FP7 Information & Communication Technologies (ICT)

CONSERN

Deliverable D3.1

Enablers for Energy-Aware Cooperative Decision and Control

Document Number:	INFSO-ICT-257542/CONSERN /WP3/D3.1/311010
Contractual Date of Delivery:	31/10/2010
Authors:	Henning Vetter (Editor), Woon Hau Chin (Editor), Andreas Merentitis, Evangelos Rekkas, Makis Stamatelatos, Eli De Poorter, Lieven Tytgat, Opher Yaron, Gunnar Hedby, George Koudouridis
Workpackage:	WP3
Distribution / Type:	PU (Public)
Version:	1.0
Total Number of Pages:	56
File:	D3.1-v1.0-r2.docx

Abstract

This deliverable is written with two objectives in mind, and is organised as such. In the first part, it identifies the scope of the work package, introduces the key concepts and lays the foundation on which the work package develops. Next, it reviews the literature and technology available and provides an assessment of techniques that can be used to facilitate improvements and invent new technologies.

Executive Summary

Low energy communication between one or multiple networked devices is envisioned to be fundamental in future systems. One of the aims of the CONSERN project [1] is to develop solutions for optimized energy and power consumption through autonomic and cooperative approaches. Through use cases developed in D1.1 of the project, the Work Package 3 (WP3) aims at developing techniques and mechanisms which are tailored to suit these use cases. In the CONSERN framework, WP3 focuses on:

- Cooperation and collaboration enablers, introducing techniques for wireless communication between heterogeneous network objects and between network elements and mobile terminals,
- Design and develop self-learning methods, including methods for information representation and information fusion,
- Introduction of algorithms for cooperation between network elements,
- Study the relation/balance between autonomic capabilities and cooperative optimization in order to maximize the energy gains,
- Optimisation of fault detection and error correction algorithms in cooperative environments under energy constraints.

This deliverable is written with two objectives in mind, and is organised as such. In the first part, it identifies the scope of the work package, introduces the key concepts and lays the foundation on which the work package develops. Next, it reviews the literature and technology currently available and provides an assessment of techniques that can be used to facilitate improvements and invent new technologies.

In the first part, the process of collaboration and coordination consists of three components, namely:

- Information/context exchange,
- Decision coordination and control,
- Layer mechanisms.

Additionally, four attributes i) energy awareness, ii) autonomicity, iii) dependability, and iv) reconfigurability, defined in WP1 are identified as being related to cooperativeness. Accordingly, the use cases related to cooperation are identified. The relevant parameters on cooperation in each use case are also identified.

Applicable technical areas are specified next. In particular, the possible techniques and mechanisms which could be used to realise low energy and high efficiency communications are described. Three main technical areas are identified as possible directions in which improvements can be made to advance the goal of low energy, high efficiency communications. These are:

- Mechanisms for Energy Efficient Wireless Networks,
- Cooperative Decision Making,
- Information Fusion and Knowledge Representation.

The second part of this deliverable provides the State-Of-The-Art of the related cooperative and collaborative techniques. The main techniques and mechanisms reviewed are:

- Relay and Cooperative Communications,

- SON Mechanisms,
- System Conceptualisation and Modelling,
- Cooperative Decision Control,
- Cooperative Power Control,
- Energy Savings,
- Discovery of Neighbouring Networks and Cooperation Profile.

In addition, the document encompasses the ideas, assumptions and plan for future work of the different partners.

Contributors

First Name	Last Name	Company	Email
Henning	Vetter	TREL	henning.vetter@toshiba-trel.com
Woon Hau	Chin	TREL	woonhau.chin@toshiba-trel.com
Andreas	Merentitis	NKUA	amer@di.uoa.gr
Evangelos	Rekkas	NKUA	erekkas@di.uoa.gr
Makis	Stamatelatos	NKUA	makiss@du.uoa.gr
Eli	De Poorter	IBBT	eli.depoorter@intec.ugent.be
Lieven	Tytgat	IBBT	lieven.tytgat@intec.ugent.be
Opher	Yaron	IBBT	opher.yaron@intec.ugnet.be
George	Koudouridis	HWSE	george.koudouridis@huawei.com
Gunnar	Hedby	HWSE	gunnar.hedby@huawei.com

Acronyms

Acronym	Meaning
3G	3rd Generation
3GPP	3rd Generation Partnership Project
ANDSF	Access Network Discovery and Selection Function
BS	Base Station
BTS	Base Transceiver Station
CCU	Cell-Centre User
CEU	Cell-Edge User
CoMP	Coordinated Multi-Point
CR	Cognitive Radio
CSI	Channel State Information
DAML	DARPA Agent Markup Language
DAS	Distributed Antenna System
DL	Downlink
DMTF	Distributed Management Task Force
DoW	Description of Work
DTX	Discontinuous Transmission
eNB	Evolved Node B
FFR	Fractional Frequency Reuse
HII	High Interference Indicator
ICIC	Inter-Cell Interference Coordination
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Telecommunication Union
LTE-A	Long Term Evolution-Advanced
MAC	Medium Access Control
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
NE	Network Element
O&M	Operations & Maintenance
OI	Overload Indicator
OIL	Ontology Inference Layer
OMA	Open Mobile Alliance
OMG	Object Management Group
PCI	Physical Cell Identification
PER	Packet Error Rate
PRB	Physical Resource Block
RAN	Radio Access Network
RDF	Resource Description Framework
RDT	Receiver Defined Transmission

RF	Radio Frequency
RRM	Radio Resource Management
SFR	Soft Frequency Reuse
SINR	Signal-to-Interference-Noise Ratio
SNR	Sign-to-Noise Ratio
SON	Self Organising Network
SOTA	State Of The Art
UE	User Equipment
UL	Uplink
UML	Unified Modeling Language
UMTS	Universal Mobile Telecommunications System
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WOL	Web Ontology Language
WSN	Wireless Sensor Network

Table of Contents

List of Figures

List of Tables

1. Introduction

The CONSERN project aims at developing and validating a novel paradigm for dedicated, purpose-driven small-scale wireless networks with special focus on energy-aware self-growing systems. The main goal of the project is to design mechanisms and solutions in order to enable functionality improving the **dependability**, **cost** and **energy efficiency**, as well as **robustness** of (heterogeneous) wireless networks by utilizing reconfigurable nodes and distributed cooperative control functions.

Within the CONSERN project, WP3 targets cooperation and collaboration enablers and mechanisms, cooperative decision and control algorithms, as well as all techniques that maximize the expected gain explicitly by utilizing cooperative behaviour and balancing autonomic capabilities and cooperative decision and control.

In the WP3 context, there is plan to introduce novel techniques for bi-directional wireless communications between heterogeneous network objects, design and develop self-learning methods with necessary means of information representation and fusion in order to distribute the decision base, and study the trade-off between autonomic and cooperative optimisation.

This Deliverable, D3.1, targets enablers for energy-aware cooperative decision and control. At this early stage of the CONSERN project, WP3 uses the technical use cases which have been identified within WP1 and collected in deliverable D1.1 as a base for further refining the preconditions and the required technical advances in order to achieve cooperation and collaboration within the CONSERN network.

This deliverable D3.1, titled “Enablers for Energy-Aware Cooperative Decision and Control”, is structured as follows.

- In Section 2, energy efficiency and the dependable operation at the level of cooperative wireless elements are introduced coupled with the CONSERN objectives and linked to the self-growing paradigm. Enablers and other terms and notation are defined in the context of cooperation in this deliverable. The dimensions of cooperation within the use cases of D1.1 are visualised and further refinements are made, in that the use cases are analysed with respect to coordination and collaboration. Then, specific technical areas and enablers for the required functionality are extracted from the preconceived use cases.
- Section 3 is concerned with enablers for cooperative operation, which are linked to the specific technical areas which are extracted from the relevant use cases in Section 2. The subsections are grouped into classes of enabling mechanisms and present the enablers which have been identified to be elaborated in the scope of the project; such presentation includes state-of-the-art aspects and required developments on cooperation in order to achieve the self-growing, energy-aware operation modes envisaged in the CONSERN project.
- Section 4 concludes the deliverable.

2. Concepts, Use Cases and Related Enablers

In this section the energy efficiency and the dependable operation at the level of cooperative wireless elements are introduced coupled with the CONSERN's objectives and linked to the self-growing paradigm. An approach is presented for the description of the different dimensions of cooperative decision. Moreover, the CONSERN scope is outlined in relation to the cooperative decision and control through the concepts definitions, the use cases analysis and a set of specific technical areas presentation. Finally, a set of requirements are extracted which are related to the identified technical areas and serve as an introduction for the enablers description in section 3.

2.1 Dimensions of Cooperative Decision and Control

Enablers in the context of cooperation refer to the mechanisms, procedures and/or protocols that make it possible for network nodes to exchange information/knowledge, make decisions cooperatively and coordinate their actions.

The envisaged collaboration spans between information exchange, actions coordination and decision making; moreover, such aspects are expected to be exploited in different dimensions thus featuring different levels and corresponding capabilities.

In this section, the various ways of cooperation for decision and control are identified; a number of aspects can be envisaged which are related to decision and control based on cooperation, with regards to:

- Collaboration by means of **information exchange**, ranging from node independent sensing (*i.e.*, no information exchange between nodes) to full context/knowledge presentation and sharing,
- Coordination of **decision and configuration control** ranging from independent decisions up to fully coordinated decisions about reconfigurations,
- Utilisation of **layer mechanisms** ranging from PHY/MAC layer mechanisms to L3 and above for cooperative transmissions.

The highlighted aspects also form the three dimensions of cooperative operation.

Network nodes are expected to interrelate the presented aspects in different degrees thus exploiting different levels of collaboration. For example:

- Two network nodes may collaborate by simply exchanging information between each other whilst they can make their own decisions independently,
- Alternatively, two nodes may cooperate by deciding on a coordinated plan of configurations divided between them.

Finally, cooperation may be performed by each layer separately or in a cross-layer fashion. A tentative three-dimensional map can be drawn to classify different kinds of solution arrangements for cooperation.

In Figure 2-1, the three different dimensions of cooperative operation are illustrated. As an example it can be seen that the information exchange (collaboration) axis ranges between "no information exchange" and "full information exchange". In case of "no information exchange", it is assumed that nodes rely on their capabilities of sensing/monitoring of the environment. Although this implies local (partial) knowledge of the environment it is still possible to have nodes cooperating as for instance in pure conflict resolution protocols where nodes sense collisions and reacts by means of back-off thus giving the opportunity to other nodes to transmit. It should be pointed out that this is a very simple case of cooperation of independent decisions.

Another example of independent decision making without cooperation constitutes a cognitive radio scenario consisting of licensed (primary) users and non-licensed (secondary) users. In this scenario secondary users senses the radio environment and, at any time, can make independent decisions on utilising spectrum holes i.e., spectrum which is not used by the licensed users at a specific time slot. Time slots of unused spectrum comprise the so called “White Space”. To this respect, secondary users are independent decision makers because they decide on the acquisition of white space based on their own sensing data and without any knowledge about or coordination with other users (primary or secondary).

Figure 2-1 also illustrates the scope of the cooperation as **planes** in the 3-dimensional space. Such planes represent specific technical features and mechanisms composing the CONSERN cooperation framework and have been placed in the cooperation space according to their envisaged relation against the 3-dimensions of cooperation (information exchange, decision and configuration control, and Layer mechanisms). It must be noted, however, that the planes which are illustrated here are only tentative and they should be considered as examples. Generally, depending on the actual definition of cooperation it is also possible that the scope can be a line, a vector or a point in this space. Moreover, the different dimensions of cooperative decision and control are expected to be exploited in the WP3 progress; this means that corresponding planes can be re-positioned in the 3-dimension illustration of the scope of cooperation.

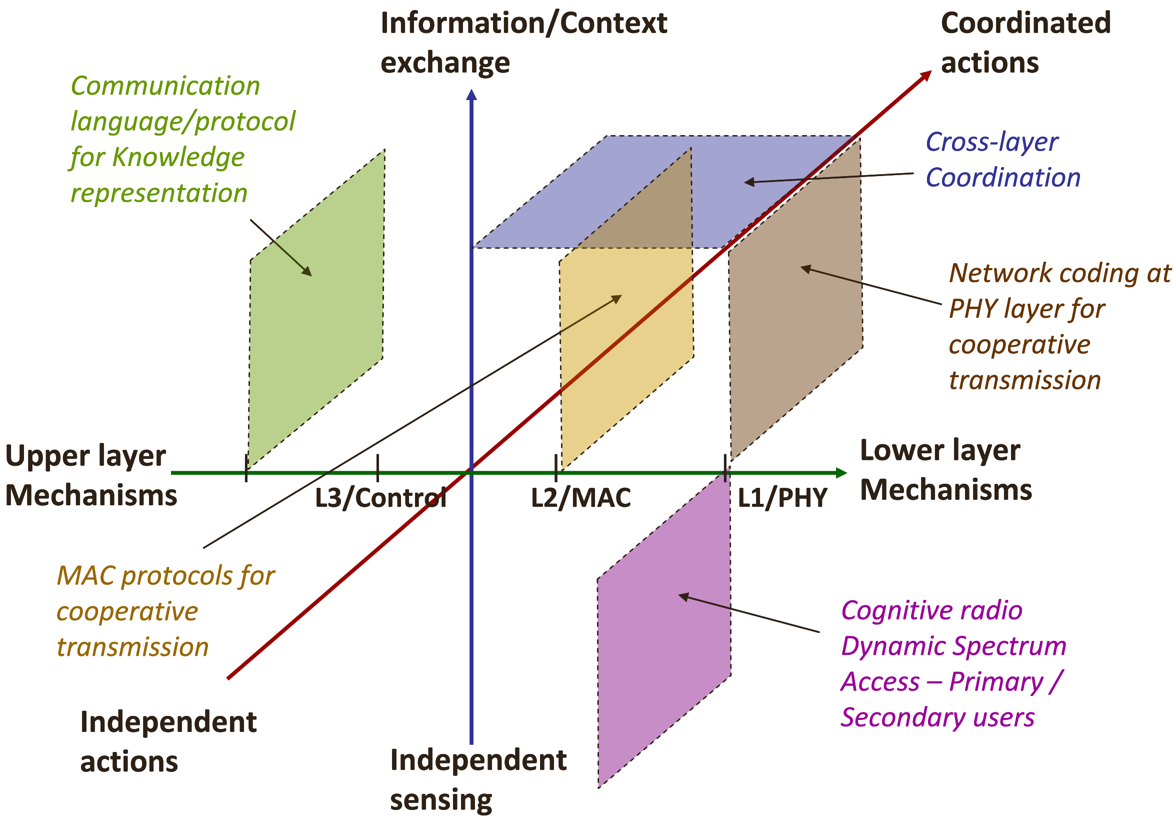


Figure 2-1: Dimensions of Cooperative Decision and Control.

For each one of the above dimensions a set of enablers and technical areas for cooperative decision and control should be associated to it. In particular, the following associations are envisaged:

- Information/Context exchanging axis (or collaboration axis):
    - Sensing data,
    - Configuration settings,

    - Fused/processed information,
    - Knowledge representation, etc.,
- Decision coordination and control axis (or coordination axis)
    - Routing/relaying control,
    - Negotiation protocol,
    - Coordination planning,
    - Synchronisation,
    - Distributed decision making,
    - Knowledge reasoning,
    - Conflict resolution, etc.,
- Layer mechanisms axis (or layer axis):
    - Routing / relaying at L3 layer,
    - MAC protocols and/or relaying at L2 layer,
    - Cooperative multi-point transmission at L1 (PHY) layer,
    - Network coding and cross-layer, etc.

The above resembles an optimisation system where information, control and configuration are specified as part of the enablers. In general, collaboration axis is reflected in section 2.3.3; coordination axis is reflected in section 2.3.2, whilst layer axis corresponds to section 2.3.1.

2.2 Cooperation in the CONSERN scope

2.2.1 Methodology

In the Deliverable D1.1 a set of attributes have been introduced, which are associated to the CONSERN scenarios and describe properties that are expected to be captured by devices, network nodes, networks and systems which will incorporate CONSERN capabilities. Such attributes include the Energy Efficiency attribute, the Self-growing attribute, the Reconfigurability attribute, the Cooperativeness attribute, etc, and have been classified as “benefits”, “enabling attributes”, and “efficiency attributes” (a complete list and description of the CONSERN attributes is included in the deliverable D1.1 [91]). Each one of the mentioned attributes is further detailed by a set of parameters which capture mainly specific properties which are subject to changes.

In D1.1 the methodology was targeting to the identification of the project attributes, the attributes classification and the definition of the parameters for the attributes “breaking down” towards a set of specific properties (which are subject to changes); in this deliverable, the D1.1 methodology is extended in order to:

- Derive the Use Cases which include cooperativeness aspects: this is performed by identifying those Use Cases which “observe” parameters accredited to cooperativeness,
- Identify technical aspects and areas which are described in the Use Cases coming from the previous step of the methodology and relate them to the cooperativeness parameters.

In this sense, the scope of WP3 are described in different level of details based on attributes, a subset of the project Use Cases, specific technical areas within cooperative decision and control which have been interrelated to a set of parameters.

2.2.2 Attributes related to Cooperativeness

Here, a summary is provided on the cooperation aspects that have been included in the Use Cases; specifically, such summary is based on parameters which have been identified as observed under each Use Case scope as well as the actions which describe the Use Case lifecycle; moreover, a linkage is provided to Figure 2-1 and the 3-dimensions of cooperation.

WP1 developed scenarios and use cases starting from a set of key benefits and enabling attributes in order to outline the technical scope of the CONSERN project. The approach taken in WP3 is based on the identification of cooperation related aspects within the overall use cases portfolio as well as highlighting those use cases that significantly rely on enabling attributes accredited to cooperative operation.

Initially, cooperativeness is related to certain attributes as they have been defined in WP1. The relation of those attributes will be further exploited and detailed within the WP3 context. In WP3 and based on the WP1 reference framework, the following attributes are, in principle, related to the Cooperativeness attribute:

- **Energy Awareness** is the collective term which can be used to specify:
  - How much energy a network element (NE) uses,
  - What the NE actually use the energy for,
  - Where the energy comes from,
  - The knock-on effects of us using it (e.g. environmental impact, depletion of resources), and,
  - What a NE can do to reduce its energy consumption and its undesirable knock-on effects.
- **Autonomicity** is the ability of a network node to make rational decisions in order to fulfill its own objectives.
- **Dependability** is the collective term used to describe the trustworthiness of a system and its influencing factors including reliability performance, maintainability performance and maintenance support performance.
- **Reconfigurability** – the **adaptability** aspect: Ability to change in order to be efficient and successful in new situations and for different purposes. Adaptability is an aspect of reconfigurability.

The relationship of those attributes will be further exploited within the WP3 context.

2.2.3 Use Case Analysis for Cooperation

Table 2-1 presents an indication of the level of relevance of CONSERN use cases regarding cooperativeness. Such indication is based on the parameters which are related to cooperativeness and are observed in certain Use Cases; Use cases are indicated by numbers as ordered in the WP1 use case list. Table 2-2 accounts for the specific cooperation-related aspects and technical areas and maps them to the observed parameters.

Parameters applicable to Cooperativeness	Use Cases involved	
Change in degree of coexistence (number of nodes and/or networks which are coexisting)	4	1, 3, 8, 16
Diversity of decision making (number of decision making entities in relation to number of networks)	1	1

Parameters applicable to Cooperativeness	Use Cases involved	
Amount of control signalling (signalling overhead)	-	-
Amount of information exchange	4	5, 6, 7, 12
Ability to recognize cooperative behaviour needs	1	14
Establishing cooperation links between network elements	1	14
Percentage of own resources (e.g. energy, bandwidth,...) consumed by taking into account other co-located networks	-	-
Ability to jointly cooperate and share load with other heterogeneous Radio Access Technologies	1	4
Configuration time	-	-
Granularity of information exchange	1	12
Level of autonomicity (e.g. regarding to available policies)	1	2
Autonomic Decision Making	1	13
Autonomic performance optimization	1	13
Learning time, the time required for a network to learn a completely new situation and the best configuration for it	2	5, 15
Convergence time (towards an efficient configuration for a given situation), the time required to converge to an optimal configuration for a situation (part of learning time)	2	3, 5
Number of learned situations	1	15

Table 2-1: Parameters and Use cases linked with the Cooperativeness Attribute.

Use Case Id	Aspects related to cooperativeness	Observed Parameters
UC 1	Relayed Transmission, Information Fusion (measurements from NEs), Cooperative transmission power planning (between relays and BTSs).	Amount of control signalling, Amount of information exchange, Granularity of information exchange, Establishing cooperation links between network elements, Learning time, Number of learned situations.

Use Case Id	Aspects related to cooperativeness	Observed Parameters
UC 2	Information Fusion (measurements from Nes and WSN), Knowledge sharing and evaluation.	Amount of information exchange, Granularity of information exchange, Percentage of own resources (e.g. energy, bandwidth,...) consumed by taking into account other co-located networks, Learning time, Number of learned situations.
UC 3	Information Fusion (measurements from NEs and WSN), Relayed transmission, WSN discovery.	Amount of control signalling, Amount of information exchange, Granularity of information exchange,
UC 5	Control layer based on Cooperative RRM and SON mechanisms Cooperative decision making based for power planning between base stations incl. switch on/off base stations for Energy Savings Information exchange for control/cooperation signalling.	SINR, Traffic load, Spatial User distribution and location, Throughput (in cell centre and in cell edge), Service Outage, Change in network topology, Change in number of nodes, Transmitted power (energy required for transmission), Network energy consumption, Node energy consumption Number of optimal policies, Bits transmitted for control signalling, Bits transmitted for information exchange, Reconfiguration time, Situation learning time.
UC 6	Cooperative transmission, Cooperative transmission between DAS nodes, Cooperative transmission decision making, Information exchange for control/cooperation signalling.	Link quality (in terms of instantaneous CSI), Change in the traffic load, Change in nodes spatial distribution, Energy required for transmission,

Use Case Id	Aspects related to cooperativeness	Observed Parameters
		Throughput at cell centre, Throughput at cell edge, Amount of information exchange, Reconfiguration time.
UC 7	Relayed transmission, Cooperative relay transmission, Cooperative transmission decision making, Information exchange for control / cooperation signaling	Change in network topology, Change in the traffic load, Change in the channel information, Change in the service parameters, Energy required for transmission, Total Network Throughput, Network response time, Amount of information exchange, Reconfiguration time.
UC 14	Cooperative transmission, Relayed transmission.	Energy required for transmission, Energy required for processing, Change in number of nodes (over network lifetime), Change in the (number/type) available networks/systems in the area, Number of active/idle nodes in the network, Change in Network Elements status, Ability to recognize cooperative behaviour needs, Establishing cooperation links between network elements, Cooperation initiation successful (yes/no/percentage), Signal to Interference Noise Ratio (SINR), Interference level experienced (victim) or caused (aggressor), Adaption to change in situation successful.

Table 2-2: Cooperation Aspects and related Parameters in CONSERN Use Cases.

2.3 Envisaged Technical Areas and Related Requirements

This section elaborates on the requirements tailored to cooperative operation and related functionalities based on Table 2-2. The provided technical areas are coming from WP3 partners' priorities and workplan and are associated to the enablers' identification to the next section.

2.3.1 Mechanisms for Energy Efficient Wireless Networks

This subsection describes mechanisms for energy efficient wireless networks including Physical Layer Mechanisms, mechanisms for Modified Medium Access Control, and Radio Network Control Mechanisms.

From the use cases analyses (Section 2.2) certain requirements of the use cases are identified. Without these preconditions, the proposed functionality of the use cases cannot be achieved. Hence, these subsections, conveniently aligned with the Dimensions of cooperative decision and control (Figure 2-1), initiate the enablers' considerations which are required for the WP3 use cases.

2.3.1.1 Physical Layer Mechanisms

Key objectives of the cooperative system are to increase the network capacity, reduce power consumption and expand network coverage. Communication relayed by mobile terminals is emerged as a key technology for efficient cooperative communication and, to this direction, the amount and the selection of relay nodes becomes a critical issue. The basic idea is that the relay nodes can help the source node's transmission by relaying the replica of the information.

Indeed, relaying and cooperation between multiple terminals are excellent methods of increasing energy efficiency in communications. Relaying, in particular, is able to reduce the transmission power required to reach a destination node. However, in situations where two nodes attempt to transmit to each other through a relay, the data rate and energy efficiency could be severely reduced due to the transmission process. A normal two-way communication process between two nodes, A and B, through a relay node R is illustrated in Figure 2-2, where four steps are required to complete the process of exchanging information between the nodes A and B

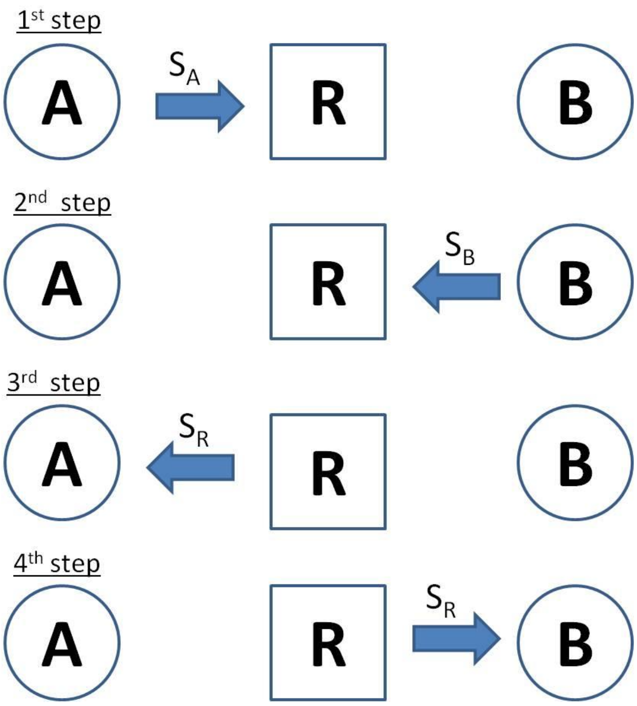


Figure 2-2: Two way communications through a relay.

In such situations, network coding could effectively increase both the data rate and the energy efficiency. Network coding works by exploiting the fact that each node knows what it is transmitted to the other node. Hence, if a network node receive a signal comprising of the message itself has transmitted and a message that was intended for it, it can recover the intended message by cancelling the known component of the signal. A simple illustration of the network coded transmission is shown in Figure 2-3, where only three steps are required to complete exchange of information between node A and B.

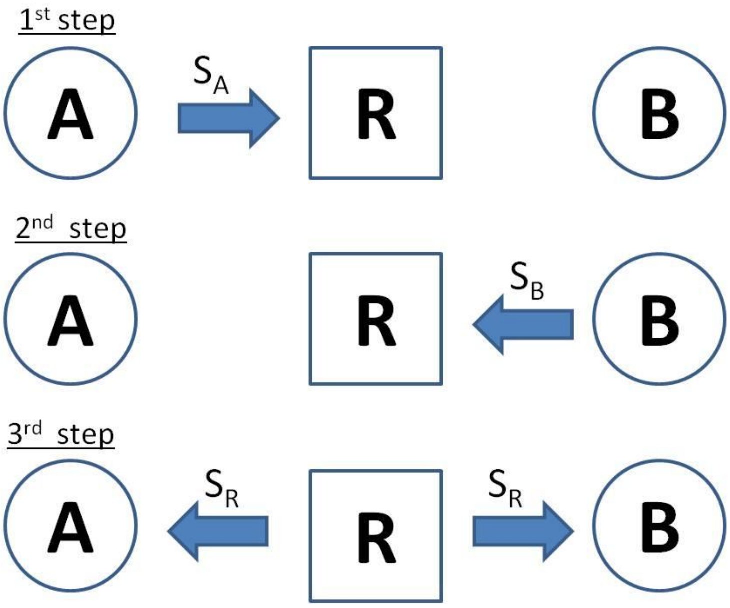
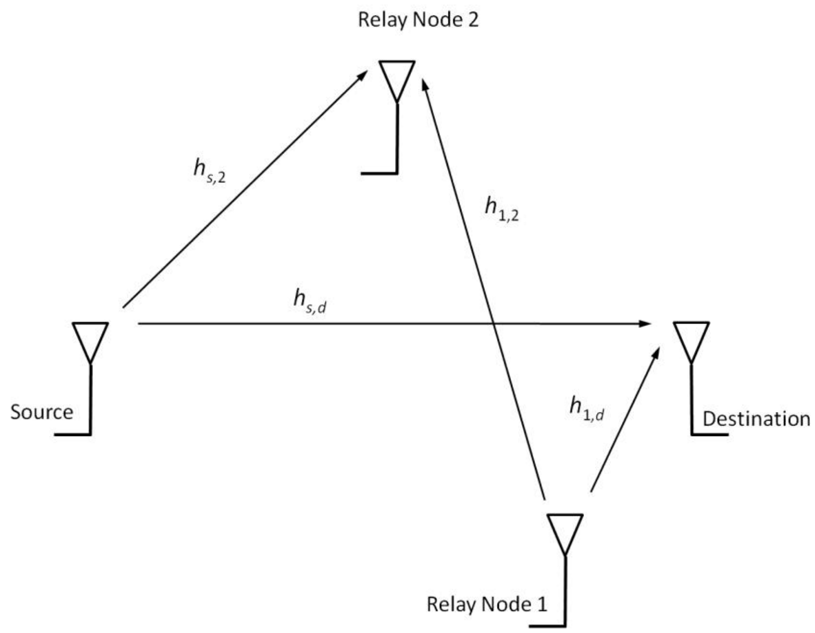


Figure 2-3: Network coded two way communications process.

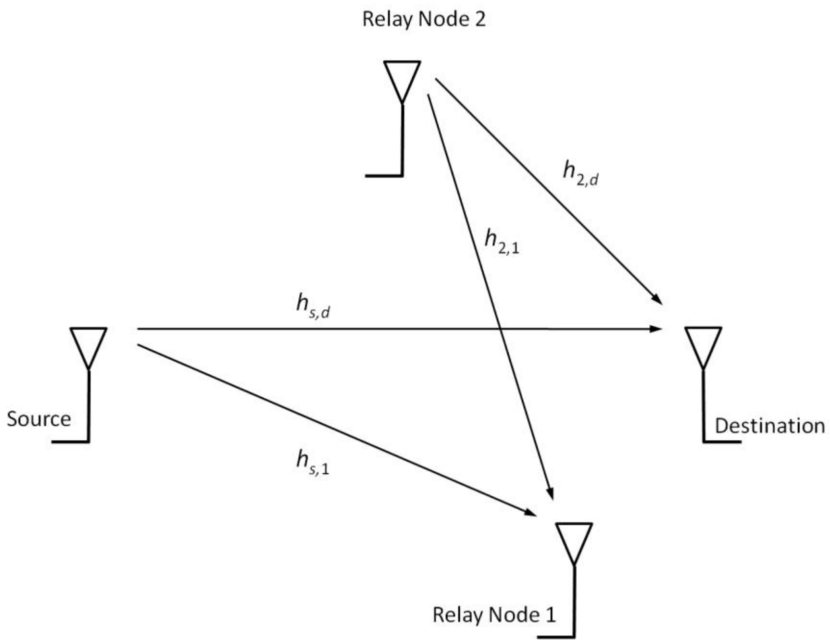
On the other hand, in situations where there is only a one-way transmission, cooperative communications is extremely helpful in reducing energy consumption by improving the diversity order of the communications link. However, due to the fact that cooperative and relay communications require an additional transmission phase (source to relay, destination, and relay to destination), where the source sits idle, this reduces the energy efficiency of the transmitter as the source node cannot be completely switched off even in idle mode. Ensuring continuous transmission of data from the source node will improve the energy efficiency and data throughput of cooperative and relay communications.

A way of ensuring that the source continuously transmits is to use two path relaying. The requirement for such a scheme is the availability of at least two relays. The two relays will alternately relay the signal from the source node to the relay node. The two phases of two path relaying is shown in Figure 2-4, where it can be seen that the two relay nodes alternate between receive and transmit mode to forward information to the destination node.

The only drawback of the scheme is the additional signal processing which is required at either the relay nodes or the destination nodes in order to process the signals.



(Phase 1)



(Phase 2)

Figure 2-4: Two path relaying (Phase 1 & 2).

2.3.1.2 Modified Medium Access Control

Efficient communications in wireless networks are characterized by a low ratio of the number of incorrectly transferred data packets versus the total number of transferred packets, i.e. the Packet Error Rate (PER). As is generally accepted, the PER is a function of the Signal to Interference plus Noise Ratio (SINR).

Consequently, a promising approach to increase the energy efficiency of a wireless network is to operate in a channel with the least interference and noise. In current operation of many wireless networks, e.g. WiFi and sensor networks, this is a common practice. Some measurements are performed, and a single channel with relatively low noise and interference is selected for the operation of the entire network.

However, noise and interference are local by nature, and therefore when selecting a single channel for the operation of the entire network, some of the nodes may suffer more interference or noise than others. One mechanism to overcome this problem is the Receiver Defined Transmission (RDT). This mechanism allows logical separation of the transmission and quiescent (=receive) channels of each node. With RDT each node selects its own quiescent channel, while still being able to communicate fully meshed with all surrounding nodes.

The working principle of RDT is fairly straightforward. When the node is idle, it uses its quiescent channel to listen to incoming messages. Every sending node can now communicate with every neighboring receiving node by sending a packet on the receiver's quiescent channel, as is shown in Figure 2-5. Node A chooses channel 11 as its quiescent channel and node B selects channel 26. When node A wants to send a packet to node B, it sends the packet over channel 26.

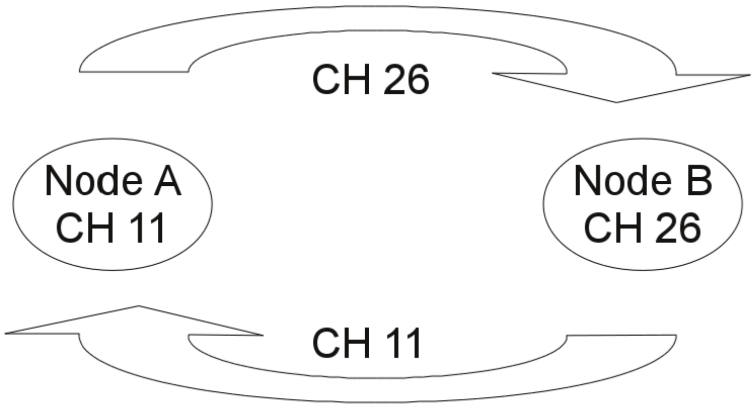


Figure 2-5: Basic Operation Principle of RDT.

Two major components of RDT, that have significant impact on its effectiveness, are the algorithm to select the quiescent channels, and the mechanism to inform neighbouring nodes of this channel selection. Different algorithms for these two components will be studied and compared with regards to energy efficiency, simplicity, backwards-compatibility, etc.

2.3.1.3 **(Radio) Network Control Mechanisms**

The Network Control layer governs functionality for exchanging information between the corresponding layers in other network nodes. It contains algorithms for control of the functions for measurements and statistics, detection of neighbouring nodes, information exchange with neighbouring nodes and network cooperation.

A node used for cooperative transmission is required to be able to cooperate and negotiate with its neighbouring nodes to agree on its behaviour. The nodes can act autonomously or be controlled by a central device. Decisions on a node’s behaviour are based on both long-term and short-term statistics measurements of the network environment. From the measurements the nodes shall also be able to find the locations of individual terminals so to control their radio transmissions.

Several nodes may cooperate to send information to the user simultaneously (multi-point transmission). In this case the energy used by each node is reduced so that the sum of the energies is less than the energy that would be required if a single node was transmitting. As described in D1.1 [91], there are two use cases related to cooperative multi-point transmission, the Distributed Antenna Systems (DAS) (UC-6/HWSE) and cooperative relay particularly by means of network coding (UC-14/TREL). In a DAS a central processor is required to collect the measurement information from all the antenna units in the cell and make decisions on which antenna units to assign to a given user.

The central processor shall also be able to exchange the received measurement information with central processor in neighbouring cells. Cooperative relay is efficiently achieved by means of network coding (e.g. relay retransmission can use network coding [25][26][27] for multiple UEs to save transmitting bandwidth) which is controlled to accommodate energy-efficient cooperation decisions.

Introducing relays which can facilitate network coding is one viable approach for energy efficient network usage. Another viable approach is **household with power consumption**. In energy efficient radio networks each node transmits with as low power as possible while still keeping a certain level of user satisfaction – Quality of Experience (QoE). Power can be reduced by means of switching off nodes with low or virtually no load and transferring the load to nodes covering the same area. By doing so the total power consumed per area unit is reduced.

Power can be reduced if the distance between the nodes is reduced. In fact, reducing the distance between the user and the network node is an efficient way to decrease the transmission power as the transmitted power needed scales as a power of the transmission distance. To cope with the decreased transmission range when the power is lowered extra nodes (relays or extra antenna elements) can be introduced.

Generally, the energy required by a network node can be divided into the energy required for radio transmission, information processing, and idle mode. The idle mode energy consumption is the lowest energy needed for a network node while still being able to activate it whenever needed. The idle mode energy consumption is related to the time it takes for a node to resume to full power transmission. So, depending on resumption time requirements the idle mode energy consumption may vary. The information processing energy is the energy required to process, measure and decide on the actions to take in a cooperative network while the radio transmission energy is the energy required to transmit the information over the air to the mobile equipment.

Moreover, improved power control mechanisms in a relayed network play a significant role since they can compensate with high transmission power levels of terminals as well as with balancing a trade-off between high interference and delays in packet delivery. Additionally, when communication ranges of terminals are properly controlled using power control schemes, better load balancing can be achieved using shortest paths only, thus resolving the problem of disproportional amount of relaying nodes, which in turn lead to their reduced batter life. Therefore, power-controlled relays that receive and retransmit the signals between mobiles can be used to increase throughput and extend coverage of cellular networks.

The list below describes requirements on the control layer in order to perform cooperative decisions and information fusion. The requirements are expressed in terms of capabilities of the nodes. Two categories of nodes are considered here: (i) network nodes e.g., base stations and action points, and (ii) relay nodes e.g., relays and remote antennas.

Requirements on network nodes

A network node shall be able to:

- Cooperate with other nodes by means of an interface,
- Exchange measurement data with other nodes,
- Exchange (from the physical layer) short term instantaneous channel state information measurements,
- Exchange long term traffic load measurements,
- Exchange (from the physical layer) short and long term terminals locations and distribution measurements,

- Exchange (from the physical layer) measurements which can be used to decide on actions to take,
- Exchange (from the physical layer) measurements on the efficiency of the spectrum usage,
- Control the network coding parameters when network coding is used,
- Share its load with other heterogeneous radio access technologies,
- Simultaneously operate several Radio Access Technologies, in case of multi-mode nodes,
- Detect and report the presence/location of mobile devices,
- Detect and report information about neighbouring nodes locations,
- Detect and report information about its coverage,
- Remotely update its firmware,
- Detect co-located networks,
- Partition/aggregate networks,
- Share information between network nodes and sensor devices,
- Detect changes in the desired network purpose,
- Share its knowledge about other nodes with its neighbours.

Requirements on relay nodes

Some more specific relay requirements are listed below:

- Relay monitoring
  - Minimize response time when conditions change,
  - Optimized collection of the communication environment such as network topology, channel information, traffic load, service features and neighbour nodes statistics,
  - Relay nodes learning ability,
  - Relay cooperation decision making,
  - Density measurement.
- Relay load balancing
  - Minimize amount of information exchange (content-oriented traffic offloading),
  - Minimize delays during configuration and inter-relay communication,
  - Improve network system capacity,
  - Extend relays nodes' battery and network lifetime.
- Relay power allocation
  - Methods to switch off or reduce its power to save energy,
  - Optimized cooperative relay power allocation.
- Relay efficient cooperation
  - Minimize relay cooperative transmission data,
  - Optimize communication between relay nodes and (external or internal) network elements,

- Cooperatively provide high data rate service for heavy traffic conditions,
- Optimized relay decision making,
- Optimized relay nodes reconfiguration time,
- Optimized relay handover,
- Enhanced cooperation to select the suitable transmitting power.

2.3.2 Cooperative Decision Making

A cooperative decision making process generally consists of three steps. In the first step, the context information is collected. This could be either the inherent information available at the network node itself or the information provided by the cooperative partners. In the second step, the optimal configuration is calculated based on the collected information. In the third step, the control information is forwarded to the corresponding network nodes. If an iterative cooperative algorithm is applied, e.g. a negotiation game or an auction game, the second step will be repeated several times based on the updated input information.

In order to support this process, a network node (a CONSERN-enabled node) should be able to collect the context information of the environment and receive/transfer the required information from/to the cooperative node. In certain concrete use cases, the node should be able to collect the physical layer information, e.g. short term / long term channel/interference information, and the MAC/Control layer information, e.g. the traffic load. Based on the information, the network node should have the ability to find out the optimal solution of resource allocation. The optimal solution in this case is understood as the configuration that can minimize the overall energy consumption. At last the network node should have the ability to carry out the optimal solution, i.e. it should be able to configure the parameters such as transmission power, frequency usage, coding scheme, user assignment, etc. The capabilities of a network node that are required for the cooperative decision making are presented in the following list.

A network node should be able to:

- From the received measurements calculate/decide which antenna element(s) to assign to a given user while minimising the network's energy consumption,
- Decide on which antenna element(s) to assign to users who are (equally) close to antennas from both central controllers,
- Based on the learned information and predefined policies, make decisions and cooperate with other nodes to provide high system throughput and energy efficiency,
- Cooperate in order to reduce their mutual interference,
- Choose its frequency assignments as to minimise the mutual interference between nodes,
- Based on measurements at the physical layer take the energy it consumes in idle mode into account when deciding on its action,
- Based on measurements at the physical layer take the energy it consumes for information processing into account when deciding on its action,
- Based on measurements at the physical layer take the energy it consumes for transmission into account when deciding on its action,
- Know the time it takes to resume to full power into consideration when deciding on its action.

2.3.3 Information Fusion and Knowledge Representation

2.3.3.1 **Information *F*usion**

Information fusion (integration) is one of the core problems in cooperative systems. A short but indicative definition is given in [8] where information fusion is defined as the merging of information data from disparate sources with differing conceptual and contextual representations. A more detailed definition on data fusion is given by [9] stating that “data fusion is a formal framework in which are expressed means and tools for the alliance of data originating from different sources. It aims at obtaining information of greater quality; the exact definition of ‘greater quality’ will depend upon the application.” Information fusion is enabled by means of a conceptual representation that also incorporates the information requirements that the fusion functionality has to address [10].

A **conceptual representation** is provided by a formal description of the concepts which compose the reference system (such as network elements types, actors, configurations, etc) and the relationship between concepts: such description can be provided for example by an information model (see Section 3.3). At the level of the conceptual representation the mentioned formal description must be agnostic to any actual system consideration, platforms and so. The objective here is to express the related semantics – how to enable interpretability within the managed system.

On the other hand, a **contextual representation** goes further than adding meaning to system elements and aims at capturing the specific context (such as for example the type or the internal status of the system component / information source) in order to address polysemy. Polysemy – the term comes from linguistics – refers to a specific information item having two or more meanings. This means, for example, that an information item may be assigned different meanings depending on the different context it reflects. In terms of requirements, additional meta-information or rules may be needed in order to overcome such barrier.

The information fusion must be considered in conjunction with the independent sensing: information fusion enables global knowledge whereas independent sensing can provide local knowledge; next section elaborates on the global and partial knowledge.

2.3.3.2 **Knowledge Representation**

Knowledge representation is an aspect which can be considered as complementary to the mentioned information representation, conceptual and contextual. In [12] the content of the human mind is classified into five categories as cited:

- **Data**: symbols, self-existent without relation to other things,
- **Information**: data that are processed to be useful; provides answers to "who", "what", "where", and "when" questions,
- **Knowledge**: application of data and information; answers "how" questions,
- **Understanding**: appreciation of "why",
- **Wisdom**: evaluated understanding.

Based on this a definition for Knowledge Representation as coming from the field of Artificial Intelligence (AI) is provided by [13]: “A knowledge representation (KR) is most fundamentally a surrogate, a substitute for the thing itself, used to enable an entity to determine consequences by thinking rather than acting, i.e., by reasoning about the world rather than taking action in it”. Usually, knowledge is represented using complex structures. These include various forms of logic and graphs integrating also rules to enable inference and reasoning on the data, concepts and relations.

As indicated in [14] in the one extreme each node may have full knowledge of the environment nodes operate in by exchanging both sensing and decision information. However, this would require extensive information exchange. Also a more frequent information exchange increases the probability of having up-to-date information about the environment. On the other extreme less frequent or even lack of information exchange implies imperfect and partial knowledge restricted to local environment.

This discrimination reflects the global and local/domain knowledge: a global knowledge model encapsulates knowledge about the reference system as a whole, whereas a local knowledge model captures knowledge about a specific node, a type of nodes, or an area. Global knowledge needs to be composed by local knowledge which reflects partial view(s) of the managed system under consideration. This implies the need for a knowledge representation scheme supporting partial knowledge model integration and extensions to support enhanced inference capabilities.

2.3.3.3 Summary

In this section an overview of the information fusion and knowledge representation concepts have been presented; corresponding requirements have been identified that are related to:

- Need for platform-agnostic abstraction model to capture the system entities and interrelations,
- Need to integrate contextual representation to reflect the different context of each concept,
- Need to incorporate in the model policies, rules and constraints reflecting different technical and environmental contexts,
- Need to have a harmonised and interpretable approach on knowledge representation in order to accommodate for example nodes that have limited capabilities and views of the entire system,
- Need to adopt and develop an approach to model concepts and rules in a formal, agreed and shared way to enable sharing and reusability,
- Need to support inference and reasoning on the system concepts and relation,
- Need to capture local knowledge supporting also dynamic composition of the global knowledge by integrating partial knowledge.

A complete representation mechanism putting together concepts and rules is important for self-growing energy aware systems and networks. Knowledge representation with conceptual and contextual representation can be used in many ways:

1. In terms of cooperation it can be used to identify more effective cooperation conditioned to the actual context,
2. In terms of self-growing it can be used to identify new purposes related to environment contexts and demands.

2.4 Balance between Autonomicity and Cooperative Operation – an Overview

Autonomic computing is a self-managing computing model named after, and patterned on, the human body's autonomic nervous system. The goal of autonomic computing is to create systems that run themselves, capable of high-level functioning while keeping the system's complexity invisible to the user [89]. Autonomic Networking follows the concept of Autonomic Computing, an initiative started by IBM in 2001 [90]. On the other hand, the term cooperative communications typically refers to a system where users share information and coordinate their resources in order to enhance the transmission quality. Two features differentiate cooperative transmission schemes from conventional non-cooperative systems:

- The use of multiple users' resources to transmit the data of a single source, and,
- A proper combination of signals from multiple cooperating users at the destination.

As mentioned, different degrees of cooperation can be distinguished according to the level of synergistic behaviour that is considered in the system:

- **Information exchange**, ranging from node independent sensing (i.e., no information exchange between nodes) to full context/knowledge representation and sharing. In this sense:
    - Systems that exchange information could still be considered autonomic in the case that decision is made separately for each of them; moreover,
    - In the case of knowledge sharing, an autonomic system shall be able to evaluate the shared knowledge under its own context and then decide separately.
- **Decision coordination and control** ranging for independent decisions towards coordinated decisions about reconfigurations.
    - Such systems are considered cooperative (and not autonomic) in the sense that the decision making process itself is not independent but coordinated (e.g. the nodes try to maximize an overall utility function),
    - Cooperative systems are also expected to decide on different parts of one more complex problem; such decision can be made separately, but it is considered as an intermediate decision aiming at solving more complex problems in a collaborative and coordinated way.

The balance between autonomicity and cooperativeness can be studied in two different directions. In the first direction it captures the balance between a node's individual objectives and network objectives. In its simplest form a network objective can be defined as the sum of all nodes' objectives (as in social welfare). A node may defer from taking actions that maximise its individual objectives for the benefit of the maximisation of the network objectives. For instance, a cell may select a lower power setting that maximises the overall network throughput (e.g., cause less interference) to the expense of its cell throughput performance. On the other hand a node may select a higher power setting to increase its own cell throughput causing more interference to all neighbouring cells and thus reducing the overall network throughput. In both cases the node is rational; however the selected strategy could be a matter of balance.

The second direction focuses on the identification of optimal configurations for the network operation (e.g. with the least energy consumption) that balance the benefits offered by a fully cooperative (coordinated decisions) and a simpler autonomic (independent decisions) approach. For example this should take into account on one hand that the complete picture can be available to cooperative systems (e.g. utilizing information sharing, coordinated actions, etc) but this additional fine-grained information and flexibility comes with a cost in signalling that should be justified from the expected gains. In this scope, by utilizing synergistic operations we can fine-tune the configuration of the network nodes in order to converge to the most energy efficient pattern (a global optimal point). In order to define the optimal balance, the energy consumption should be compared to a simpler decision making method using a limited information exchange and autonomic decision making process.

3. Enablers for Cooperative Operation

This section elaborates on the technical areas described in the previous section from the use cases and according to the CONSERN Description of Work (DoW) and shed light on them by enumerating corresponding enablers. The following subsections provide a state of the art description for each of the defined enablers and the envisaged role of each of the enablers within WP3 workplan.

3.1 Relay and Cooperative Communications

3.1.1 Cooperative Relay

Due to the cubic channel fading between base stations BSs and mobiles in wireless networks, as already described in section 2, relay nodes reduce the distance to mobiles, which means relay node consumes less power compared to direct BS transmission in order to achieve same SNR level [68].

Besides, relay nodes can cooperate with each others to provide high data rate service and energy efficiency furthermore [69]. There are several schemes such as Amplify-and-Forward strategies [70], Decode-and-Forward [71] and Coding Cooperation [72] for relay cooperation.

Relay cooperation provides a possible way to make the use of diversity in the spatial and temporal dimension to mitigate the effects of fading and therefore to increase the reliability of radio links in wireless networks [73]. Also, relay cooperation is combined with different wireless technologies to improve the performance furthermore, e.g. combine the idea of cooperative relay and cooperative MIMO, provides benefits of spatial diversity without physical antenna arrays [74].

Current work on relay cooperation is considering the performance of cooperation coding or combining relay cooperation with single technology (e.g. MIMO) to achieve performance improvement. The relay nodes collect and learn about the network topology, channel information, traffic load, and neighbour nodes statistics, based on learned information and predefined policy, relay nodes make joint decisions, and cooperate with other nodes to provide high system throughput and energy efficiency. In this project, relay node definition, usage (e.g. transparent relay or non-transparent relay), and its possible cooperation scheme will be defined (e.g. coding cooperation, etc) and its impact on relay cooperation decision will be described.

In recent years, a number of new communication techniques have sprung up. In particular, two are important in the energy efficiency context. The first, network coding, was first invented as a network layer technique for increasing network flow through the use of a priori knowledge at the receiver [28]. The scheme considered is a multicast network where a data source transmits to multiple data sinks over a number of relay nodes, where the links between the nodes have different capacity. Considering the network information flow it is shown that decoding, data combination and encoding of the transmitted information at the network relay nodes can be beneficial for the system. This scheme is hence named network coding.

Most famous in this regard is the so-called butterfly network, displayed in Figure 3-1, where the aforementioned single source multicasts to two receivers over a number of relay nodes. The capacity of the edges of the graph is 1. Data to be received are messages b1 and b2, where the edged from source s to nodes 1 and 2 are limited to transmitting a single message on either link. Further part of the model is a direct link from nodes N1 and N2 to terminal data sinks T1 and T2, so that the messages b1 and b2 will arrive directly. However the missing part at either sink will be delivered as a combination b1+b2 over relay nodes N3 and N4, where N3 encodes the combined message and N4 relays it to T1 and T2. Since both terminal data sinks know one part of the message, they can decode the missing information easily. Thus the capacity constraint edge between nodes N3 and N4 is able to provide necessary information, so that effectively four messages (though not independent because of multicast) could be received over three edges.

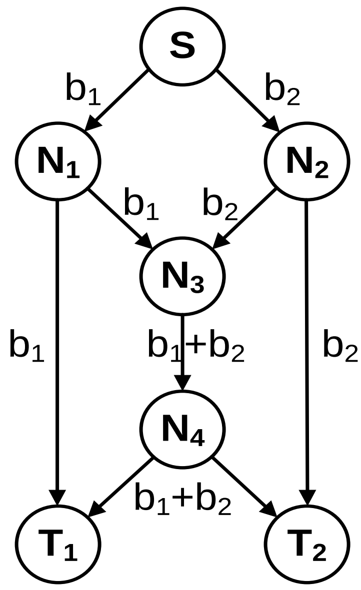


Figure 3-1: Butterfly network.

A good and widely used application for network coding analysis is a three node relay network as depicted in Figure 3-2. Nodes N1 and N2 are both data source and sink, which communicate wirelessly over a relay node N3. In a normal network set-up, the relay would operate in a routing mode, where messages are either amplified and forwarded or decoded and forwarded. The process would include first transmission of independent messages b1 and b2 from node N1 and N2 to the relay (uplink), which occupies two units of network allocation units, for example two time slots. Second part of the process is relaying of b1 and b2 independently to the respective receivers (downlink), thus occupying another two network allocation units, totalling four units, where the order of the network occupation is arbitrary (obviously downlink of one message can only be after uplink of the same message).

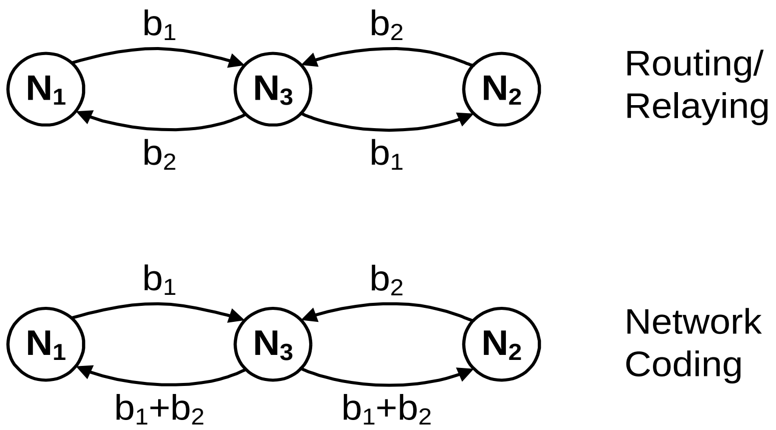


Figure 3-2: Relaying and Network Coding

Network coding can be easily applied to the downlink transmission, where the relay combines the two uplink messages and encodes them to a single message b1+b2 and transmits thus the downlink message on only one network allocation unit, totalling three units. The receiving nodes can decode the received message, for example b2 for N1, by subtracting the information about the previously transmitted own message b1. Thus the implementation of network coding saves one network allocation unit. Uplink transmission order is arbitrary, but the encoded message b1+b2 must be transmitted last. Note however that the two messages b1 and b2 must be of the same size, otherwise zero-padding of the shorter message may be used, but this impacts throughput and therefore makes network coding less efficient.

"XORs in the air: practical wireless network coding" [29][30] is a 2006 work by Katti *et al.* that describes a first trial deployment of network coding using a unicast-traffic wireless mesh network. Routing nodes not only forward messages, but also collect and store, encode and decode them, so that messages from several sinks may be combined and transmitted at once. It is shown that doing so can increase network throughput. However the gains highly depend on used protocols (for example, a protocol using timely acknowledgement messages is less efficient), buffer sizes, time delay constraints, congestion level, traffic patterns, and so on. So the achieved gains reach from none to very large. However it indicates that network coding on higher layers can be very beneficial if implemented using system parameters supporting it.

Physical layer network coding goes one step further and attempts to combine the messages on the air interface at the network coding receiver, which means for the above relaying example depicted in Figure 3-2, uplink messages b1 and b2 are transmitted at the same allocation unit (for example, the same time) and overlay each other at the relaying network coding node N3. Thus the received signal is already a superposition of the transmitted waveforms b1+b2. Depending on the assumptions on the system, the relay node N3 can simply forward the physically combined messages to the data sinks N1 and N2 without further processing and leave detection to them, considering they know their own part of superposition; alternatively one can assume that the relay node N3 can decode the superposition, and then transmits a broadcast to N1 and N2 of the combined message b1+b2. One interesting point is that the number of network allocation units for the complete message exchange is reduced to two units, thus a 100% increase in throughput as compared to the simple routing relay.

However physical layer network coding is an area, in which ideal conditions are often assumed in order to be able to do it in the first place. This includes perfect knowledge of parameters such as channel responses, ideal precoding (channel pre-equalisation) and power control, symbol synchronisation. Especially information processing at the relay node is challenging. A major research area for decoding at the relay node is superposition constellations in adequate fields and their detection [31]. Practical physical layer network coding is thus far from realised yet.

On the other hand, cooperative communications can also improve the energy efficiency of systems by lowering the transmission power required for achieving a certain throughput. The method to cooperate with other terminals or nodes were first proposed by Sendonaris *et al.* in [32], [33], and then Laneman *et al.* in [34], [35]. The technique requires a relay node which listens in to the transmission of the source node and then relays a version of what it has heard to the destination node.

Many improvements to the scheme have been proposed over the past few years, including power allocation schemes [36], [37], and [38], power control schemes [39], [40], relay selection [41], [42], and alternative protocols [43]. However, only recently was there some effort on improving the throughput of cooperative schemes. The first effort to address the problem was presented in [44]. The problem was more thoroughly explored in [45]. An effort was made in [46] to effectively cancel some of the inter-relay interference through beamforming at the relays.

In [2] power control is studied as a means to achieve better load balancing of the relayed nodes and, therefore, extend nodes' battery life and network lifetime. The proposed centrality-based power control scheme manages to confront unfair and disproportional amount of relaying nodes, although it requires global knowledge of the topology for determining power levels. Additionally, in [3] centralized power allocation schemes are presented assuming that all relay nodes help and based on this a selection forward protocol to choose only one 'best' relay node to assist transmission is proposed, in order to further minimize the system outage behaviours and improve the average throughput. On the other hand, authors in [4] propose a distributed relay selection method that requires no global knowledge. Distributed selection is achieved through an access scheme based on distributed timers and channel estimation using reciprocity. In [5] the authors propose a distributed buyer/seller game theoretic framework, over multiuser cooperative communication networks that always decide the optimal power consumption of each relay terminal. In [6] a power-control problem for data traffic relayed over an intermediary node in cellular networks is presented. The authors investigate a set of Power-Controlled Medium Access algorithms which achieve great performance in terms of both power usage and packet delay. Furthermore, in [7] the authors present a distributed power control algorithm for wireless relay networks in interference-limited environments. The proposed scheme aims to minimize the total transmission power subject to the SINR requirements. This algorithm requires low computational resources and, combined with its distributed characteristics, may be adopted in large-scale relayed wireless networks.

Benefits of network coding and physical layer network coding regarding to the CONSERN project goals in terms of energy efficiency are shorter transmission and reception periods for the same amount of data, which enable longer sleep times (or other inactivity modes) for the network nodes, hence saving energy and increasing standby times when battery powered. Also, for example in the three-node relay network of Figure 2-2, the relay node has a lower number of transmissions, since messages b1 and b2 are broadcast at the same time rather than one after another. This, on top of fewer periods of activity, reduces transmit power by one half and increases battery life yet again.

This must however be evaluated against the increase in processing time and energy needed for the network coding part. Thus envisaging a type of amplify and forward relay node for physical layer network coding, which will effectively avoid this decoding energy overhead, may improve energy gains by a large amount.

Other benefits include more silence periods on the transmission channel, which may be used to enable further cooperative behaviour or other improvements.

3.1.2 Distributed Antenna Systems

A Distributed Antenna system (DAS) [75], [76], consists of a number of spatially separated antenna nodes connected to a common source via a transport medium that provides wireless service within a geographic area or structure. In a network employing DAS, the distributed antennas are connected to a base station through cable, fibre, or microwave. DAS provides low power transmission, less interference to other systems, and uniform coverage of a service area. It achieves larger system throughput resulting from an improved spatial multiplexing gain as the distributed antenna nodes have low correlation. Also, the energy efficiency can also be greatly improved as the travelling distances of wireless signals in the air are reduced in DAS network.

The concept of distributed antennas was first proposed to solve the problem of indoor coverage [77], [78]. These early distributed antenna systems (still in use today) essentially redistributed a cellular signal throughout a building using an amplifier and multiple antennas or used the concept of a leaky coaxial cable. DAS has received renewed interest in cellular systems for supporting outdoor coverage [79], [80]. Results from [81] show a doubling in capacity improvements using distributed antennas. The results also indicate that selecting the best distributed antenna for a given user may be preferable to a simulcast across all distributed antennas. Furthermore, the distributed antennas do not need to be placed regularly in the area [82]. Current work on distributed antennas is considering the performance of distributed antennas in light of other capacity achieving techniques like MIMO [68], [69] or CoMP [70].

For the deployment of urban heterogeneous environments, the whole coverage area is divided into several cooperative DAS cells seamlessly. In each DAS cell, an individual DAS system is deployed, where multiple distributed antenna nodes separately located within the cell are connected with a central controller via high speed backhaul, e.g. fibre. There are also inter-connections among the central controllers of different DAS cells.

The central controller in a DAS cell collects operational statistics of both long term and short term from own measurements, measurements and feedback from mobiles and by exchanging information with other DAS cells. The statistics include terminal distribution or traffic load of long term and instantaneous channel state information or terminal locations of short terms. According to this statistics, the cooperation among distributed antenna nodes within a DAS cell is carried out in a centralized way at the central controller. The cooperation among distributed antenna nodes over several DAS cells is carried out in a distributed way among different central controller.

In this project, the structure of cooperative DAS network and the functions of its elements will be defined. Both the centralized and distributed cooperation schemes for distributed antenna nodes will be introduced as key enablers for the urban heterogeneous environments.

3.2 Self-Organising Networks (SON) Mechanisms

Within 3GPP Long Term Evolution (LTE), the notion of Self-Organising Networks (SON) [48] corresponds to a set of automation mechanisms that include several different functions from base station activation to radio parameter tuning. SON is a basic framework for all self-configuration/self-optimization functions as depicted in Figure 3-3.

Self-configuration process is defined as the process where newly deployed nodes are configured by automatic installation procedures to get the necessary basic configuration for system operation. This is the installation (or pre-operational) state when the eNB is powered up and has backbone connectivity until the RF transmitter is switched on. The Self Configuration process comprises: (i) Basic Setup and (ii) Initial Radio Configuration.

Self-optimization process is defined as the process where User Equipment (UE) & enhanced Node B [1](eNB) measurements and performance measurements are used to auto-tune the network. This optimization/adaptation process works in operational state, which is the state where the RF interface is additionally switched on.

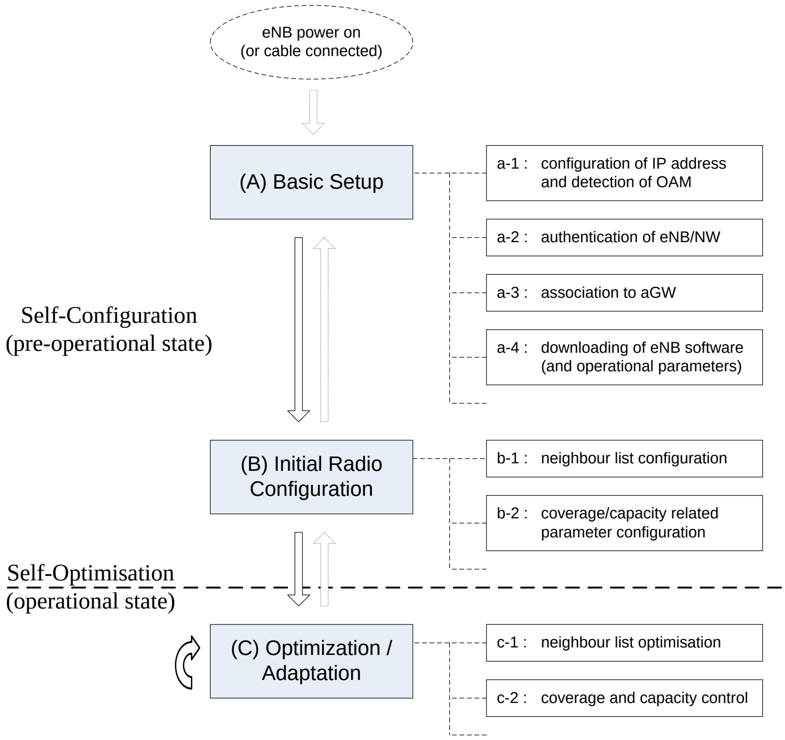


Figure 3-3: Ramifications of Self-Configuration /Self-Optimization functionality [83]

[1] Base station in 3GPP LTE parlance.

More specifically, self-configuration deals among others with:

- Dynamic configuration of the interface towards core network (which in 3GPP LTE is referred as S1-MME),
- Dynamic configuration of the interface towards other radio nodes ((which in 3GPP LTE is referred as X2),
- Automatic Neighbour Relation (ANR) Function,
- Selection of Physical Cell Identification (PCI).

With regards to Self-optimisation relevant to this context mechanisms that LTE SON deals with are:

- Support for Mobility Load Balancing (MLB),
- Support for Mobility Robustness Optimisation (MRO),
- Support for energy efficiency.

The objective of mobility load balancing is to distribute cell load evenly among cells or to transfer part of the traffic from congested cells. This is done by the means of self-optimisation of mobility parameters or handover actions. Support for mobility load balancing consists of one or more of following functions:

- Load reporting,
- Load balancing action based on handovers,
- Adapting handover and/or reselection configuration,
- Triggering of each of these functions is optional and depends on implementation.

Mobility Robustness Optimization is mainly used to detect radio link connection failures that occur due to Too Early or Too Late Handovers, or Handover to Wrong Cell. These three cases are defined and their respective detection mechanisms are carried out.

Finally, the aim of this energy saving function is to reduce operational expenses through energy savings. The function enables for example the possibility for a cell providing additional capacity, to be switched off when its capacity is no longer needed and to be re-activated on a need basis. Energy savings is further described in 3.5.1.

3.3 System Conceptualisation and Modelling

This section builds on Sections 2.3.3, 2.3.3.1, and 2.3.3.2, and describes the idea of concepts-based system representation. Moreover, it presents SOTA Information Models (*e.g.* 3GPP ANDSF and IEEE P1900.4). In the context of this section, an Information Model is considered as enabling information fusion from various sources as it provides a common way of different concepts representation whilst ontology is considered as enabling knowledge capturing and sharing whilst provides reasoning and inference capabilities.

Information models provide a tool of systems conceptualisation and can be built using a formal language (*e.g.* UML) in order to fully describe the entities in a system as well as the interrelation between those entities. Corresponding serialisations (data models) can be provided (for example RDF triples) for the information exchange between system components. This will enable information processing which takes into account the defined semantics as well; more complex approaches will be also described (*e.g.* ontology and owl serialisation) to enable domain knowledge modelling and dynamic incorporation of different views of the system.

An Information Model (IM) is an abstracted representation of the entities in a managed environment. Such an abstraction includes the entities properties and operations, and the identified inter-relationships. An Information model is independent of any specific repository, application, protocol and platform [49].

As stated in [50] an Information Model can be defined using a formal language; more specifically, the Unified Model Language (UML) [51] class diagrams can be used for the specification of an Information Model in order to represent the involved entities and the relationships that have been defined between them in a standard graphical way thus facilitating the understanding of the underlying model given that UML is a widely accepted and used multi-purpose modelling tool as it has been standardised by the Object Management Group (OMG [52]).

An information model provides a uniform abstraction of the managed environment and thus facilitates knowledge sharing and transfer among the autonomic entities and from element to domain. Distributed environments require dynamic and flexible information management in terms of representation and storage. Additionally, an extensible OO information model fills the identified gaps.

Several organisations have been using UML for Information Models specification including the DMTF, the ITU-T SG 4, 3GPP SA5, and the IEEE P1900.4 WG within the IEEE SCC41, the TeleManagement Forum, and the Autonomic Communication Forum. An overview of such Information Modelling activities is also provided in later section**.**

Within the scope of the CONSERN, the managed environment is mainly characterised of:

1. A plethora of network and system devices, with different capabilities and configurations, being operated in a dynamic and reconfigurable mode; additionally, the self-growing capabilities provide additional complexity and heterogeneity in the system,
2. High availability of different types of networks (e.g. WLAN, 3G, UMTS, WiMAX and so on).
3. User Equipments, and,
4. Wireless Sensor Network Nodes.

In such a complex and challenging managed environment the corresponding abstraction through Information Models is expected to be alike demanding and extended; the information space that is key concepts and entities that will form the abstraction in question is ever growing up. Additionally, the elementary information include not only context information but also policies and self-growing rules information which need also to be represented in a uniform and interpretable way.

In [52] **context** is referred to as “any information that can be used to characterise the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves”. Such interaction is extended to include also interactions among all the involved actors within the managed system. The Context concept need to be further categorized as including Profiles that, usually, capture static information that characterizes an entity within the telecommunication ecosystem such as terminal capabilities, user data and preferences; alike, context refers to more dynamic information such as resource measurements, and sensing information.

On the other hand, the concept of “Policy” stands for the counterpart of the contextual information that is required to model the behaviour of the entities within a managed environment. Context conceptualizes entities, actors and interactions; policies, are used for abstracting specific actors goals, and objectives in various levels, business, technical and administrative. In [49] the term “Policy” can be defined from two perspectives:

- A definite goal, course, or method of action to guide and determine present and future decisions. In this sense, "Policies" are implemented or executed within a particular context (such as policies defined within a business unit),

- Policies as a set of rules to administer, manage, and control access to network resources.

Knowledge Modelling builds on the system conceptualisation - which can be provided through the information model – in order to enable sharing and capturing of additional aspects such as system behaviour and experience. Basic concepts related to Knowledge management have already been presented in Section 2.3.3.2. Semantic Web is currently playing a driving role in Knowledge Representation and reasoning [14]. Such developments include also knowledge representation languages RDF, RDF Schema, DARPA Agent Markup Language (DAML), Ontology Inference Layer (OIL), and Web Ontology Language (OWL).

The Resource Description Framework (RDF) [15], [16], is often used for representing system resources, services and knowledge [17], [18], [19]. It is a language framework for supporting resource description, or metadata (data about data) of Semantic Web and it provides common structures with Extensible Mark-up Language (XML) that allows other language development to be used as a framework such as Web Ontology Language (OWL) [20], Composite Capabilities/Preference Profiles (CC/PP) [21] and so on. In addition, a number of RDF application programming interface (API) implementations to the open source community are available, such as Sesame [22] and Jena [23].

Typically, an information modelling enables specifying the structure and integrity of data sets. Creating data models from information models usually depends on the specific tasks and needs. On the other hand, in open and heterogeneous environments **knowledge** needs to be modelled in order to formally specify agreed logical theories for an application domain.

Among the various semantic web-driven knowledge representation languages, ontology seems to be the more mature and adapted for reasoning and inference [24]. Ontology provides formal descriptions of terminologies that can be interpreted in an automated way providing “understanding” at the machine – level. The Web Ontology Language (OWL) [20] is the W3C standard for ontological modelling. OWL, which has been optimized to represent structural knowledge at a high level of abstraction, can be used to create domain models that can be shared and reused providing interoperability to applications that will share these models.

Ontology [67] is a formal, explicit specification of a **shared** conceptualisation. "Explicit" means that the type of concepts used and the constraints on their use are defined explicitly. "Formal" means that the ontology should be machine interpretable. "Shared" refers to the fact that ontology captures consensual knowledge. Moreover, ontology is not restricted to an individual, but is accepted by a group that commits to a common ontology. Finally, ontology provides a vocabulary of terms and relations with which to model its domain.

By using ontologies, the relationships between entities can be more clearly expressed and it allows for better reasoning. Ontology can be used to:

- Share common understanding of the structure of information among people, software engines, or network nodes,
- Enable reuse of domain knowledge,
- Make domain assumptions explicit,
- Separate domain knowledge from the operational knowledge, and analyze domain knowledge,
- Compose global knowledge by integration of multiple domain ontologies.

In the context of the CONSERN WP3 workplan, a system conceptualisation will integrate the system and network elements, the applied policies, rules and constraints for cooperative management and control in energy awareness and optimisation. Local and global knowledge will be captured and modelled in conjunction to the mechanisms for adaptation to energy efficient operation utilising also knowledge sharing and evaluation.

Information modelling is initiated in section 3.8 where the Cooperation Profile is described; this is considered as a part of the overall element and system abstraction which will be carried out in the context of WP3.

3.3.1 State of the Art: Overview of the IEEE P1900.4 Information Model

The IEEE P1900.4 "Standard for Architectural building blocks enabling network-device distributed decision making for optimized radio resource usage in heterogeneous wireless access networks" defines the building blocks comprising (i) network resource managers, (ii) device resource managers, and (iii) the information to be exchanged between the building blocks, for enabling coordinated network-device distributed decision making which will aid in the optimization of radio resource usage, including spectrum access control, in heterogeneous wireless access networks.

The P1900.4 Information Model abstracts the Composite Wireless Network and the Terminal as two discrete managed objects. The Terminal includes user, application device and radio resource selection policies whereas the Network includes the operator and the operating RANs context information (Channels, Regulation, Base Stations and Cells). The mentioned top level concepts are further detailed with corresponding profiles, capabilities, preferences and measurements.

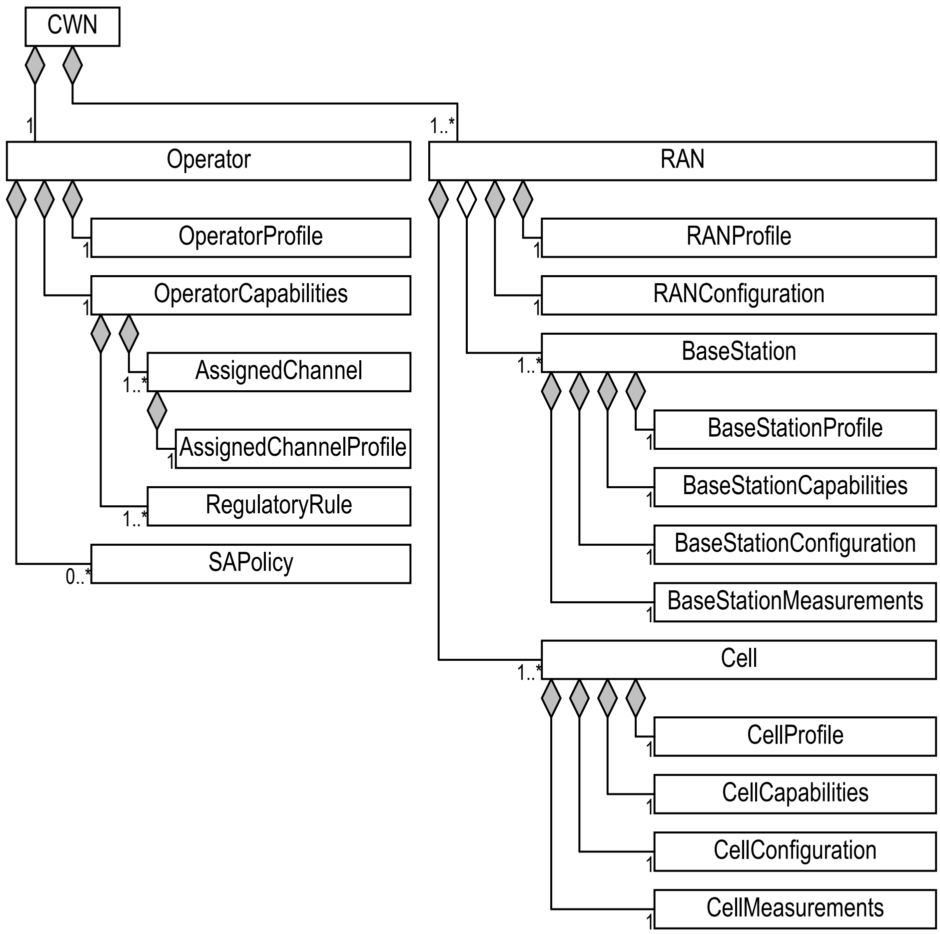


Figure 3-4: IEEE P1900.4 Information Model: The Composite Network Managed Object.

3.3.2 State of the Art: 3GPP Access Network Discovery and Selection Function (ANDSF) Management Object

The ANDSF MO is used to manage intersystem mobility policy- as well as access network discovery information stored in a UE supporting provisioning of such information from an ANDSF. The ANDSF contains data management and control functionality necessary for providing network discovery and selection assistance data to the User Equipment (UE) as per operator's policy. The ANDSF is able to initiate data transfer to the UE based on network triggers, and respond to requests from the UE. The 3GPP ANDSF specifications cover network discovery and network selection for WiMAX, WiFi and WLAN access networks among others and therefore are seen relevant also for WiMAX Forum, WiFi Alliance and IEEE 802 11. Signalling for information exchange between the ANDSF and UE/MS is based on OMA Device Management protocol and the corresponding ANDSF Management Object is being specified in [53].

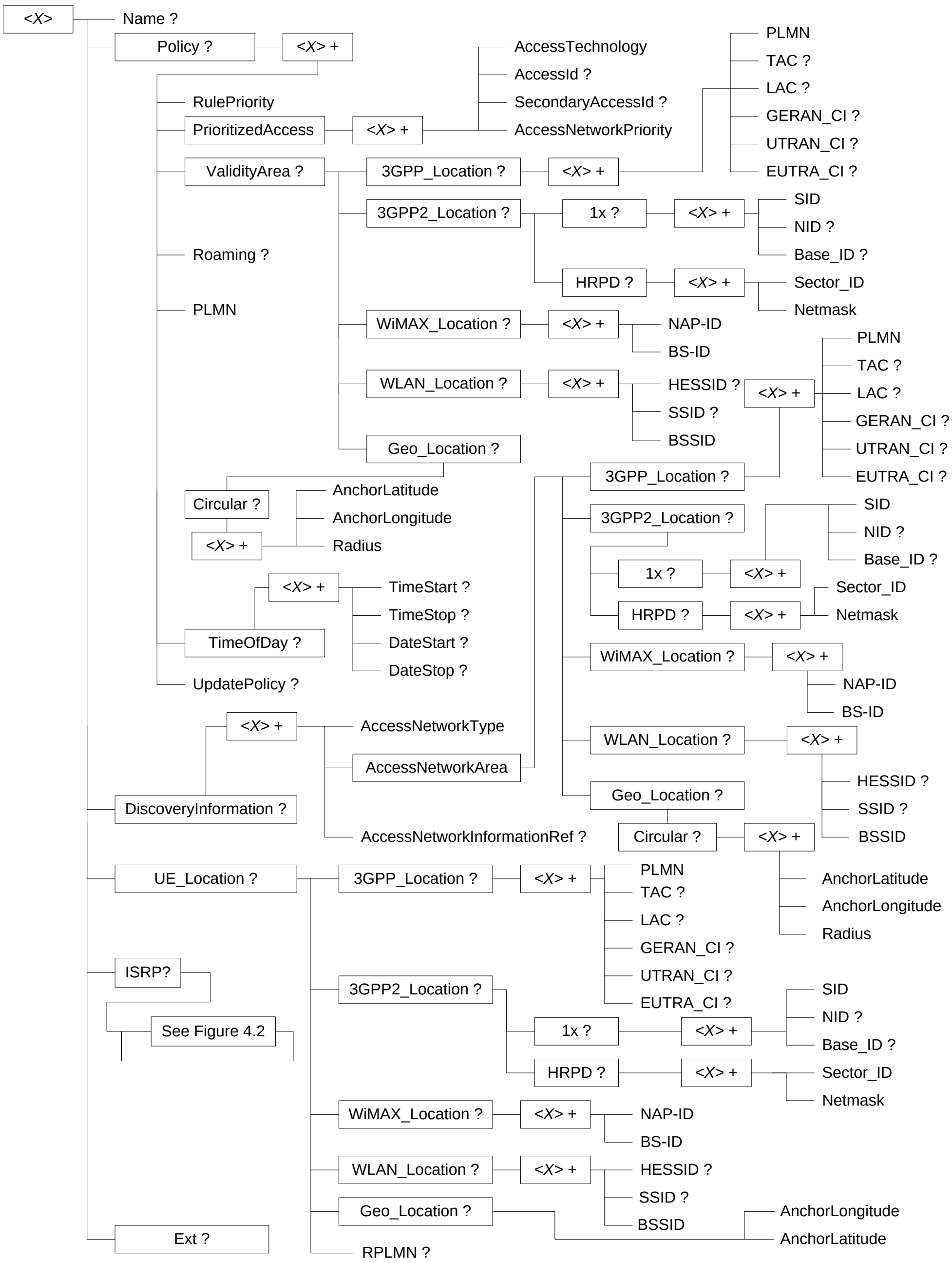


Figure 3-5: The ANDSF Managed Object.

3.4 Cooperative Decision Control

There are different mechanisms that can be adopted to realize the cooperation between the network elements (e.g., [92], [93]). The choice of which mechanism should be used in a particular use case is determined by a number of technical conditions.

In a heterogeneous environment various wireless networks coexist within the same geographic area. The networks could be built on different radio access technologies and even belong to different owners / operators. It is expected that the information exchange between the networks is very limited. A negotiation-based mechanism [93], [94] can be applied to this case. In an initial phase a set of negotiation policies is distributed among the networks. The policies clarify the objective of the negotiation and guarantee that the negotiating partners will surely come to an agreement. Afterwards, only necessary information required for negotiation, such as provided benefit and required cost, will be exchanged between the networks. Hence, the negotiation-based mechanism is suitable for cooperation on high level with constraint on information exchange.

An alternative to using a negotiation-based mechanism is to use an auction-based mechanism [95], [96], [97] which requires less information exchange during the operation time than the negotiation-based mechanism. Similarly as for the negotiation-based mechanism, a set of rules is distributed among the cooperation partners during an initialization phase. The rules specify a uniform metric that is used later in the auction between the partners. During the auction, a signalling channel is required to upload the quotation from each partner and to broadcast the result of the auction.

The amount of information exchanged between the networks (network nodes) gives different possibilities to find low energy consumption solutions. The more information that is exchanged and distributed between the networks the easier it will be to decide on a sustainable solution but the solution may also require more energy to reach. The computational complexity of the decision making algorithm is closely related to the computing capability of the network element and other physical constraints like power consumption. On one hand, the more information shared between the nodes the more complex will be the algorithms and longer will be the processing time, while at the other hand it increases the chances to achieve the set goals. Examples of information that can be exchanged between cooperation partners are the nodes' capability information, interference situation and load situation.

In the CONSERN project, the self-growing character of the system will be considered when designing the cooperative mechanisms and we plan to further extend the ideas of negotiation-based and auction-based mechanisms to also include the idea of self-growing systems. By this we mean that networks can collect statistics and learn from their previous behaviour. We may also study some ideas from game-theory to see if they can be used to find energy efficiency configurations and evaluate the network energy efficiency. When adding a new network element to the system, the network topology and/or the purpose of the network could be changed. As a consequence, the cooperative decision making method, including the policies and rules, should be updated in time. This is a big challenge but can also be an opportunity to breed a complete new kind of cooperative mechanisms.

3.5 Cooperative Power Control

Algorithms that employ cooperative spectrum sharing in order to maximize the overall system performance and minimize energy consumption are a key evolutionary step for practical cooperative systems. These algorithms need to be distributed in order to be applied efficiently in unlicensed spectrum bands. At the same time the considered algorithms should also be able to employ efficient message exchange schemes in order to maximize the overall system utility therefore the related systems are characterized as cooperative Cognitive Radio (CR) systems. It is important to note that particularly for systems that target low energy consumption the potential gains from power control should be balanced against the cost of the extra signaling that is required for cooperation. This implies that message exchange schemes utilized for the cooperation should be as economic as possible, avoiding costly acknowledge messages and retransmission. In this context, uncertainties in message exchange should also be taken into consideration because real systems do not usually operate in ideal conditions. Finally, the proposed algorithm for power control should be able to converge to an optimal solution within a finite number of iterations to be viable for large scale applications but also to cope with heterogeneity of the nodes, specifically regarding the co-existence of cognitive and legacy devices.

In order to address some of the previous challenges, the authors in [54] propose a price-based iterative water-filling algorithm which allows users to converge to the Nash Equilibrium. This algorithm can be distributive with CRs negotiating their best transmission powers and spectrum areas. In [55], a Dynamic Open Spectrum Sharing Medium Access Control (MAC) protocol for wireless ad hoc networks is proposed. This protocol performs real-time dynamic spectrum allocation by allowing nodes to adaptively select an arbitrary spectrum for the incipient communication subject to spectrum availability. In [56], a distributed approach to spectrum allocation that starts from the previous spectrum assignment and performs a limited number of computations to adapt to recent topology changes is considered. According to the proposed local bargaining approach, the users affected by a mobility event self-organize into bargaining groups and adapt their spectrum assignment to approximate a new optimal conflict-free assignment. The authors in [57] propose a graph-theoretic model for efficient and fair access in open spectrum systems. Three policy-driven utility functions that combine efficient spectrum utilization and fairness are described and a vertex labelling mechanism is used to build both centralized and distributed approximation algorithms. In [58], a group-based coordination scheme and distributed group setup and maintenance algorithms where users select coordination channels adaptively is proposed. Finally, in [59], an algorithm that allows for transmission power and transmission frequencies to be chosen simultaneously by CRs competing to communicate over a frequency spectrum is proposed.

In the approach that will be considered in CONSERN we assume that the users can exchange information about their interference levels using dedicated message exchange mechanisms. A transmitter is able to set its power level by considering on the one hand its own Signal to Interference plus Noise Ratio (SINR) information and on the other hand the negative impact in utility for other users caused from the greater interference that will come as a side effect of the increase in its transmission power [60]. This functions as a counter-motive that prevents users from always setting their transmission power to the maximum valid level. The main steps of the algorithm can be summarized as follows:

1. **Initialization:** For every user transmitting in specific channel select a valid transmission power level and a positive value for the interference price.
2. **Power Update:** For every user update its transmission power level to maximize so as to maximize the overall network utility.
3. **Interference Price Update:** For every user calculate and announce the updated interference price and notify the rest of the users for the updated value.

Steps 2 and 3 will be repeated asynchronously for all users until the algorithm reaches its final steady state. In the basic version of the algorithm from [60], an underestimation of interference prices can potentially occur in some cases (*e.g.*, due to problems in message exchange) and the outcome of such underestimation is the convergence of the algorithm to a non optimal solution. Therefore, we will introduce a coefficient to cope with uncertainties in the message exchange mechanism, such as large update time intervals from the previous interference price update (considering for example that the updates are asynchronous for all users) and potential problems in message exchange due to high mobility. In such cases, the introduced coefficient will compensate for the underestimation of interference and, it can result in a system that approximates the case of "perfect" message exchange. Furthermore, the algorithm will be extended in order to take into account that CONSERN-enabled devices can co-exist with legacy devices and thus not all nodes will be able to set their transmission power so as to maximize the overall network utility. For this scenario, the impact of the legacy nodes will be studied and network policies addressing fairness issues will be evaluated.

3.6 Energy Savings

Within 3GPP standardisation body energy saving [83], [84] has been identified one key working item for future releases of the LTE and LTE-Advanced (LTE-A) standard. The goal of energy saving in LTE-A is to minimize the energy consumption spent on providing the radio resources by the eNBs. Energy savings fall into three non-mutually exclusive schemes:

- Frequency domain savings,
- Time domain savings,
- Power domain savings.

With regards to the frequency domain energy saving can be done by turning off one frequency band, and possibly narrowing the system bandwidth of the active band. In the power domain savings are performed by means of power reductions and in time domain by means of idle transmission periods. Some categories of network energy saving for consideration potentially include:

- Cell transmitted power reduction (power domain),
- Inter-cell interference coordination (frequency domain),
- Cell Discontinuous Transmission (DTX) and BS transmission parameter adaptation (time domain),
- Cell activation/deactivation (frequency, power and time domain).

Except for the transmission related DTX that resembles LTE-specific solutions, eNB transition power reduction, inter-cell interference coordination, and cell activation/deactivation can be extrapolated to a set of energy saving mechanisms for multiple-RAT heterogeneous environments. Transmission power reduction as coordinated between cells corresponds to mechanisms that are described in section 3.5. In the subsections that follow particular attention will be given to the cell switch on/off and interference coordination state-of-art that LTE specifications rely on.

3.6.1 Cell Activation/Deactivation

Cell switch off/on for LTE system has been identified as an important energy saving use case by RAN3 and SA5 group [84], [85]. Each group has started the study of energy saving solutions from its own aspect: RAN3 working group focuses on eNB based solution while SA5 focuses on the OAM based solution. However, other energy saving scenarios or methods on underlying physical layer or air interface [87], [88] are also discussed by other RAN groups, which may also have impact on the current LTE network interface.

Energy solution builds upon the possibility for the eNB to autonomously decide to switch-off such cell to lower energy consumption (dormant state). The decision is typically based on cell load information, consistently with admission control and configuration management. The switch-off decision may also be taken by Operation and Maintenance (O&M).

The eNB may initiate handover actions in order to off-load the cell being switched off and may indicate the reason for handover with an appropriate cause value to support the target eNB in taking subsequent actions, e.g. when selecting the target cell for subsequent handovers.

The following procedures have been specified:

- eNB Configuration Update procedure: All peer eNBs are informed by the eNB owning the concerned cell about the switch-off actions over the X2 interface,
- Cell Activation procedure: All informed eNBs maintain the cell configuration data also when a certain cell is dormant. eNBs owning non-capacity boosting cells may request a re-activation over the X2 interface if capacity needs in such cells demand to do so,
- Reactivation response and indication: The eNB owning the dormant cell should normally obey a request. The switch-on decision may also be taken by O&M. All peer eNBs are informed by the eNB owning the concerned cell about the re-activation by an indication on the X2 interface,
- Energy saving function configuration: Operators should be able to configure the energy saving function typically by means of O&M.

The configured information should include:

- The ability of an eNB to perform autonomous cell switch-off,
- The ability of an eNB to request the re-activation of a configured list of dormant cells owned by a peer eNB,

O&M may also configure:

- The policies used by the eNB for cell switch-off decision,
- The policies used by peer eNBs for requesting the re-activation of a dormant cell.

3.6.2 Interference Coordination

A major problem in Orthogonal Frequency Division Multiple Access (OFDMA) systems is the inter-cell interference that neighbouring cells create when using the same frequency band. This may lead to severe performance degradation or connection loss especially in the border areas of cells. Inter-cell interference coordination techniques are demanded to reduce effectively these frequency collisions and hence, to improve cell-edge users performance. Resource allocation in OFDMA and Single Carrier Frequency Division Multiple Access (SC-FDMA) based LTE is performed among others by means of Inter-Cell Interference Coordination (ICIC) and scheduling. LTE system interference can be reduced or avoided in uplink and downlink by a coordinated usage of the available resources in the related cells which leads to improved SIR and corresponding throughput. The role of ICIC is to facilitate optimal allocation of the physical resource blocks (PRB) to UEs and among cells. The scheduler determines for each Transmission Time Interval (TTI) which UEs will get scheduled and which/how many PRBs they will get based on the fairness and QoS criteria. Then depending on the ICIC scheme it will be selected which particular PRB in the frequency domain will be assigned to the UE. In general ICIC is assumed to manage in the frequency domain while scheduler operates in the short time-scales on both frequency and time. The scope of this section is restricted to frequency therefore the discussion about scheduling is excluded.

In the multi-cell scenario a reduction of interference can be achieved by dividing the frequency resources among the cells in an orthogonal manner (as in frequency 3-reuse) or by adjusting transmit power or a combination thereof. The allocation of frequency resources and the adjustment of the transmit power levels can be decided individually by each cell with or without coordinating with its neighbouring cells. The coordination between the cells can range from a static coordination such as frequency reuse one to a semi-static or to a more dynamic coordination. Dynamic coordination may range from long time-scales (order of seconds or longer) to short time-scales (order of ms to seconds) as imposed by

- The update rate of the measurements and statistics used, *e.g.* UE measurements and traffic distribution,
- The signalling rate between cells facilitating the exchange of resource usage indicators, *e.g.*, High Interference Indicator (HII), Overload Indicator (OI) and TX Power indicator referred to as Relative Narrowband Transmit Power (RNTP).

In dynamic ICIC, coordination is done in every TTI which renders it impractical due to the excessive signalling between network nodes and the high complexity of the resource scheduler. In general only Static or Semi-static ICIC is considered under the 3GPP LTE study item [61].

In **Static interference coordination** the coordination is associated with cell planning and the frequency resource allocations are fixed. Static coordination cannot adapt to changing radio and traffic conditions with possible performance degradations as a result. On the other hand there is no need for signalling between neighbour cells via X2.

Semi-static interference coordination [65], [66] implies reallocations carried out on a time-scale of the order of seconds or longer and implies inter-cell communication over the X2 interface.

Static interference coordination mainly refers to the notion of Fractional Frequency Reuse (FFR). The idea behind FFR is to divide the users in cell-centre users (CCUs) and cell-edge users (CEUs) based on their location or geometrical information within the cell and then each user category is assigned a different sub-band out of the available spectrum. A good summary of FFR proposals from different companies is presented in [62]. Two variants of FFR are soft frequency reuse (SFR) and partial frequency reuse (PFR). In SFR the reuse factor is 1 in the cell-centre and greater than 1 in the cell-edge and it has been proposed in [63] where the available bandwidth is divided into two groups; the major subcarrier group and the minor subcarrier group. The major subcarrier group is assigned to the cell-edge users which is also referred as cell-edge band and is usually 1/3 of the available bandwidth and orthogonal among neighbouring cells. On the other hand, the minor subcarriers referred as cell-centre band are used exclusively by the cell-centre users. The cell-edge band can also be used by CCUs in the case where it is not occupied by CEUs. The transmission power for the major subcarriers (cell-edge band) is higher than that for minor subcarriers (cell-centre band). It should be notes that in LTE resources are assigned to users in groups of subcarriers called Physical Resource Blocks (PRBs). This scheme is depicted in Figure 3-6 for a 3-sector cell site.

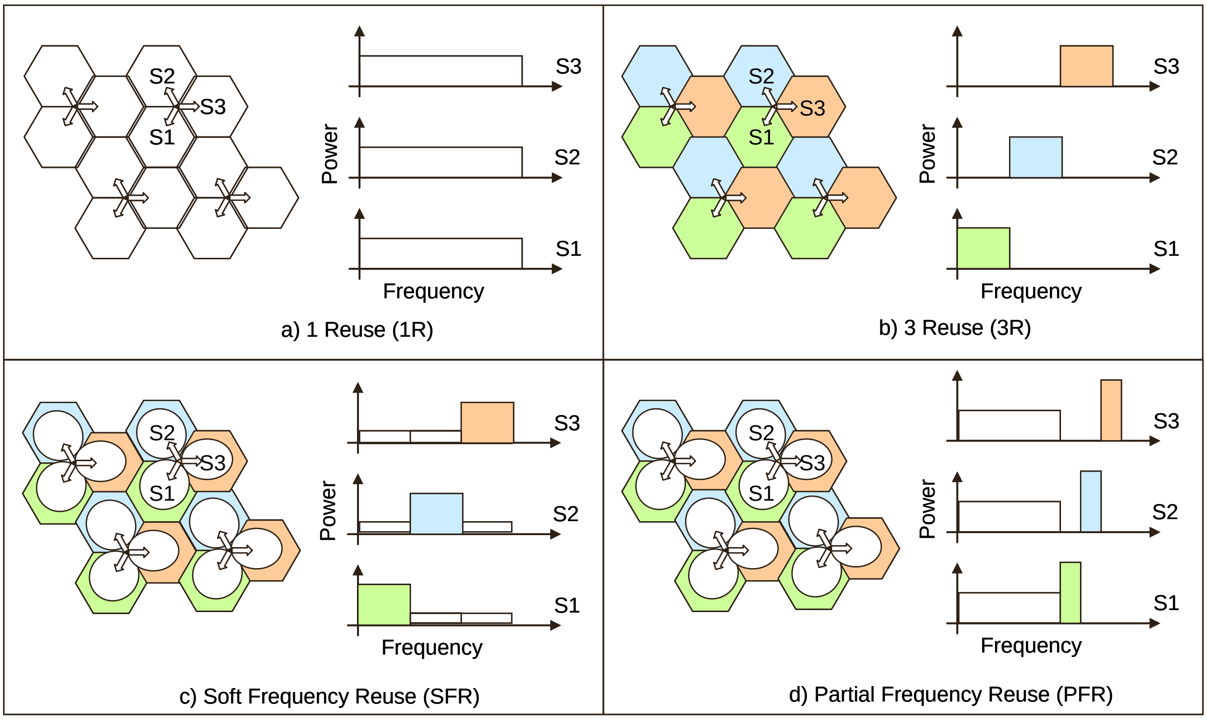


Figure 3-6: Reuse-1, SFR, PFR, reuse-3 schemes [64].

According to [63], the so called Power Ratio which is the ratio between the transmit power of minor subcarriers and major subcarriers is a variable parameter that can be adjusted to regulated the level of power to CEUs based on the current traffic distribution within the cell. Results show how the cell-edge performance increases by varying the power ratio whilst the overall cell throughput decreases.

The SFR outlined in [63] is based on a static coordination scheme since 1/3 of the available spectrum is reserved for cell-edge users. In the case of varying traffic loads and data rate requirements close to the cell edge the aforementioned approach will be sub-optimal. In [65], a semi-static coordination scheme is proposed in which the number of the frequency sub-bands reserved for CEUs vary according to the traffic load near the cell edge. A cell with high traffic load at the edge gets larger number of reserved sub-bands than a cell with low traffic load at the edge. The performance of the proposed scheme is presented in [66]. The results show that with semi-static frequency coordination the cell-edge throughput is improved 10% - 15% for equal traffic loads and 50% for unequal traffic loads.

For the semi-static and dynamic IC schemes signalling is the enabler mechanism. Generally, signalling methods fall into two categories: **Proactive** and **Reactive**.

Proactive methods:

- eNB informs its neighbours how it plans to schedule users by sending announcements,
- For Uplink, (UL) HII is sent over X2 which is a bit per PRB indicating whether the sending eNB aims at scheduling cell-edge UEs on those PRBs,
- Different HII messages can be sent to different eNBs,
- For Downlink (DL) RNTP is sent which indicates the maximum anticipated downlink transmit power per level PRB,
- Possible to dynamically Switch among different re-use patterns,
- Neighbouring schemes can take this info into account and schedule their low interference users on those PRBs.

Reactive methods:

- Monitor interference levels, QoS and load/interference status from neighbour cells ,
- Detect problems (*e.g.* high interference levels, QoS degradation) ,
- Take action to deal with problem, *e.g.*, :
  - Switch to a fractional re-use scheme,
  - Change maximum transmit power,
  - Send indicators to neighbours.

For the UL eNB measures the UL I+N power and creates OI reports to be sent via X2. I stands for interference and N stands for noise. The report is on per PRB group and it's primarily used to control UL power so as a maximum desirable I+N is maintained.

3.7 Discovery of Neighbouring Networks

Cooperation between separate networks cannot be achieved without the networks being aware of each other. In order to become aware, at least one network needs to be able to discover the other network(s) in its area. Network discovery is performed to identify other co-located networks and to determine their cooperative networking capabilities.

Before discovery can start, some nodes in the network need to be assigned with the functionality of discovering other networks. This assignment of **Discovery Nodes** is autonomous within each cooperative network. In the initial implementation, some of the nodes are statically configured as Discovery Nodes. An attempt is made to distribute the Discovery Nodes relatively evenly throughout the network, to increase the likelihood of actually discovering co-located networks, and at the same time to minimize the impact on network performance. Later on, automatic mechanisms for the assignment of Discovery Nodes may be considered. Such a mechanism will attempt at optimizing the number and distribution of Discovery Nodes, so as to achieve high discovery probability at low impact on network performance.

Two methods for network discovery will be considered:

- **Passive detection:** In this method a Discovery Node periodically scans different channels in relevant frequency bands, trying to overhear packets of other networks. Through analysis of various features of overheard packets, Discovery Nodes are able to detect the presence of other networks and potentially also the protocols they use. However, due to the large variation in wireless protocols at the physical and MAC layers, passive detection does not guarantee that all possible packets can be detected.
- **Active detection:** In addition to the passive detection method, Discovery Nodes may also actively broadcast beacon packets to announce their presence. These beacon packets may be structured in ways that make them discoverable by a wide range of Discovery Nodes of other networks.

Once a neighboring network is discovered, it is necessary to establish an initial communications link with it. This link will be used to exchange information between the two networks and to negotiate terms for cooperation. One possibility for such an inter-network communications link is to take advantage of the capability of Discovery Nodes to receive packets from other networks, and to establish single hop wireless communications between two Discovery Nodes, one at each network. For this end, each cooperative network broadcasts beacon packets that contain the information that is necessary in order to establish single hop communications with its Discovery Nodes. For example, each Discovery Node broadcasts its network ID, the radio frequency that can be used to contact it, and the packet types and MAC settings that should be used. Based on these settings**, single hop communications between the Discovery Nodes of separate cooperative networks is possible.**

Once this direct communications link between the two networks is established, they can start to exchange information and negotiate cooperation. The type of information that is exchanged between the two networks is specified in the next section.

3.8 Cooperation Profile, Incentives for Cooperation, and Negotiating Cooperation

After separate networks discover each other, and before they can decide to cooperate, they need to exchange the information that is necessary for this decision:

- **Incentives for Cooperation** – the benefits each network expects to achieve from cooperation,
- **Network Capabilities** – cooperative techniques each network supports,
- This information must be arranged and formatted in a unified and agreed structure – the **Cooperation Profile**.

These three concepts are further detailed in the following subsections.

3.8.1 Incentives for Cooperation

The incentives describe the expected networking benefits for one network when it cooperates with another. Networks will only engage in cooperation with other networks when this cooperation improves the performance of these incentives. Incentives are configured at an application or management level. As such, the incentives do not express low-level performance metrics, but instead indicate high level functional and network requirements:

- An incentive is a high level objective (*i.e.*: application or management level),
- An incentive is a reason for cooperation between networks (*i.e*.: if cooperation with another network can improve this high level objective, cooperation might be opportune).

Example incentives are:

- Lowering human exposure (due to health regulations),
- Increasing coverage (to reach more clients),
- Obtaining public access (to get internet connectivity),
- Increase network lifetime (to reduce battery consumption),
- Increasing QoS guarantees (higher throughput, higher reliability, lower delay, etc),
- In their Cooperation Profiles, each network specifies the priority of each incentive for its preferred operation.

The priority of each incentive (as specified in the profile) can be changed by management entities and by high level applications.

3.8.2 Network Capabilities

When cooperation is desired, a multitude of network techniques can be used to improve the incentives of each network. For example, to improve the lifetime of neighbouring networks, one or more of the following (cooperative) network techniques can be used: interference avoidance, packet aggregation, cooperative MAC protocols, etc. The available network techniques are called 'network capabilities'. Thus, whereas incentives indicate network goals, network capabilities are the means to realize these goals. A network capability is not crucial for the correct operation of the individual networks, but can be activated or deactivated for more efficient cooperation with co-located networks. The table below lists several examples of network capabilities and their influence on various incentives.

Network capability	Description	Influence on the incentives			
		Throughput	Delay	Reliability	Lifetime
Packet sharing	Allows networks to interpret and route packets from other networks	+	+	+	+/-
Interference avoidance	Networks cooperate by selecting the transmission frequencies which are least harmful for each other	+	+/-	+	+/-
Packet aggregation	To reduce the number of transmissions, multiple information exchanges are aggregated into a single packet	+	-	-	+

Table 3-1: Network Capabilities and their influence.

3.8.3 Cooperation Profile

The above information will be exchanged using standardized profiles. A profile can be represented using xml-like presentations such as, for example, the standardized Device Profile for Web Services (DPWS). Next to the DPWS description, a binary format can be applied for the (de)serialisation of parts of the basic profile for light-weight devices in sensor networks. Following is a list of minimum requirements that should be represented.

Timestamp of last update	
Description	Contains the last time the profile has been updated
Possible values	In seconds (sec) since a reference time
Representation	64 bit unsigned integer

Security certificate	
Description	A valid certificate guaranteeing that the network can be trusted
Possible values	Any type of SOTA certificate can be used. For proof-of-concept purposes this is not really needed.
Representation	binary representation

Network ID	
Description	The network ID. A network is uniquely identified by a common set of prioritized incentives and a common security certificate
Possible values	A unique number
Representation	64 bit unsigned integer

Network priority	
Description	The network priority. Equal to 1 for normal networks, only certified security networks can have priority higher than 1

Possible values	The number of different priorities depends on the Use Case. For example, in certain use cases 8 level of priority might be sufficient, in which case the possible values will be 1, 2, ..., 7.
Representation	8 bit unsigned integer

List of incentives	
Description	A unique identifier that maps to an incentive. The mapping can be fixed in advance
Possible values	LOW_EXPOSURE, HIGH_COVERAGE, PUBLIC_ACCESS, NETWORK_LIFETIME, THROUGHPUT, RELIABILITY, DELAY
Representation	A list of 8 bit unsigned integers

List of incentive priorities	
Description	The priority of each incentive (the priorities of all incentives are normalized to 100%)
Possible values	SHARED_ROUTING, AGGREGATION, CHANNEL_SELECTION, INTERFERENCE_AVOIDANCE
Representation	A list of 8 bit unsigned integers

List of network capabilities	
Description	A unique identifier that maps to a cooperative networking technique. The mapping can be fixed in advance
Possible values	SHARED_ROUTING, AGGREGATION, CHANNEL_SELECTION, INTERFERENCE_AVOIDANCE
Representation	A list of 8 bit unsigned integers
Additional Criteria	Each service can have additional information associated with it, such as dependencies, the node ID on which they are deployed, whether or not the service needs to be activated on both networks, etc.

List of Configurable settings	
Description	Additional network settings that can be configured when cooperative networking is active
Possible values	Channel (frequency, expressed as unsigned 8 bit integer), Tx power (dbm, expressed as a signed 8 bit integer), etc.
Representation	XML file, or list of Type-Length-Value (TLV) tuples.

3.9 The way forward

In this section, a set of cooperation enablers has been presented based on the 3-dimension space of Cooperative Decision and Control, the WP3 technical areas, and, the derived requirements. As a summary, Figure 3-7 attempts to capture the requirements tailored to cooperative operation and related functionalities based on the framework for cooperation as described in the previous sections and the related technical areas and enablers. As depicted in Figure 3-7 the basic node and network functionality and the general requirements for cooperation include communication layer mechanisms, information and context exchange, neighbour discovery, cooperative decision making, and cooperation incentives and negotiations.

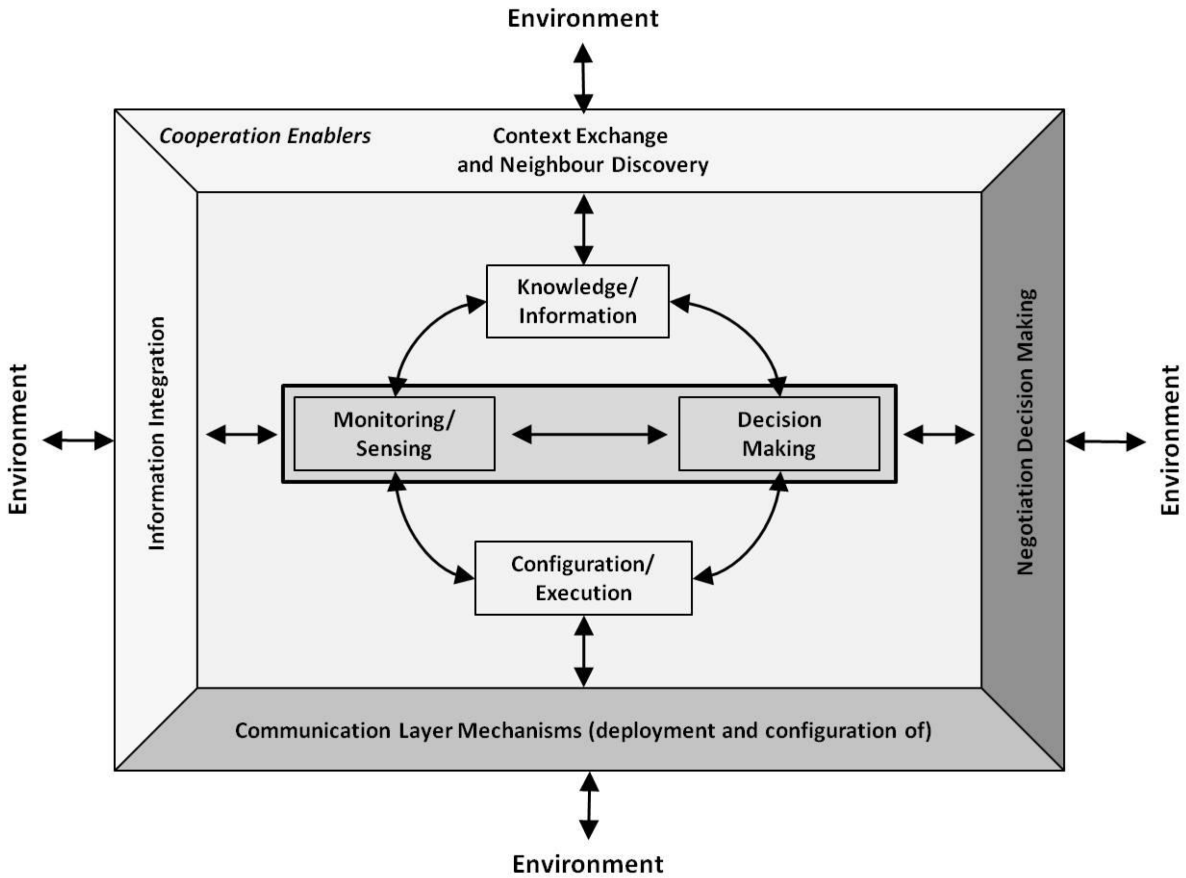


Figure 3-7: Cooperation functionality, enabler and requirements.

In this sense, the following items are planned as the way forward in the framework to drive and assist the enablers' development:

- Elaboration on the actual interrelation between the WP3 technical areas and the cooperation enablers,
- Mapping of the considered Use Cases to the Cooperation enablers; this will enhance the traceability of WP3 work back to the "dawn" of the project's scope – the technical use cases which form the very first basis of reference,
- Mapping of the defined requirements to the cooperation enablers in order to refine the envisaged functionality and the mechanisms design. Moreover, those requirements shall be taken into account for the Self-growing architecture which is currently being developed within WP4.

4. Summary

This deliverable is concerned with laying the foundation on which future work in the work package 3 rests on. The deliverable set out the concepts of cooperative decision and control and defined possible components of cooperative decision and control systems. An extensive study of the state of the art of related and possible technologies was completed, and future paths to be taken were planned.

In the first part of the deliverable, the following was achieved:

- Defined an enabler, and the relevant terms in the work package. This part of the deliverable also explicitly defines the concepts related to cooperation and coordination,
- Provided an initial view of the Cooperation Decision and Control framework as a three-dimensional space and an initial mapping of technical areas and enablers to that space,
- Identified use cases from D2.1 which are related to cooperation and coordination. The relevant parameters on cooperation in each use case are also identified,
- Provided an overview of the balance between the autonomic and the cooperative operation which is centric to the scope of WP3. This work will be further elaborated based on the actual mechanisms and the problems' solutions which are being developed,
- Specified the applicable technical areas forming WP3 technical scope and priorities; in particular, the techniques and mechanisms which could be used to realise low energy and high efficiency communications were described, together with an initial set of more specific functional requirements related to each technical areas. Elaboration is planned in the context of WP3 in order to map those requirements to the identified cooperation enablers. Specifically, the highlighted technical areas include:
    - Physical Layer Mechanisms,
    - Modified Medium Access Control,
    - (Radio) Network Control Mechanisms,
    - Cooperative Decision Making, and
    - Information Fusion and Knowledge Representation.

  The highlighted technical areas formed as a basis for the identification of the cooperative enablers which were presented in the second part of D3.1, the section 3.
- Initiated the discussion regarding the views and the considerations on the balance between the autonomic capabilities and the cooperative operation which is a centric concept within WP3.

The second part of this deliverable provided the following:

- State-Of-The-Art of the related cooperative and collaborative enablers. Specifically, the following enablers are considered:
    - Cooperative Relay,
    - Distributed Antenna Systems,
    - Self-Organising Networks Mechanisms,
    - System Conceptualisation through Information and Ontology Modelling,
    - Cooperative Decision Control,

  - Cooperative Power Control,
  - Cell Activation/Deactivation,
  - Interference Coordination,
  - Discovery of Neighbouring Networks,
  - Cooperation Profile,
  - Incentives for Cooperation, and, Negotiating Cooperation.
- For each of the above presented enablers, the specific context, the ideas, the assumptions, the initial considerations and the plan for future work of the CONSERN partners have been provided.

This deliverable has laid out the foundation for future work in Work Package. The next steps to be taken will be:

- Refine models and assumptions of systems different partners will work on,
- Study and identify specific algorithms and mechanisms in the context of the CONSERN cooperation which could possibly solve the identified problems,
- Construct simulation platforms to verify results,
- Identify specific mechanisms and solutions to be showcased as part of the CONSERN demonstrator which is being developed in the context of WP5.

5. References

[1] The CONSERN Project, http://www.ict-consern.eu/

[2] Pathak, Parth H.; Dutta, Rudra; “Impact of Power Control on Relay Load Balancing in Wireless Sensor Networks”, Wireless Communications and Networking Conference (WCNC), 2010 IEEE , vol., no., pp.1-6, 18-21 April 2010

[3] Yi Zhao; Adve, R.; Teng Joon Lim; "Improving Amplify-and-Forward Relay Networks: Optimal Power Allocation versus Selection," Information Theory, 2006 IEEE International Symposium on , vol., no., pp.1234-1238, 9-14 July 2006

[4] Bletsas, A.; Lippnian, A.; Reed, D.P.; "A simple distributed method for relay selection in cooperative diversity wireless networks, based on reciprocity and channel measurements," Vehicular Technology Conference, 2005. VTC 2005-Spring. 2005 IEEE 61st , vol.3, no., pp. 1484- 1488 Vol. 3, 30 May-1 June 2005

[5] Beibei Wang; Zhu Han; Liu, K.J.R.; "Distributed Relay Selection and Power Control for Multiuser Cooperative Communication Networks Using Buyer/Seller Game," INFOCOM 2007. 26th IEEE International Conference on Computer Communications. IEEE , vol., no., pp.544-552, 6-12 May 2007

[6] Gitzenis, S.; Bambos, N.; "Power-controlled packet relays in wireless data networks," Global Telecommunications Conference, 2003. GLOBECOM '03. IEEE , vol.1, no., pp. 464- 469 Vol.1, 1-5 Dec. 2003

[7] Sheng Zhou, Hongda Xiao, and Zhisheng Niu, “Distributed power control for interference-limited cooperative relay networks”, roceedings of the 2009 IEEE international conference on Communications, Dresden, Germany, pp. 4201-4206, 2009

[8] http://en.wikipedia.org/wiki/Information_integration

[9] D. Calvanese, G. De Giacomo, M. Lenzerini, D. Nardi, and R. Rosati, Information Integration: Conceptual Modeling and Reasoning Support, in the Proceedings of the 3rd IFCIS International Conference on Cooperative Information Systems

[10]Smart, P. R., Shadbolt, N. R., Carr, L. A. and schraefel, m. c. (2005) Knowledge-Based Information Fusion for Improved Situational Awareness. In: 8th International Conference on Information Fusion, 25-29 July 2005, Philadelphia, USA

[11]E. F. Nakamura, A. A. F. Loureiro, and A. C. Frery, Information Fusion for Wireless Sensor Networks: Methods, Models, and Classifications, ACM Computing Surveys, Vol. 39, No. 3, Article 9, Publication date: August 2007

[12]Ackoff, R. L., "From Data to Wisdom", Journal of Applies Systems Analysis, Volume 16, 1989 p 3-9

[13]R. Davis, H. Shrobe, and P. Szolovits. What is a Knowledge Representation? AI Magazine, 14(1):17-33, 1993

[14]http://en.wikipedia.org/wiki/Knowledge_representation_and_reasoning

[15]The Resource Description Framework, http://www.w3.org/RDF

[16]Shelley Powers, “Practical Resource Description Framework “, Publisher O’Reilly 2003, ISBN:0-596-00263-7

[17]Philippe Martin, “Knowledge representation in CGLF, CGIF, KIF, Frame-CG and Formalized-English”, Proceedings of ICCS 2002, 10th International Conference on Conceptual Structures (Springer, LNAI 2393, pp. 77-91), Borovets, Bulgaria, July 15-19, 2002

[18]Philippe Martin and Peter Eklund, "Conventions for Knowledge Representation via RDF", Proceedings of WebNet 2000 (AACE, isbn:1-880094-40-1), San Antonio, Texas, November 2000

[19]Lu Zhen, Zuhua Jiang, Hai Su, Jun Liang, "RDF-based innovative design knowledge representation", Semantic, Knowledge and Grid, 2005. Page(s) 77-77

[20]The Web Ontology Language overview, http://www.w3.org/TR/owl-features/

[21]The CC/PP Information Page, http://www.w3.org/Mobile/CCPP/

[22]The OpenRDF community site, http://www.openrdf.org

[23]Jena – A Semantic Web Framework for Java, http://jena.sourceforge.net/

[24]D. T. Tran, H. Lewen, and P. Haase, "On the role and application of ontologies in information systems", Proceedings of 5th IEEE International Conference on Research, Innovation & Vision for the Future (RIVF), Hanoi, Vietnam, pages 14--21, March 2007

[25]P. A. Chou, T.Wu, and K. Jain, "Practical network coding", in 51st Allerton Conf. Communication, Control and Computing, Oct. 2003

[26]J. Widmer, C. Fragouli, and J.-Y. L. Boudec, "Low–complexity energy–efficient broadcasting in wireless ad–hoc networks usign network coding", in Proc.IEEE Information Theory Workshop, Oct. 2004

[27]C. Fragouli, J. Widmer, and J.-Y. L. Boudec, "A network coding approach to energy efficient broadcasting", Proceedings of INFOCOM06, April 2006

[28]Ahlswede, R.; Ning Cai; Li, S.-Y.R.; Yeung, R.W.; "Network information flow," Information Theory, IEEE Transactions on , vol.46, no.4, pp.1204–1216, July 2000

[29]Katti, S.; Rahul, H.; Wenjun Hu; Katabi, D.; Medard, M.; Crowcroft, J.; "XORs in the Air: Practical Wireless Network Coding," Networking, IEEE/ACM Transactions on, vol.16, no.3, pp.497–510, June 2008

[30]Katti, S.; Rahul, H.; Wenjun Hu; Katabi, D.; Medard, M.; Crowcroft, J.; "XORs in the Air: Practical Wireless Network Coding," in Proc. SIGCOMM, pp. 243–254, Oct. 2006

[31]Shengli Zhang, Soung Chang Liew, Patrick P. Lam: "Hot topic: physical-layer network coding," in Proc. on Mobile Computing and Networking (MOBICOM), pp. 358-365, 2006

[32]Sendonaris, A.; Erkip, E.; Aazhang, B.; "Increasing uplink capacity via user cooperation diversity," Information Theory, 1998. Proceedings. 1998 IEEE International Symposium on , vol., no., pp.156, 16-21 Aug 1998

[33]Sendonaris, A.; Erkip, E.; Aazhang, B.; "User cooperation diversity. Part I. System description," Communications, IEEE Transactions on , vol.51, no.11, pp. 1927- 1938, Nov. 2003

[34]Laneman, J.N.; Wornell, G.W.; Tse, D.N.C.; "An efficient protocol for realizing cooperative diversity in wireless networks," Information Theory, 2001. Proceedings. 2001 IEEE International Symposium on , vol., no., pp.294, 2001

[35]Laneman, J.N.; Tse, D.N.C.; Wornell, G.W.; "Cooperative diversity in wireless networks: Efficient protocols and outage behavior," Information Theory, IEEE Transactions on , vol.50, no.12, pp. 3062- 3080, Dec. 2004

[36]Seddik, K.G.; Sadek, A.K.; Weifeng Su; Liu, K.J.R.; "Outage Analysis and Optimal Power Allocation for Multinode Relay Networks," Signal Processing Letters, IEEE , vol.14, no.6, pp.377-380, June 2007

[37]Panah, A.Y.; Heath, R.W.; "Single-User and Multicast OFDM Power Loading With Nonregenerative Relaying," Vehicular Technology, IEEE Transactions on , vol.58, no.9, pp.4890-4902, Nov. 2009

[38]Nguyen, D.H.N.; Nguyen, H.H.; Hoang Duong Tuan; "Power Allocation and Error Performance of Distributed Unitary Space–Time Modulation in Wireless Relay Networks," Vehicular Technology, IEEE Transactions on , vol.58, no.7, pp.3333-3346, Sept. 2009

[39]Ahmed, N.; Behnaam Aazhang; "Throughput Gains Using Rate and Power Control in Cooperative Relay Networks," Communications, IEEE Transactions on , vol.55, no.4, pp.656-660, April 2007

[40]Beibei Wang; Zhu Han; Liu, K.J.R.; "Distributed Relay Selection and Power Control for Multiuser Cooperative Communication Networks Using Stackelberg Game," Mobile Computing, IEEE Transactions on , vol.8, no.7, pp.975-990, July 2009

[41]Li Sun; Taiyi Zhang; Hao Niu; Junsong Wang; "Effect of Multiple Antennas at the Destination on the Diversity Performance of Amplify-and-Forward Systems With Partial Relay Selection," Signal Processing Letters, IEEE , vol.17, no.7, pp.631-634, July 2010

[42]Yifei Wei; Yu, F.R.; Mei Song; "Distributed Optimal Relay Selection in Wireless Cooperative Networks With Finite-State Markov Channels," Vehicular Technology, IEEE Transactions on , vol.59, no.5, pp.2149-2158, Jun 2010

[43]R.U. Nabar, H. B¨olcskei, and F.W. Kneub¨uhler, “Fading relay channels: Performance limits and space-time signal design,” IEEE JSAC, vol. 22, pp. 1099–1109, Aug 2004

[44]T. Oechtering and A. Sezgin, “A new cooperative transmission scheme using the space-time delay code,” in Proc. Smart Antennas, 2004. ITG Workshop on, pp. 41–48, March 2004

[45]B. Rankov and A. Wittneben, “Spectral Efficient Protocols for Half-Duplex Fading Relay Channels,” IEEE JSAC, vol. 25, pp. 379–389, Feb 2007

[46]H. Wicaksana, S.H. Ting, C.K. Ho, W.H. Chin, and Y.L. Guan, “On the Diversity Order of AF Cooperative Systems with Inter-Relay Interference Cancellation,” in Proc. Vehicular Technology Conference, 2008. VTC Spring 2008. IEEE, pp. 634–638, May 2008

[47]T. Koike-Akino, P. Popovski and V. Tarokh, “Optimized constellations for two-way wireless relaying with physical network coding,” IEEE Journal on Selected Areas in Communication, vol. 27, no. 5, pp. 773-787, June 2009

[48]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 10), V10.1.0, September 2010

[49]The Internet Engineering Task Force, IETF, RFC 3198, Terminology for Policy-Based Management

[50]The Internet Engineering Task Force, IETF, RFC 3444, On the Difference between Information Models and Data Models

[51]Unified Model Language, UML, http://www.uml.org/

[52]The Object Management Group, OMG, http://www.omg.org

[53]3GPP TS 24.312 “Access Network Discovery and Selection Function (ANDSF) Management Object (MO);(Release 10, v10.0.0)

[54]F. Wang, M. Krunz and S. Cui, "Price-Based Spectrum Management in Cognitive Radio Networks", Proceedings of the 2nd International Conference on Cognitive Radio Oriented Wireless Networks and Communications 2007 (CrownCom ’07), pp. 70-78, Aug. 2007

[55]L. Ma, X. Han and C.C. Shen, "Dynamic open spectrum sharing MAC protocol for wireless ad hoc networks", Proceedings of the 1st IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks 2005 (DySPAN ’05), pp. 203-213, Nov. 2005

[56]L. Cao and H. Zheng, “Distributed spectrum allocation via local bargaining”, Proceedings of the IEEE Sensor and Ad Hoc Communications and Networks 2005 (SECON ’05), pp. 475–486, Sept. 2005

[57]C. Peng, H. Zheng and B.Y. Zhao, “Utilization and fairness in spectrum assignment for Opportunistic Spectrum Access”, Springer’s Mobile Network Applications, vol. 11, no. 4, pp. 555-576, Aug. 2006

[58]J. Zhao, H. Zheng and G.H. Yang, “Distributed Coordination in Dynamic Spectrum Allocation Networks”, Proceedings of the 1st IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks 2005 (DySPAN ’05*)*, pp. 259-268, Nov. 2005.

[59]M. Bloem, T. Alpcan and T. Basar, “A stackelberg game for power control and channel allocation in cognitive radio networks”, Proceedings of the 2nd international conference on Performance evaluation methodologies and tools, 2007.

[60]J. Huang, R. A. Berry and M. L. Honig, “Spectrum sharing with distributed interference compensation”, Proceedings of the 1st IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks 2005 (DySPAN ’05), pp. 88–93, Nov. 2005

[61]3GPP, TR 25.814 V7.1.0, “Physical layer aspects for evolved Universal Terrestrial Radio Access (UTRA)” Sept., 2006

[62]LG Electronics, “Standard aspects of Interference coordination for EUTRA”, 3GPP, TSG RAN WG1 #42bis R1-051051, October, 10 – 14, 2005

[63]3GPP R1-050841, “Further Analysis of Soft Frequency Reuse Scheme”, Huawei, September 2005

[64]Mahmudur Rahman, Halim Yanikomeroglu, William Wong, “Interference Avoidance with Dynamic Inter-Cell Coordination for Downlink LTE System”, WCNC 2009: 1238-1243

[65]3GPP R1-051059, “Inter-cell Interference Mitigation for EUTRA”, Texas Instruments, October, 2005

[66]3GPP R1-060368, “Performance of Inter-Cell Interference Mitigation with Semi-Static Frequency Planning for EUTRA Downlink”, Texas Instruments, February, 2006

[67] Gruber T.: A Translation Approach to Portable Ontology Specifications, Knowledge Acquisition, Vol 5., 1993

[68]M. Gastpar, G. Kramer, and P. Gupta, “The multiple-relay channel: coding and antenna-clustering capacity,” Proceedings of the IEEE Int. Symp. Inform. Theory, (Lausanne, Switzerland), p. 136, June 30-July 5, 2002

[69]G. Kramer, M Gastpar, P Gupta, “Cooperative strategies and capacity theorems for relay networks”, IEEE Transactions on Information Theory, pp 1-20, May 7, 2004

[70]A.Host-Madsen, “On the Capacity of Wireless Relaying”, Proc. Of IEEE VTC 2002-Fall, vol.3, pp. 1333-1337, Sept. 2002

[71]J.N.Laneman, D.N.C. Tse, and G.W.Wornell, "Cooperative Diversity in Wireless Networks: Efficient Protocols and Outage Behavior," IEEE Trans. Inform. Theory, vol.50, pp. 3062-3080, Dec. 2004

[72]Janani, M., Hedayat, A., Hunter, T.E., Nosratinia, A., "Coded cooperation in wireless communications: space-time transmission and iterative decoding", Signal Processing, IEEE Transactions on, pp. 362 - 371, Feb. 2004

[73]Hammerstrom, I., Kuhn, M., Wittneben, A.," Channel Adaptive Scheduling for Cooperative Relay Networks", Vehicular Technology Conference, 2004, pp. 2784 - 2788 Vol. 4, 26-29 Sept. 2004

[74]Arti M.K., Ranjan Bose, Manav R. Bhatnagar, Are Hjørungnes, "Relay Strategies for High Rate Space-Time Code in Cooperative MIMO Networks", Wireless Communication Systems, 2007. ISWCS 2007. 4th International Symposium on, pp. 696 - 700, 17-19 Oct. 2007

[75]A. Saleh, A. Rustako, and R. Roman. Distributed antennas for indoor radio communications. IEEE Trans. Commun., 35(12):1245–1251, December 1987

[76]K. J. Kerpez. A radio access system with distributed antennas. IEEE Trans. Veh.Technol., 45(2):265–275, May 1996

[77]Wonil Roh and A. Paulraj. Outage performance of the distributed antenna systems in a composite fading channel. In Vehicular Technology Conference, 2002. Proceedings. VTC 2002-Fall. 2002 IEEE 56th, volume 3, pages 1520–1524, September24–28, 2002

[78]Wan Choi and J. G. Andrews. Downlink performance and capacity of distributed antenna systems in a multicell environment. IEEE Trans. Wireless Commun., 6(1):69–73, January 2007

[79]Jun Zhang and J. Andrews. Distributed antenna systems with randomness. IEEE Trans. Wireless Commun., 7(9):3636–3646, September 2008

[80]Wonil Roh and A. Paulraj. MIMO channel capacity for the distributed antenna. In Vehicular Technology Conference, 2002. Proceedings. VTC 2002-Fall. 2002 IEEE 56th, volume 2, pages 706–709, September24–28, 2002

[81]A. Boal, A. Soares, J. C. Silva, and A. Correia. Distributed antenna cellular system for transmission of broadcast/multicast services. In Vehicular Technology Conference, 2007. VTC2007-Spring. IEEE 65th, pages 1307–1311, Dublin, April22–25, 2007

[82]Tao Wu. Gap analysis report on distributed antenna systems: Architecture and technologies. Huawei Technologies Co., Ltd. Internal Technical Report, June 2009

[83]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 10), V10.1.0, September 2010

[84]TR 32.826 v10.0.0. "Telecommunication management; Study on Energy Savings Management (ESM) (Release 10), March 2010

[85]3GPP TS 36.423, Evolved Universal Terrestrial Radio Access Network (E-UTRAN); X2 application protocol (X2AP), (Release 9) , September 2010

[86] 3GPP R3-100162, Overview to LTE energy saving solutions to cell switch off/on, Huawei, January 2010

[87]3GPP R1-095011, "Extended cell DTX for enhanced energy-efficient operation"

[88]3GPP R2-094677, "eNB power saving by changing antenna number"

[89]http://searchdatacenter.techtarget.com/news/1083120/IBM-releases-new-autonomic-computing-tools

[90]http://en.wikipedia.org/wiki/Autonomic_Networking

[91]CONSERN Deliverable D1.1, Scenarios, Use Cases, and System Requirements.

[92]J.Alonso, E.Kartsakli, Ch.Verikoukis and L.Alonso, “Persistent RCSMA: A MAC Protocol for a Disitributed Cooperative ARQ Scheme in Wireless Networks”, EURASIP Signal Processing Magazine, Special Issue on Cooperative Communications, vol. 2008, pp. 13, May 2008

[93]Joanna Kulik, Wendi Heinzelman, “Negotiation-based Protocols for Disseminating Information in Wireless Sensor Networks”, Wireless Networks, vol. 8, pages 169—185, 2002

[94] J. Huang, R. A. Berry, and M. L. Honig, “Auction-Based Spectrum Sharing”, Mobile Networks and Applications 11, 405–418, 2006

[95] T. Holliday, A.J. Goldsmith and P. Glynn, “Distributed power control for time varying wireless networks: Optimality and convergence”, Proc. of Allerton Conference, 2003

[96] G.J. Foschini and Z. Miljanic, “A simple distributed autonomous power control algorithm and its convergence”, IEEE Trans. on Vehicular Technology 42(4), 1993

[97] I. Stanojev, O. Simeone, U. Spagnolini, Y. Bar-Ness, and R.L. Pickholtz, “Cooperative ARQ via auction-based spectrum leasing”, IEEE Transactions on Communications 58(6), 2010