bus is still driving between bus stops and when it is at a bus stop. The proposed SON algorithm will exploit this information to use a different threshold V_0^i for the MRVAH algorithm at each bus stop i. This parameter will furthermore be tuned for each bus stop separately by the proposed SON algorithm. Moreover the MRVAH algorithm will be disabled while the bus is driving between bus stops, as there is no point in handing over users away from the nomadic node on the bus when it is not possible that users leave the bus.

A flowchart describing the actions that are taken by the proposed SON algorithm when the bus comes closer than *x* meters from bus stop i is given in Figure 4.3.

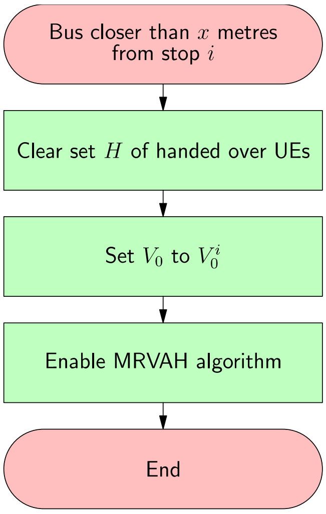

Figure 4.3: The actions that are taken by the proposed SON algorithm when the bus comes closer than x metres from bus stop i.

After the bus has stopped at bus stop i and its doors have opened and closed again to let users get off and on the bus, the SON algorithm starts performing measurements that will be used later on for optimisation of the V_0^i parameter. For this, two counters, called $N_{\text{too soon}}$ and $N_{\text{too late}}$, are reset to 0 at the moment the bus leaves stop i. These counters will count the number of handovers that were performed respectively to soon and too late by the MRVAH algorithm. Figure 4.4, Figure 4.5 and Figure 4.6 show these procedures.

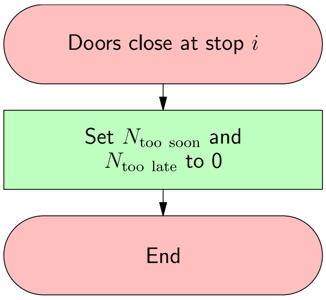

Figure 4.4: When the doors of the bus close the counters that count too soon and too late handovers are reset.

A handover that is triggered too soon by the MRVAH algorithm means that the user did not get off the bus while the MRVAH algorithm decided to hand it over away from the nomadic node to another base station. When this happens the user will be handed back to the nomadic node on the bus soon after the bus leaves the bus stop. During the period after the closing of the doors and before the bus has moved further than *y* meters away from the bus stop, the counter $N_{\text{too soon}}$ is increased each time this happens. Note that the algorithm explicitly checks whether a user that is handed over to the nomadic node was previously handed over away from the nomadic node by the MRVAH algorithm, as new users that got on the bus will also be handed over to the nomadic node. Figure 4.5 describes what happens during the period after the doors have closed and before the bus has moved more than *y* metres away from the bus stop when a user is handed over to the nomadic node on the bus.

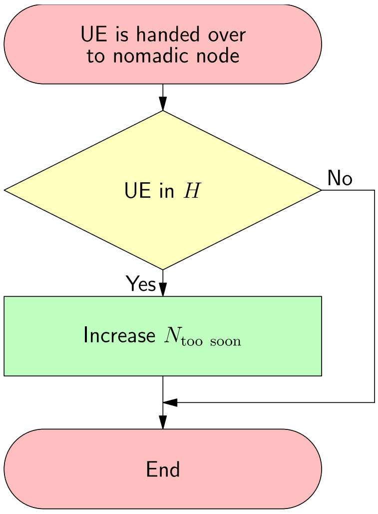

Figure 4.5: Users, which were previously handed over by the MRVAH algorithm away from the nomadic node, and that are handed back to the nomadic node, are an indication of handovers that were triggered too soon. In this case $N_{\text{too soon}}$ is increased.

Conversely, a handover that is triggered too late by the MRVAH algorithm means that a user got off the bus while the MRVAH algorithm did not decide to hand over the user to another base station outside the bus. When this happens the user is likely to be lost as soon as the bus leaves the bus stop. During the period after the closing of the doors and before the bus has moved further than *y* metres away from the bus stop, the counter $N_{\text{too soon}}$ is increased each time this happens. Figure 4.6 describes what happens during the period after the doors have closed and before the bus has moved more than *y* metres away from the bus stop when a user experiences a Radio Link Failure.

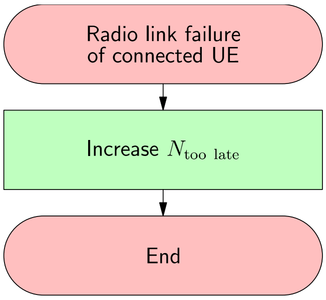

Figure 4.6: Users that experience a Radio Link Failure are an indication of handovers that were triggered too late. In this case $N_{too\ late}$ is increased.

Once the bus has moved more than y metres away from bus stop i again, the V_0^i parameter is updated and stored for further use the next time the bus visits stop i.

A handover that is performed too soon by the MRVAH algorithm signifies that the V_0 parameter of the MRVAH algorithm is set to a too low value. If a majority of errors made by the MRVAH algorithm are handovers that were performed too soon, the SON algorithm should increase the V_0^i parameter associated with stop i.

A handover that is performed too late by the MRVAH algorithm signifies that the V_0 parameter of the MRVAH algorithm is set to a too high value. If a majority of errors made by the MRVAH algorithm are handovers that were performed too late, the SON algorithm should decrease the V_0^i parameter associated with stop i.

In order to avoid that the proposed SON algorithm causes ping-pongs between a handful settings of the V_0^i parameters there has to be a significant difference between the $N_{\text{too soon}}$ and $N_{\text{too late}}$ counters in order for the V_0^i parameters to be adapted.

After a V_0^i parameter has been updated and stored, both the MRVAH algorithm and the collecting of measurements by the proposed SON algorithm for updating the V_0^i parameter of the MRVAH algorithm are disabled. Figure 4.7 shows the flowchart that describes the actions that are taken once the bus has moved further than y metres away from the bus stop i.

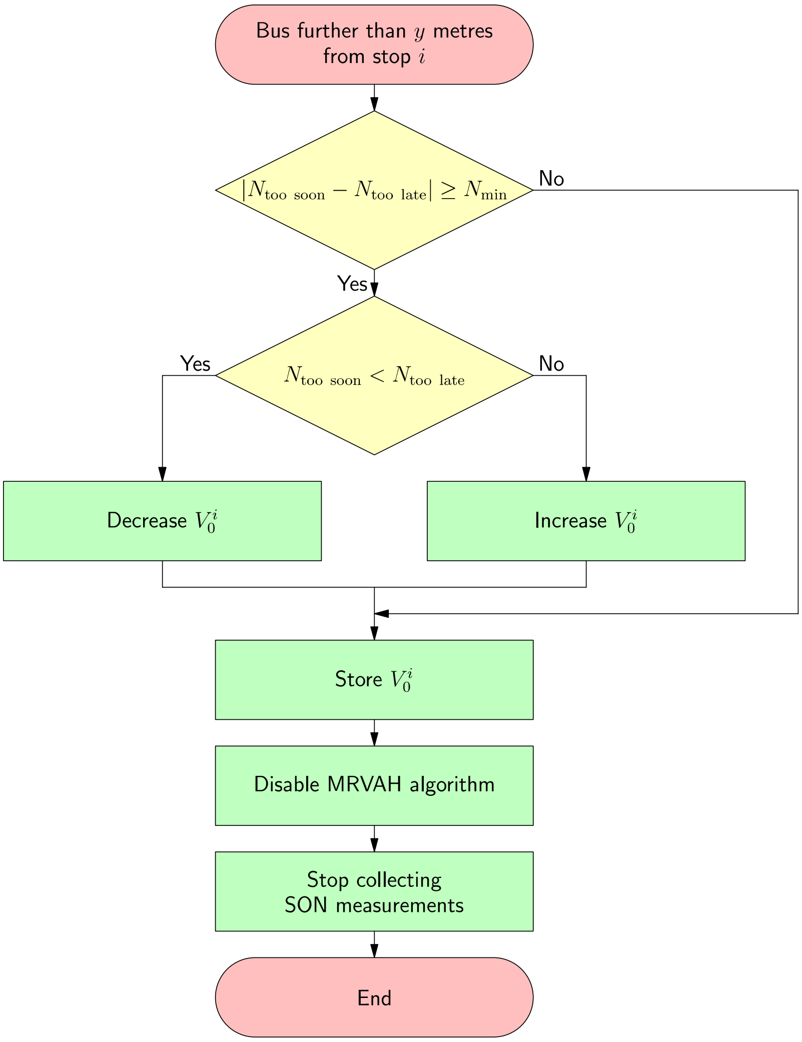

Figure 4.7: Once the bus has moved further than y metres away from bus stop i, the V_0^i parameter is updated. Then both the MRVAH algorithm as well as the collecting of measurements by the SON algorithm are disabled.

4.4 Conclusions

In this chapter nomadic networks in general and the problems that occur when nomadic nodes and users move out of each other's vicinity in particular, are studied. We focused on a bus scenario where a nomadic node is mounted on a bus to provide better coverage to users on the bus. In order to improve the handover decision when users that are connected to the nomadic node get off the bus, a SON function was proposed. At its core this function has the MRVAH algorithm, which is based on the algorithm that was proposed in [12]. The SON algorithm will set and optimise the V_0 parameter of this algorithm per bus stop such that more accurate and distinctive decisions per bus stop can be made.

4.5 References

[1] EU FP7 METIS, Deliverable 6.2: 'Initial Report on Horizontal Topics, First Results and 5G System Concepts', April 2014.

[2] F. Schaich, B. Sayrac, M. Schubert. 'On the Need for a New Air Interface for 5G', IEEE COMSOC MMTC E-Letter, Vol. 9, No. 5, September 2014.

[3] 3GPP TR36.836, 'Evolved Universal Terrestrial Radio Access (E-UTRA); Study on Mobile Relay (Release 12)', June 2014.

[4] Z. Ren, P. Fertl. ‘Performance Assessment of Different Relaying Techniques for 5G Vehicular Nomadic Nodes’, IEEE COMSOC MMTC E-Letter, Vol. 9, No. 5, September 2014.

[5] 3GPP TS 36.300, ‘Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall Description; Stage 2 (Release 12)’, March 2015.

[6] M. Coldrey, U. Engström, K.W. Helmersson, M. Hashemi, L. Manholm, P. Wallentin. ‘Wireless Backhaul in Future Heterogeneous Networks’, Ericsson Review, November 2014.

[7] O. Bulakci, Z. Ren, C. Zhou, J. Eichinger, P. Fertl, S. Stanczak. ‘Dynamic Nomadic Node Selection for Performance Enhancement in Composite Fading/Shadowing Environments’, IEEE VTC 2014-Spring, Seoul, Korea, May 2014.

[8] Z. Ren, S. Stanczak, P. Fertl, F. Penna. ‘Energy-Aware Activation of Nomadic Relays for Performance Enhancement in Cellular Networks’, IEEE International Conference on Communications (ICC 2014), June 2014.

[9] V. Deniau. ‘Analysis of the Attenuation of the WIFI Signals Inside and Outside a Railway Vehicle’, EC: RAILCOM, June 2009.

[10] Qualcomm Incorporated, ‘LTE Mobility Enhancements’, February 2010.

[11] P.A. Barany, A. Gupta, B.Spinar, A.S. Khobare, U.S. Patent 2011/0268085 A1, November 2011.

[12] H. Zhao, R. Huang, J. Zhang, Y. Fang. ‘Handoff for Wireless Networks with Mobile Relay Stations’, IEEE WCNC 2011, March 2011.

[13] http://www.televic-rail.com/en/iCoM

[14] J. Lorca, A. Sierra, ‘A Simple Speed Estimation Algorithm for Mobility-Aware SON RRM Strategies in LTE’, Wireless Days 2013, November 2013.

5 SON for LAA-LTE Channel Selection

5.1 Introduction

With the increasing traffic demand in mobile networks, operators continuously seek solutions to provide higher capacity to the users. One of the limiting factors when it comes to increasing the capacity is the limited amount of spectrum that can be used by each operator for their 3GPP networks. One possibility to bypass this limitation that has been discussed more and more lately is the usage of unlicensed spectrum as a complement to the licensed spectrum. Unlicensed spectrum are free to use, but comes with an increased risk of unexpected interference since any system might use the spectrum. In order to utilize the gains of the unlicensed spectrum without risking loosing crucial information, a technology for using unlicensed spectrum for LTE capacity enhancement while still using the licensed spectrum for any control signaling, License Assisted Access LTE (LAA-LTE), is being investigated.

In 3GPP TSG RAN #65 (September 2014), a study item called “Study on Licensed-Assisted Access Using LTE” was approved [1]. Focus is on LTE Carrier Aggregation configurations and architecture [1], where the primary carrier for control signaling, mobility and user data is always placed on the licensed spectrum, and secondary carriers can be placed on the unlicensed spectrum. The unlicensed spectrum may be used only for downlink, or for both uplink and downlink.

The usage of unlicensed frequency bands comes with requirements in some regions of the world, e.g. Listen-Before-Talk. Independent of regulations, LAA-LTE should be able to co-exist with other technologies on the unlicensed band, for example Wi-Fi, without causing too much interference. The target is that LAA-LTE would operate as a “good neighbor”, without significant impact on legacy systems [2].

One part of operating as a “good neighbor” is to select a suitable channel for LAA-LTE. In the channel selection, both interference on LAA-LTE caused by other transmissions in the band, as well as the interference LAA-LTE creates towards others should be considered. This study aims at defining conceptual SON solutions to automatically perform LAA-LTE channel selection, including solutions for triggering such selection in a good manner. A starting point will be to investigate existing channel selection methods used for Wi-Fi, and the possibility to use these, or similar methods as input to the development of a channel selection SON function for LAA-LTE.

5.2 Background on LAA-LTE and Channel Selection in Unlicensed Bands

5.2.1 Literature Review

The usage of LTE in unlicensed frequency and the coexistence with other technologies bands has been studied and discussed in literature during the last couple of years. In [3], three design principles are presented, proposing LTE in unlicensed spectrum (LTE-U) to be designed 1) integrated with the licensed spectrum, 2) with minimum changes to the LTE air-interface, and 3) ensuring co-existence with other systems using the unlicensed spectrum. The 3GPP study item “Study on Licensed-Assisted Access Using LTE” goes in line with principle 1), focusing on LTE in unlicensed frequency bands with assistance from licensed frequency bands [1]. In practice, this means that LTE Carrier Aggregation configurations and architecture is used, utilizing the licensed spectrum for control signaling, mobility and user data, while secondary carriers for user data can be placed on the unlicensed spectrum. Using LTE Carrier aggregation for LAA-LTE is also described and evaluated in [4].

The main candidate for LAA-LTE transmissions is the 5 GHz band, which has relatively large amount of unlicensed spectrum with global availability [3]. This band is also commonly used by Wi-Fi, which is the most commonly access technology considered in LTE co-existence in unlicensed bands investigations in literature. Studies show that an LTE system in co-existence with Wi-Fi in unlicensed bands is not highly affected by the interference caused by the Wi-Fi system [4], [5], [6].

In [4], the a heterogeneous network deployment is considered with LTE macro cells, LAA-LTE pico cells and Wi-Fi APs, where the macro cell and the pico control signaling is on a licensed frequency and the Wi-Fi APs and the pico data transmissions uses an unlicensed frequency and interfere with each other. The Wi-Fi nodes use the commonly known method carrier sense multiple access with collision avoidance (CSMA/CA) to listen before talk, while the pico node senses the channel before DL transmission and the UE senses the channel in UL before using its assigned subframe. Simulation results show that LTE can deliver significant capacity even while sharing the spectrum with WiFi.

In [5] and [6], the performance of both technologies, LTE and Wi-Fi, in unlicensed bands and their impact on each other when co-existing is investigated. Similarly to in [4], it can be seen that the impact on the LTE system due to interference from Wi-Fi is not significant. The reason behind this is that in a loaded situation, LTE normally has transmissions in every subframe, while CSMA/CA causes the Wi-Fi system to avoid transmission due to these transmissions. The interference caused by Wi-Fi on LTE occurs when the Wi-Fi perceives the channel as free and transmits, but then collides with an LTE transmission. During the limited time when Wi-Fi transmissions do interfere with LTE the impact can however be large, since Wi-Fi usually transmits with full power.

A number of investigations have been performed on methods for allowing a harmonious co-existence between LTE and Wi-Fi in unlicensed frequency bands; see for example [7] and [8]. In [7], three different co-existence mechanisms are described for markets without requirements on Listen-Before-Talk (LBT). First, channel selection is used for the small cell to choose the cleanest channel based on measurements. The channel selection algorithm also monitors the operating channel and can select a more suitable channel if conditions change. In case no clean channel is available, Carrier-Sensing Adaptive Transmission (CSAT) is used to apply adaptive TDM transmission based on long-term carrier sensing of co-channel Wi-Fi activities. In addition, in case of low traffic demand, the secondary LTE carrier in the unlicensed band can be turned off to avoid transmission of overheads.

Also in [8], channel selection is mentioned as an LTE and Wi-Fi co-existence enabler. Here, a generalized collaborative co-existence algorithm is described where system parameters are negotiated between the co-existing systems for a fair co-existence. The systems then switch to a co-existence mode where flexible spectrum access, (Wi-Fi) channel selection, (LTE) blank sub frames and (LTE) transmit power control are methods used to facilitate the co-existence.

The literature contains little discussion on how channel selection should be done in an LAA-LTE network to enable co-existence with other technologies in unlicensed bands. There are many examples of automatic Wi-Fi channel selection available in the literature. Some of the most promising work is introduced in the following.

Reference [9] presents a strategy to choose Wi-Fi channels in urban areas. Two main scenarios are considered (i) inter-channel interference where adjacent channels interfere with each other in Wi-Fi systems and (ii) urban situations where many APs in different systems are deployed in an uncoordinated way. A channel scoring function that estimates the performance level of each channel is utilized and a regression analysis has been applied where channel occupancy patterns, traffic volumes and RSS (Received Signal Strength) in those channels are used as explanatory variables. The proposed mechanism has been evaluated in site-specific deployment scenario with few nodes (4 interferers) only.

In [10] the authors propose a cognitive radio algorithm for practical deployments, which uses Received Signal Strength Indicator (RSSI) and RF (Radio Frequency) utilization (AP load) observed at different APs to generate a periodically-updated interference map for the network. Time-filtered (with forgetting factor) intra-system and inter-system interference metrics (edge weights) are computed. The interference metric is the RSSI weighted with the RF utilization. A centralized data base is used to determine the best channel set to be used. The algorithm seems difficult to scale to systems using large number of channels.

A new channel selection mechanism for Wi-Fi is proposed and analyzed in [11], which is based on channel utilization and channel quality metrics. The Non-Utilized Outage Capacity (NUOC) is introduced as a cross-layer channel metric which provides an intelligent adaptivity between the two performance metrics. The performance of the new mechanism is compared to the well-known channel selection methods introduced, and with random channel and fixed channel selection. The proposed NUOC based mechanism is distributed (runs in each AP). The clients are assumed to measure the interference in their neighborhood and to report their SINR. The AP estimates the overall channel utilization (Tx+Rx+Intf+Free). Additionally a mechanism based on NUOC change threshold is utilized to provide a good balance between unnecessary and necessary channel switches.

The paper [12] analyses fully distributed algorithms that allow (i) multiple interfering 802.11 Access Points to select their operating frequency in order to minimize interference, and (ii) users to choose the

Access Point they attach to, in order to get their fair share of the whole network bandwidth. The proposed algorithms only require the participating wireless nodes to measure local quantities such as interference and transmission delay. The algorithms are shown to lead to optimal bandwidth sharing, where optimality is defined according to the minimal potential delay. The practical feasibility of the schemes is validated on an actual implementation on a small scale testbed.

The white paper by Aricent's [13] documents the development of a simple auto channel selection algorithm that would enable the selection of an interference-free channel, thereby enhancing the overall customer experience. The AP sends a periodic beacon on its chosen channel to indicate specific information, including MAC address, SSID, channel number, and other parameters. The auto channel mechanism requires only the MAC address and channel number fields. The access controller (AC) unit has the auto channel selection algorithm running on it. Each AP passively scans all available channels for beacons and reports the information to the controlling AC and assigns a channel number to the AP based on the information provided by the AP and the neighboring active APs. The proposed solution is using a 'static channel relationship table' where the extent of channel overlap is inversely proportional to its priority. Channels with no/minimum overlap are selected. Graph theory modeling is applied.

A fully distributed and self-managed channel selection algorithm is introduced in [13]. It targets for a channel selection which minimizes the interference with other WLANs and guarantees that the interference/channel noise is within acceptable levels. A certain degree of "stickiness" to remain on the selected channel is guaranteed as well, in order to ensure that any channel allocation that removes interference between WLANs is an absorbing state. The scheme relies on the periodic UE measurements of the channel quality and its feedback to each WLAN on the presence of interference on a chosen channel. The scheme does not require direct communication between APs nor explicit estimation of the network interference graph. Rapid convergence under a wide range of network conditions and topologies is demonstrated.

The paper [15] proposes and evaluates a distributed channel assignment algorithm for uncoordinated WLANs, where APs can self-configure their operating channels to minimize interference with adjacent APs. The Client-Assisted Channel Assignment Optimization (CACAO) algorithm relies on the clients to feedback traffic and interference conditions, to their APs. This leads to better network condition knowledge and better channel assignment decisions at the APs which are made based on minimizing a local objective function. It results in switching to a channel that has least expected interference. The scheme converges quite fast and reduces co-channel interference significantly.

In [16] a load-aware channel (LAC) allocation scheme for WLANs is proposed and evaluated. LAC utilizes an airtime cost metric as part of the channel scanning process, where the channel choice is made by the APs. The selection is assisted by the UEs which inform their affiliated AP with regards to the uplink conditions. The airtime cost metric captures the effects of the AP load in terms of channel conditions, number of associated users as well as traffic-load, and provides an estimation of the average packet transmission delay, reflecting the performance of the WLAN in terms of AP throughput. The channel scanning procedure based on such metric converges to allocate a channel with the minimum average airtime cost (for both uplink and downlink), thus managing to maximizing long-term AP throughput.

5.2.2 3GPP Status (April 2015)

In general, the 3GPP discussions target the introduction of some kind of UE measurements on the unlicensed spectrum (RSSI and/or RSRP), while the channel selection mechanism/algorithm is left for eNodeB implementation. Nevertheless, the UE measurements which are going to be standardized on the un-licensed carrier will determine also what information is available at the eNodeB and to be used for channel selection.

For example, in [21] there are two proposals for UE measurements: 1) allow a UE to measure and report channel measurements on a larger amount of carriers than the allocated active component carriers; and 2) allow a UE that reports channel measurements on a larger amount of carriers than the current allocated and active component carriers to report such measurements with less frequency compared to the allocated active component carriers. Furthermore, in [22] the proposals are to: introduce possibility for UEs to report detected energy from signals not being LAA on the LAA frequency band; and to introduce possibility for UEs to report detected system specific information from signals not being LAA on the LAA frequency band, specifically Wi-Fi system information.

In order to support more flexible carrier selection in LAA there have been further proposals discussed in RAN WG 1 to introduce standardized support for : Wi-Fi measurements [23], enhanced carrier selection scheme with differential LAA/Wi-Fi selection criteria [24], channel occupancy measurements/ reports [25], DRS transmission on non-selected/non-utilized carriers [26], and fast carrier selection [27].

5.2.3 Spectrum Regulations

Since unlicensed spectrum is subject to a higher risk of interference from other systems, the requirements on equipment transmitting in unlicensed frequency spectra are usually stricter than on equipment transmitting in licensed spectra. The spectrum regulations are set by the authorities in each country, often through international organizations; regulations in Europe are for example set by the European Commission and the *European Conference of Postal and Telecommunications Administrations (CEPT)* in Europe, and regulations for the USA are set by the *Federal Communications Commission (FCC)*.

An overview of the spectrum regulations for the unlicensed 5 GHz band in different countries in presented in [16]. Table 5.1 shows a schematic view of available frequency bands for unlicensed services in different regions. The number within each spectrum block shows the amount of (full) 20 MHz channels that would fit in that block. It can be seen that most regions have unlicensed bands on 5150-5350 MHz and on 5470-5650 MHz available. For each band and region certain constraints are given, for example on maximum effective radiated power, indoor or outdoor usage, mandatory Dynamic Frequency Selection, allowed leakage to adjacent frequency bands etc. These constraints could of course be of interest to take in to account in the channel selection decisions, for example a channel with higher allowed power could be more beneficial than one with a low power, if the channels are otherwise comparable in terms of (relative) interference level. For more information on the constraints on different frequencies and in different regions, see [17].

<table>
<tr><th>Freq (MHz)</th><th>Europe</th><th>Israel</th><th>Russia</th><th>South Africa</th><th>Turkey</th><th>USA</th><th>Canada</th><th>Brazil</th><th>Mexico</th><th>China</th><th>Japan</th><th>Korea</th><th>India</th><th>Singapore</th><th>Australia</th></tr>
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</table>

Table 5.1: Frequency bands available and number of (full) 20 MHz channels per block for unlicensed services in different regions. Based on information from [17].

5.3 Approach for SON in Future Networks

5.3.1 Applying Methods from Wi-Fi Channel Selection to LAA-LTE

As described in section 5.2, several methods have been proposed and evaluated for achieving a good channel selection for Wi-Fi, and learning from these evaluations can be reused when developing a LAA-LTE channel selection SON function. Specifically, we look at the distributed methods, where each channel selection can be done without coordination from some central entity. This is considered a most reasonable solution, as different LAA-LTE eNBs in the unlicensed spectrum may be operated by different operators, and these, as well as other systems operating on the band (for example Wi-Fi), will most likely be troublesome to coordinate centrally.

By looking at the existing WiFi channel selection methods, it is noted that several of them are based on the received power from the own AP and its associated UEs together with the received power from other APs and their associated UEs s on the considered channel. RSSI measures are used and SINRs are calculated and used as input to the channel selection. Alternative solutions use the bitrate to understand the interference situation on the channel.

Further, most existing methods use some kind of measurement of channel business, or the utilization of the considered channel in order to understand how large part of the time the channel is busy.

In addition, information of the allowable power can be beneficial for the channel selection. This should be a prerequisite data known in the network nodes.

In the following, LTE measurements relating to the Wi-Fi measurements discussed above, that could be used as input to a LAA-LTE channel selection are described, and their usefulness is discussed. The focus is on channel selection for the LTE downlink, as only downlink transmissions over the unlicensed band are seen as the most likely scenario at a first stage of the implementation.

5.3.1.1 RSRP

The UE regularly measures the Reference Signal Received Power, RSRP, of the serving cell and surrounding cells. The RSRP is defined as the linear average over the power contributions of the resource elements that carry the cell-specific reference signals within the considered measurement frequency bandwidth [18].

By using RSRP measurements on the serving and surrounding eNodeBs, an understanding of the worst case signal to LTE interference ratio can be achieved. The measurements can be done both on intra-frequency (serving channel) and on inter-frequency (candidate channels). To get an understanding of the signal strength of the serving eNodeB on a candidate channel, the eNodeB could send a reference signal on the considered channel, but the simplest way would be to assume the same RSRP as on the served channel. This should be a good enough approximation since the evaluated LAA-LTE channels are not placed far away from each other.

It should be noted that when only using RSRP measurements to understand the (worst case) interference situation in the network, only interference caused by LTE, on bands transmitting a reference signal, will be taken into account. In case other systems are also using the considered channels, additional measurements would be needed to understand the interference situation.

5.3.1.2 Wi-Fi RSSI

In LTE UEs, there is also support for measuring IEEE 802.11 Beacon RSSI [18]. If used together with LTE RSRP measurements, an understanding of the worst case LTE plus Wi-Fi interference situation could be given, but still this would not capture other systems, and it would also focus on the reference signal/beacon transmissions only.

5.3.1.3 RSRQ

The Reference Signal Received Quality, RSRQ, measured by the LTE UEs is defined as [18] the ratio

$$RSRQ = \frac{N \cdot RSRP}{RSSI}$$, where

- *N* is the number of Resource Blocks of the E-UTRA carrier RSSI measurement bandwidth,
- *RSRP* is defined as described in section 5.3.1.1, and *RSSI* is the E-UTRA carrier Received Signal Strength Indicator, comprising of the linear average of the total received power observed only in OFDM symbols containing reference symbols for antenna port 0, in the measurements bandwidth, over *N* resource blocks by the UE from all sources, including co-channel serving and non-serving cells, adjacent channel interference, thermal noise etc.

The RSRQ measurements give a better understanding of the SINR of the considered channel compared to a calculation based on RSRP measurements, as the RSSI used in the denominator of the above expression is including power received from all sources. Also here, however, the interference is only measured in OFDM symbols containing reference symbols.

Similar to RSRP, the RSRQ measurements can be done both on intra-frequency (serving channel) and on inter-frequency (candidate channels). To understand what RSRQ that would be achieved for the serving eNodeB at a different channel than the current one, the serving eNodeB would need to transmit a reference signal on that channel.

5.3.1.4 CQI

The Channel Quality Indicator, CQI, is a measurement sent from the UE to the serving eNB indicating a suitable modulation and coding scheme and code rate for transmissions. The CQI is based on the achieved SINR on the considered frequency band, as well as the UE capabilities. In LTE, there is support for CQI measurement reports both per subband (a set of adjacent resource blocks) and for wideband (the entire channel bandwidth). More details on the CQI reporting can be found in [19]. The CQI could give a good indication of the interference situation on a channel, since it takes the actual interference on the considered channel into account, not only reference signals. Therefore, the CQI is considered as the most suitable measurement to use as input for interference situation analysis in an LAA-LTE channel selection SON function.

5.3.1.5 Channel Utilization

The channel utilization, or channel business is used as input by several Wi-Fi channel selection methods proposed in the literature. In some cases, transmissions both between an AP and its served MSs, as well as between other APs and MSs is listened to and taken into account in the channel selection. In today's IEEE 802.11k standard there is support for measuring channel load caused by communication with the served MSs, or serving AP, defined as "the percentage of time, linearly scaled with 255 representing 100%, the station STA sensed the medium was busy, as indicated by either the physical or virtual carrier sense (CS) mechanism" [20]. This metric in principle can also capture the load due to transmission in other APs than the serving AP of a given MS.

In LTE systems today, there is limited support for measuring activity in downlink. The eNodeB could, if equipped with a downlink receiver, measure the traffic on a given channel. In order to understand the channel business in the vicinity of the UEs connected to an eNodeB, the eNodeB would need to request measurements from these UEs. In future work, a simulation study could be done in order to understand the potential of this method, examining both possible gains from such measurements and how overhead caused by the measurements and reporting would affect performance.

5.3.2 Triggering of LAA-LTE Channel Selection

A LAA-LTE channel selection SON function would typically be triggered upon the introduction of a new carrier over unlicensed spectrum. As traffic conditions change, and other systems may pop up at the selected channel, it is however likely that the optimal channel for the LAA-LTE communication will change over time. A LAA-LTE Channel Selection SON function should therefore include some triggering mechanism, detecting situations when it might be beneficial to select a new LAA-LTE channel, and starting a new channel selection procedure. Some possible methods for triggering a new channel selection procedure are discussed below.

One typical indication that a new channel selection is needed is that problems are discovered in the transmission on the currently selected channel. A new channel selection procedure could for example be triggered if the achieved system throughput goes down, the reported RSRQ and/or CQI indicate higher interference, or if the block error rate increases. This could indicate that there is new communication on the selected channel disturbing the LAA-LTE transmissions.

Another channel quality/metric indicator that it might be beneficial to start a new channel selection procedure is that the channel utilization or the traffic demand increases. Even if only the own LAA-LTE transmissions are considered, a change of the traffic characteristics in the own network could often be correlated with a change also in other transmissions on the unlicensed band, and a new channel selection could therefore give a better performance.

The triggering of the LAA-LTE channel selection could of course be based on one or several of the above methods, and different weights could be given the different methods depending on the estimated potential that performance would increase upon a new channel selection. The triggering should also take the possible gains of a new channel selection versus the performance decrease due to measurements and possible testing of different channels into account. A periodical triggering of the channel selection, with a relatively long periodicity, to avoid staying on a sub-optimal channel even if no problems arise, could also be considered.

5.3.3 Conceptual LAA-LTE Channel Selection Algorithm

The WLAN channel selection mechanisms summarized in Section 5.3.1 all use certain type of channel quality metric when selecting the optimal channel. In practice, for both LAA-LTE and WLAN systems the exact procedure to estimate the channel quality metric depends on the available and standardized signaling, channel measurements and terminal capabilities**.** When the channel selection is triggered, see discussion in Section 5.3.2, a channel selection algorithm is to be executed to ensure an optimal operating channel (or set of channels) is used for all subsequent transmissions in the corresponding LAA-LTE cell.

The proposed LAA-LTE channel selection algorithm is conceptually depicted in Figure 5.2. An LAA-LTE cell is assumed to be able to scan certain set of pre-configured *K* channels *Ck*, *k=1...K*. Henceforth, we generically denominate the channel quality metric as the weight *Wk* of the channel *Ck* (*k=1...K*) and we do not assume a specific estimation algorithm for it. The higher the *Wk* value the more likely should be to select the corresponding channel. Furthermore, a channel *Ck* is defined as a contiguous frequency band with a minimum bandwidth of 20 MHz in which the LAA-LTE system can operate. The channel selection algorithm consists in a channel scanning loop which assigns weights to each channel, and after all channel have been scanned a simple selection is done for the channel with highest weight.

The proposed channel scan loop has two main phases for each available channel *Ck*, see Figure 5.2:

1. **Mandatory**: Measure radio interference and compare to a interference detection threshold, *Dthr*
    a. This step is mandatory because of regulations when operating in an un-licensed band.
    b. This is a typical wideband signal/interference level estimation, representative for the entire bandwidth of the channel *Ck*.

2. **Optional**: When interference level is above *Dthr* then calculate a channel weight *Wk* based on a set of interference conditions *ICx* and the identified interference type WLAN or LAA-LTE (if/when possible to distinguish)
    a. This step is optional and required only for improved LAA-LTE/WLAN co-existence. The WLAN *ICx* are evaluated first in order to provide higher sensitivity towards interference to/from Wi-Fi.
    b. The different *ICx* can each represent a different way of estimating the weigh *Wk*.
    c. A simplified option is to use only one *IC* per interference type, which leads to only 3 possible channel weights values: *WLAN specific*, *LAA-LTE specific*, or *Neutral*, see Figure 5.2.
    d. When none of the WLAN and LAA-LTE *ICx* are met, then the algorithm assigns a default (pre-set/configured by SON) weight to the scanned channel.

After all available channels have been scanned and the channel weights have been assigned, the channel with the highest *Wk* is selected.

The proposed algorithm can also be applied when selecting pairs of channels, i.e. multiple of 20 MHz frequency bands for LAA-LTE operation. This is a similar to the WLAN operating scenario with band aggregation.

5.3.3.1 SON function for LAA-LTE channel selection

The SON functionality built on the proposed channel selection algorithm, Section 5.3.2 and Section 5.3.3, can provide configurability in terms of:

a) Triggering condition(s)
b) Set of possible weights, *Wk*,
c) The interference conditions used, *ICx*
d) The interference detection threshold, *Dthr*,
e) Periodicity of execution/scanning, *Tper*.

In the simplest form, the first three parameters can be pre-configured for a given deployment scenario and expected average traffic load. The last two parameters of the algorithm can be adjusted by the SON function depending on the varying traffic conditions (varying channel load/utilization) and the experienced transmission performance to the served UEs.

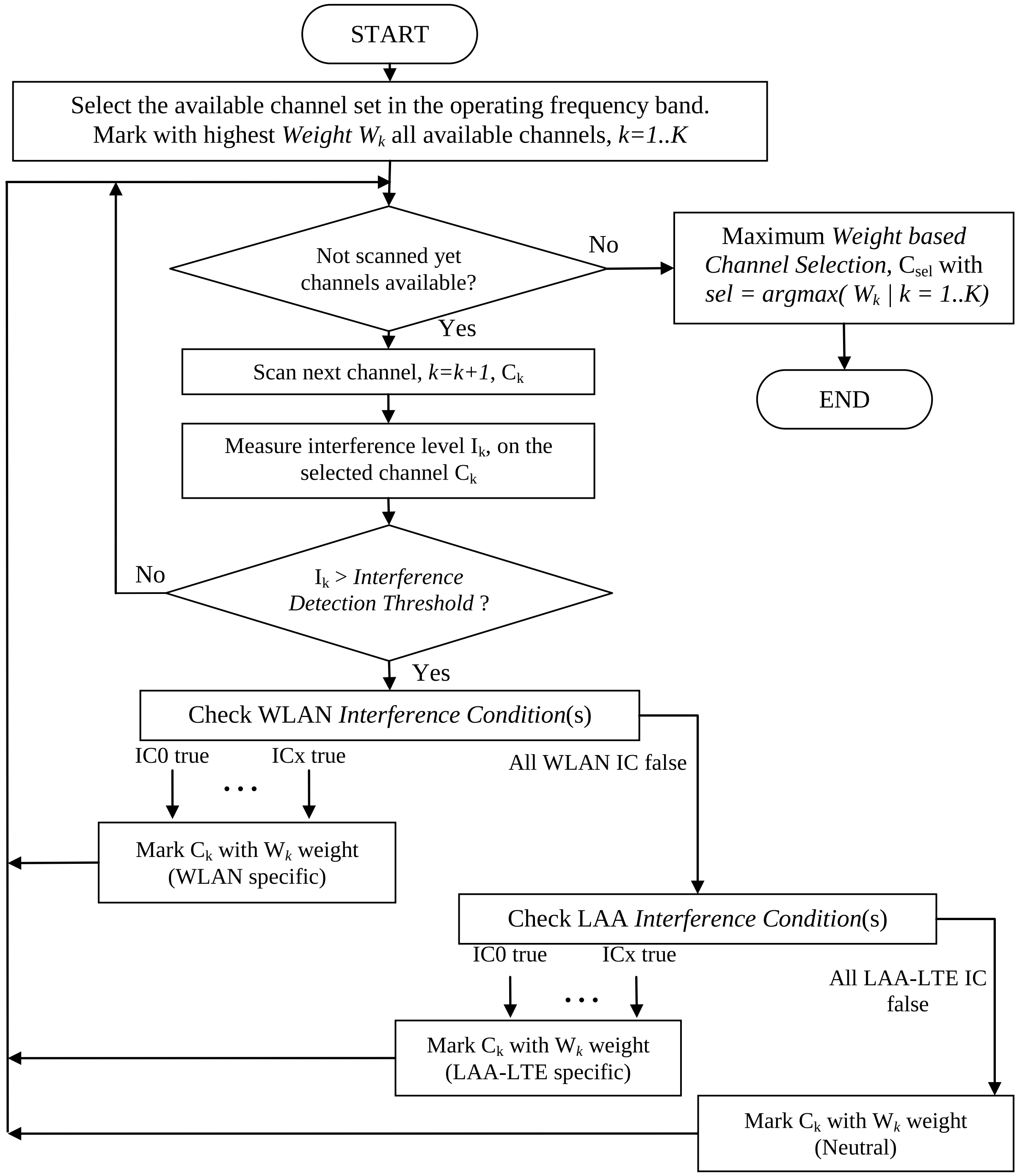

Figure 5.1: Conceptual flow chart for LAA-LTE channel selection in the unlicensed band.

5.4 Conclusion and Way Forward

Several Wi-Fi channel selection algorithms have been proposed in the literature to improve performance in densely deployed networks. These form a good starting point for the development of LAA-LTE channel selection mechanisms.

The LAA-LTE channel selection mechanism is considered to be implementation/vendor specific, thus this type of algorithms will very likely not be specified by 3GPP in Release 13. The UE channel measurements, which can be used in the channel selection triggering (section 5.3.2) and selection algorithm (section 5.3.3), are however being addressed in 3GPPP RAN WG 1 and WG 2.

For improved performance, our LAA-LTE channel selection proposed in section 5.3.3 relies on the use of the interference conditions metrics, which can also be LAA-LTE/WLAN system specific. These metrics have to be derived from standardized UE and/or eNodeB measurements in the un-licensed channel(s), thus it requires further work to investigate how improvements can actually be achieved by using the measurements to be finally adopted by 3GPP.In terms of the LAA-LTE channel selection SON algorithm there are several interesting issues to consider, such as: i) performance gain potential from faster carrier selection, ii) performance gain from power control, within the regulatory limits, iii) benefits of explicit coordination of the eNodeBs with LAA-LTE, iv) benefit of further LTE/Wi-Fi/LAA interworking, etc.

5.5 References

[1] 3GPP News, “Initial priorities for the evolution of LTE in Release-13”, Dino Flore, 3GPP RAN Chairman, September 20, 2014. http://www.3gpp.org/news-events/3gpp-news/1628-rel13 .

[2] 3GPP TD RP-141664: "Study on Licensed-Assisted Access using LTE".

[3] Huawei, “U-LTE: Unlicensed Spectrum Utilization of LTE”, 2014, www.huawei.com/ilink/en/download/HW_327803.

[4] R. Ratasuk, M.A. Uusitalo, N. Mangalvedhe, A. Sorri, S. Iraji, A. Ghosh, “License-Exempt LTE Deployment in Heterogeneous Network”, *2012 International Symposium on Wireless Communication Systems (ISWCS),* 28-31 Aug. 2012, pp: 246-250.

[5] A.M. Cavalcante, E. Almeida, R.D. Vieira, F. Chaves, R.C.D. Paiva, F. Abinader, S. Choudhury, E. Tuomaala, K. Doppler,, “Performance Evaluation of LTE and Wi-Fi Coexistence in Unlicensed Bands”, *2013 IEEE 77th Vehicular Technology Conference (VTC Spring)*, pp:1-6.

[6] T. Nihtila, V. Tykhomyrov, O. Alanen, M.A. Uusitalo, A. Sorri, M. Moisio, S. Iraji, R. Ratasuk, N. Mangalvedhe, “System performance of LTE and IEEE 802.11 coexisting on a shared frequency band”, *Wireless Communications and Networking Conference (WCNC)*, 2013, pp: 1038-1043.

[7] Qualcom Research, “LTE in unlicensed spectrum: Harmonious Coexistence with Wi-Fi”, 2014, https://www.qualcomm.com/media/documents/files/lte-unlicensed-coexistence-whitepaper.pdf

[8] Almeida, E.P.L. ; Chaves, F.S. ; Cavalcante, A.M. ; Vieira, R.D. ; Paiva, R.C.D. ; Sobrinho, A.M. ; Choudhury, S. ; Tuomaala, E. ; Doppler, K. ; Sousa, V.A., “Enabling the Coexistence of LTE and Wi-Fi in Unlicensed Bands”, IEEE Communication Magazine, Vol. 52, Issue 11, 2014.

[9] Kajita, S.; Yamaguchi, H.; Higashino, T.; Umehara, S.; Saitou, F.; Urayama, H.; Yamada, M.; Maeno, T.; Kaneda, S.; Takai, M. , “A Channel Selection Strategy for WLAN in Urban Areas by Regression Analysis”, IEEE WiMob, October 2014.

[10] Mack, J. and Ghasemi, A., “Dynamic Channel Selection in Cognitive Radio WiFi Networks: An Experimental Evaluation”, IEEE ICC Workshop, 2014.

[11] Amiri, B. and Sadjadpou , H.R., “A New Approach for WLAN Channel Selection Based on Outage Capacity”, IEEE MILCOM 2013.

[12] Kauffmann, B.; Baccelli, F.; Chaintreau, A.; Mhatre, V.; Papagiannaki, K.; Diot, C. , “Measurement-Based Self Organization of Interfering 802.11 Wireless Access Networks”, IEEE INFOCOM, May 2007.

[13] Aricent Tehcnology, “Auto Channel Selection in 2.4GHZ Using Overlap”, White paper, 2014.

[14] Leith, D.J.; Clifford, P., "A Self-Managed Distributed Channel Selection Algorithm for WLANs," *Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks, 2006 4th International Symposium on* , vol., no., pp.1,9, 03-06 April 2006.

[15] Xiaonan Yue; Chi-Fai Wong; Chan, S.-H.G., "CACAO: Distributed Client-Assisted Channel Assignment Optimization for Uncoordinated WLANs," *Parallel and Distributed Systems, IEEE Transactions on* , vol.22, no.9, pp.1433,1440, Sept. 2011.

[16] Athanasiou, G.; Broustis, I.; Korakis, T.; Tassiulas, L., "LAC: Load-aware channel selection in 802.11 WLANs," *Personal, Indoor and Mobile Radio Communications, PIMRC 2008, IEEE 19th International Symposium on* , vol., no., pp.1,6, 15-18 Sept. 2008.

[17] 3GPP TR 36.889 V0.1.1 (2014-11), Technical Report, 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on Licensed-Assisted Access to Unlicensed Spectrum; (Release 13).

[18] 3GPP TS 36.214 V12.1.0 (2014-12), Technical Specification, 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer; Measurements (Release 12).

[19] 3GPP TS 36.213 V12.4.0 (2014-12), Technical Specification, 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (Release 12).

[20] IEEE Standard for information technology - Telecommunications and information exchange between systems Local and metropolitan area networks - Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 1: Radio Resource Measurement of Wireless LANs, IEEE Std 802.11k-2008 (Amendment to IEEE Std 802.11-2007), pp. c1–222, 12 2008.

[21] R2-150181, Sony, “On LAA UE measurements”, 3GPP TSG RAN WG2 Meeting #89, Athens, Greece. 9th – 13th February 2015.

[22] R2-150182 , Sony, “LAA measurements and reporting”, 3GPP TSG RAN WG2 Meeting #89, Athens, Greece. 9th – 13th February 2015.

[23] R1-152005, Ericsson, “On Carrier Selection for LAA“, 3GPP TSG RAN WG1 Meeting #80bis, Belgrade, Serbia, 20th - 24th April 2015.

[24] R1-152026, CMCC, “Discussion on carrier selection of LAA“, 3GPP TSG RAN WG1 Meeting #80bis, Belgrade, Serbia, 20th - 24th April 2015.

[25] R1-152090, Sony, “LAA Measurements and Fast Carrier Selection Procedure“, 3GPP TSG RAN WG1 Meeting #80bis, Belgrade, Serbia, 20th - 24th April 2015.

[26] R1-152096, ETRI, “Discussion on DRS transmission for carrier selection”, 3GPP TSG RAN WG1 Meeting #80bis, Belgrade, Serbia, 20th - 24th April 2015.

[27] R1-151880, HUAWEI, “Design of fast carrier scheduling for LAA”, 3GPP TSG RAN WG1 Meeting #80bis, Belgrade, Serbia, 20th - 24th April 2015.

6 Conclusions and Outlook

In this deliverable the areas and potential for research on new SON functionalities for future networks has been investigated for four exemplary use cases. The investigations have been done in form of studies without the development of detailed solutions or implementations of simulations. Two of the studies (Cognitive PBSM and LTE-LAA) are related to the SEMAFOUR activities on PBSM and Traffic Steering, whereas the studies on D2D communications and nomadic networks are not related to any SEMAFOUR existing activities. Although SON has been subject to research, development and standardization already for years, the results of all four studies are clearly showing the need and large potential for further research on SON. The output of this deliverable can be used as a starting point for follow-up activities of the SEMAFOUR project.