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D2.4

Analysis of integration of CODIV diversity on radio resource planning and business models

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Abstract:

This deliverable reports the economic analysis, according to LRIC (Long Run Incremental Cost) models, of the different technical approaches investigated and developed within the CODIV project. It includes as well a detailed analysis of the costs and performances for a particular urban scenario used in the system level simulations carried out in WP5 in order to compare conventional and CODIV deployments. Finally, the impact of cooperative diversity techniques on current planning and business models is described, explaining the foreseen influence of CODIV techniques in future deployments.

Keyword list:

Cooperative diversity, radio network deployment, relay node, relaying-able terminal, distributed MIMO, scenarios definition, business models, performance indicator, LRIC models

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Abbreviations

3G	Third Generation
3GPP	Third Generation Partnership Pro
4G	Fourth Generation
AF	Amplify and Forward
ARQ	Automatic Repeat reQuest
ARPU	Average Revenue Per User
ATM	Asynchronous Transfer Mode
BER	Bit Error Rate
BLER	Block Error Rate
BS	Base Station
CAT	Cell Average Throughput
CAPEX	Capital Expenditures
CC	Convolutional Code
CCTV	Closed Circuit Television
CDMA	Code Division Multiple Access
CNTO	Cellular Network and Telecommunication Operator
CQI	Channel Quality Indication
CPE	Customer Premises Enterprises
CRC	Cyclic Redundancy Check
CSF	Critical Success Factor
CSI	Channel State Information
CTC	Convolutional Turbo-Code
DF	Decode and Forward
DL	Downlink
DRN	Dedicated Relay Node
DTC	Distributed Turbo Code
EBIT	Earning Before Interest and Taxes
EF	Equalize and Forward
ERP	Effective Radiated Power
E-UTRA	Evolved UMTS Terrestrial Radio Access
FDD	Frequency Division Duplex
FER	Frame Error Rate

FERIF	FER Improvement Factor
FFT	Fast Fourier Transform
FL-LRIC	Forward Looking for Long Run Incremental Cost
FTP	File Transfer Protocol
FC	Fixed Cost
GoS	Grade of Service
GPRS	General Packet Radio System
GSM	Global System for Mobile communications
HARQ	Hybrid ARQ
HSPA	High Speed Packet Access
HTTP	Hyper Text Transfer Protocol
IT	Information Technologies
JNCC	Joint Network Channel Coding
KPI	Key Performance Indicator
LDPC	Low Density Parity Check
LOS	Line of Sight
LRIC	Long Run Incremental Cost
LTE	Long Term Evolution
MAC	Medium Access Control
MAP	Mobile Application Part
MCS	Modulation and Coding Scheme
MDC	Macro Diversity Combining
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
MMR	Mobile Multi-hop Relay
MMSE	Minimum Mean Square Error
MNO	Mobile Network Operator
MRC	Maximum Ratio Combining
MSC	Mobile Switching Center
MU-MIMO	Multi User MIMO
NLOS	Non Line of Sight
NPV	Net Present Value
MVNO	Mobile Virtual Network Operator
NRTV	Near Real Time Video
OCI	Outer Coverage Increase

OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	Operating Expenditures
OSS	Operating Support Systems
PAPR	Peak to Average Power Ratio
PDSCH	Physical Downlink Shared Channel
PDU	Packet Data Unit
PEST	Political, Economic, Social and Technological
PRB	Physical Resource block
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RA	Relay Assignment
RAN	Radio Access Network
RAP	Radio Access Point
RAT	Radio Access Technology
REC	Relay Enhanced Cell
RN	Relay Node
RNC	Radio Network Controller
RNP	Radio Network Planning
RU	Resource Unit
SC-FDMA	Single Carrier Frequency Division Multiple Access
SDF	Selective Decode and Forward
SDMA	Space Division Multiple Access
SFBC	Space-Frequency Block Coding
SNR	Signal to Noise Ratio
SINR	Signal to Interference and Noise Ratio
SISO	Single Input Single Output
SLA	Service Level Agreement
SNCC	Separate Network Channel Coding
SUI	Stanford University Interim
SU-MIMO	Single User MIMO
SWOT	Strengths, Weaknesses, Opportunities and Threats
TETRA	Terrestrial Trunked Radio
TDD	Time Division Duplex

TTI	Transmission Time Interval
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UT	User Terminal
UTRA	Universal Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network
VC	Variable Cost
VoD	Video on Demand
VoIP	Voice over Internet Protocol
WACC	Weighted Average Cost of Capital
WiMAX	Worldwide Interoperability for Microwaves Access
WP	Work Package
WSE	Weighted Spectral Efficiency
ZF	Zero Forcing

Executive Summary

The present deliverable was initially planned for M30 of the CODIV project but due to the 4 months extension agreed with the Project Officer and the review commission, it was rescheduled for October 2010.

In the previous deliverables of WP2 the scenarios where CODIV technologies could be deployed were outlined and described in details (**[D2.1]** and **[D2.2]**), showing the main conclusions concerning the impact of the cooperative diversity techniques investigated in the project on the planning tools (**[D2.3]**). Also preliminary business-point-of-view analyses of the system to be addressed in the CODIV project, with the purpose to help understanding, discussion and decision-making were performed in previous documents. These business analyses were performed in two steps: first, a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis showed the strategic advantages and disadvantages of the system; and then the global benefits and features of this technology were collected and classified into a PEST (Political, Economic, Social and Technological) analysis.

The closing deliverable D2.4 of WP2 is focussed mainly on the final business analysis for the CODIV project including the economic impact of the technologies proposed and investigated within the project on the current business models.

The usage of the CODIV techniques in LTE and WiMAX standards (the wireless communication standards contemplated in the project) will have an important economic impact in the telecom market, improving the performance and efficiency of these networks. One of the objectives of this deliverable is to analyze and measure whenever possible the cost efficiency (ratio demand/cost) for each of the technical solutions proposed and investigated in CODIV, that is, the implementation of relaying-able terminal, the use of dedicated relay nodes (RNs) and the integration of MU-MIMO schemes. Independent analysis of the increased efficiency and cost reduction for each of these approaches is carried out according to an economic model based on Forward Looking for Long Run Incremental Cost (FL-LRIC) modelling methodologies. Also the advantages and drawbacks that a final user will find adopting cooperative schemes are outlined. LRIC bottom-up cost model is a techno-economic model that determines the costs associated to a theoretical network that it would be necessary to develop in order to provide certain services according to an expected demand. LRIC models may be used to estimate cost efficiency under different assumptions on demand, available technologies, service portfolio and spectrum available. In this document, the planning exercise is done for a hypothetical national incumbent operator, taking into account public Spanish geographic and population data.

Taking into account certain assumptions, several simulations are used to calculate the sensitivity of the network cost to different relevant parameters. Given that CODIV techniques are radio access techniques, they improve the radio access network efficiency, which is also the highest network cost for a wireless network operator. So the cost models used in the study are restricted to radio access network and backhaul costs, since improvement in network efficiency will be limited to this network segment.

Simulations for a cooperative dense urban scenario with short range coverage and a high density of user terminals are carried out in order to analyze the CODIV relaying-able terminal solution, showing an increase in the percentage of users served with higher modulation schemes so that the effective capacity is improved in comparison with a conventional deployment. The gain obtained in terms of average effective throughput was about 10% due to the better modulation distribution achieved with the use of cooperative terminals. This fact allows the service provider to develop new bandwidth-consuming services and increase competitiveness of an operator in mobile broadband services. Likewise the cooperative-able terminal approach may improve coverage, avoiding coverage holes so that the Grade of Service (GoS) is increased. The simulations demonstrate that the percentage of blocked terminals using the CODIV techniques decreases considerably, as the available number of

cooperative terminals increases. Also it is shown how the coverage can be extended since users located beyond the boundaries of the cell coverage area are able to use CODIV terminals as repeaters. The coverage extension is shown to be more important in areas with low user and traffic density, where network generally is built considering only coverage aspects. In these particular scenarios, the direct impact on the investment and operational costs of the network is studied, pointing out that the number of base stations needed to cover a low traffic density region could be decreased by using CODIV techniques (an increment of 20 % in cell range would translate into 30 % less BSs in rural low-density deployments). Once we have analyzed the benefits of cooperative-able terminals for the network operators, we further discuss the economic issues and impacts on business models derived from this cooperation, discussing security aspects and customer incentives that operators may pursue to take advantage of the cooperation mechanisms investigated in CODIV.

Based on the results of the relaying-able terminal simulations, the economic impact of radio network deployments using fixed and dedicated relays is performed, reaching good insights: macro relays in rural deployments with low traffic density could be interesting in order to improve the coverage of existing macro-cells, and micro/pico relays provide improvement of the throughput in urban scenarios (especially shadowing of buildings or indoor coverage), in which there is no necessity to add micro or pico base station to improve network capacity.

Concerning Multi-User MIMO scenarios, it is observed that the radio resources for the communication of different user terminals are shared in a more efficient way, and so there is a strong economic impact reducing expenditures, because the capacity of the radio interface of a base station is higher and thus the number of carriers and sites needed, will be lower. Using again the LRIC models, different alternatives to grow a network according to new demand expectations are analyzed. It is showed how MU-MIMO approach allows the network operator to increase the capacity of a cell, at the cost of extra CAPEX in BS. One first consideration is that this technique will be interesting only in areas with certain traffic density. In these cases, improved spectral efficiency increases theoretical capacity of existing network and postpones growth using additional carriers / spectrum or using additional sites. Due to the high costs of site acquisition and maintenance, it is likely that MU-MIMO would be preferable to growing the access network capacity through new sites.

After the analysis of the economic impact of CODIV techniques on different scenarios, a brief discussion of the relevance of cost analysis methodology is included. As a practical case, the costs estimation of the particular deployments contemplated in the system level simulations (WP5) is undertaken in order to find the additional expenses for the implementation of CODIV techniques in comparison with conventional deployments, and then to analyze whether or not the improvement of the performance achieved in the CODIV deployments in terms of the indicators used in the system level simulations (average service throughput, percentage of satisfied users and fairness according to Gini index), justify the costs increase necessary to implement the CODIV techniques. Taking into account the characteristics of the deployments included in the system level simulations reported by WP5, the overall expenditures for each of the deployments contemplated in these simulations are presented, showing the increase of cost due to the incorporation of dedicated fixed RNs in the CODIV deployment. After the deployment cost is estimated, the performance improvement noted for the CODIV approach based on the use of dedicated RNs is analyzed. It is concluded that as long as the operator can get more benefits with the increase of performance (more capacity, less unsatisfied customers, more fairness) in a deployment based on RNs than the additional costs, the CODIV solution will be more profitable than the conventional ones. Of course, the way for getting more benefits will depend on the business model assumed by the operator (for example on-demand or flat rate).

Finally, the main conclusion about the impact of CODIV techniques on the deployment models are highlighted, and after a brief business models literature survey, the foreseen impact of CODIV solutions on future business models for cellular network operators is outlined.

1 Introduction

This deliverable reports the concluding analysis of the impact and influence that the cooperative techniques developed in CODIV project could have on future business and deployment models for future cellular radio networks such as WiMAX and LTE which have been the systems targeted in the project.

Consequently, the main objective of the final deliverable of CODIV regarding scenarios definition and business/deployment models (WP2), is to analyze and measure whenever possible the predicted effect of CODIV techniques in telecommunication business and deployment models. Of course, each technical approach developed in CODIV will be useful in certain scenarios and in specific conditions, and will have different impacts on the wireless access network costs and efficiency. For this reason, independent analysis should be performed for each of the technical solutions proposed in CODIV.

In the first part of this deliverable (Chapter 2), the predicted economic impact of the three main technical approaches contemplated in CODIV project (cooperative-able terminals, dedicated relays and MU-MIMO techniques) will be analyzed according to forward looking for long run incremental cost (FL-LRIC) modelling methodologies, proving an increased efficiency and cost reduction. In addition, the main advantages and drawbacks that a final user will find adopting cooperative schemes will be outlined, altogether with possible practical applications, and recommendations to address economic issues arising from the cooperation among users.

Further on, the purpose of Chapter 3 is two-fold: first, to estimate the costs of the particular deployments contemplated in the system level simulations (WP5) in order to know the additional expenses for the implementation of the CODIV techniques in comparison with conventional deployments, second, to analyze whether or not the improvement of the performance achieved by the CODIV deployments in terms of the indicators used in the system level simulations justify the costs increase necessary to implement the CODIV techniques. The final idea will be to estimate the costs of the conventional deployment against the CODIV approach used in the proof of concept (WP5) for a later analysis of costs and benefits associated to each deployment (conventional compared to CODIV). Since the cost analysis of relay-based deployments is a fundamental issue to decide when and where to use these devices, important issues regarding deployment costs will be reviewed including an example of UMTS deployment cost breakdown. The costs of the deployments associated to the system level simulations (carried out in WP5 for urban scenarios) will be analyzed as well and used to determine the conditions under which the CODIV solution could be profitable as compared to conventional deployments.

Chapter 4 is devoted to summarizing the main impact and effects of the CODIV techniques on deployment models, as well as the predicted influence on future business models of cellular network operators.

Finally, in Chapter 5 we present the conclusions of this final deliverable of WP2 about the impact of the CODIV techniques on the business and deployment models.

2 Economic impact of CODIV

The usage of COoperative DIVersity (CODIV) technologies in wireless communication systems will have an important economic impact in the telecom market, more specifically in improving the efficiency of wireless access networks. In this chapter we will measure CAPEX or cost efficiency of a network as the ratio demand/CAPEX or demand/cost of a network dimensioned to cope with the given demand, which will be measured in MBytes.

First of all it is important to note that the different techniques proposed by CODIV in order to include cooperative diversity in future cellular and metropolitan networks (i.e. LTE and WiMAX) could be clustered into the three following technical approaches:

- Cooperating-able terminals. If a user adopts CODIV schemes, and sets the mobile terminal in cooperative mode, it can be used to enhance other's user communication while being in idle mode.
- Usage of dedicated relays associated to a base station. A network operator could deploy a fixed relay access network, trying to decrease the deployment cost compared to using only conventional base station systems.
- Multi-User MIMO (Multiple Input and Multiple Output). This technology exploits the availability of multiple independent radio terminals in order to enhance the communication spectral efficiency within a cell.

Each technical approach will be useful in certain scenarios and in specific conditions, and will have different impacts on the wireless access network costs and efficiency. Thus, independent analysis is given for each of the approaches investigated and developed within the CODIV project. In order to perform this analysis on increased efficiency and cost reduction, an economic model has been built based on Forward Looking for Long Run Incremental Cost (FL-LRIC) modelling methodologies.

In addition, the main advantages and drawbacks that a final user will find adopting cooperative schemes will be discussed, altogether with possible practical applications, and recommendations to address economic issues arising from the cooperation among users.

2.1 LRIC Models

In order to study the impact on network efficiency of CODIV technologies bottom-up Long Run Incremental Cost (LRIC) models have been implemented for mobile operators. This planning exercise has been done for a hypothetical national incumbent operator, taking into account public Spanish geographic and population data.

Specifically, a LRIC bottom-up cost model is a techno-economic model that determines the costs associated to a theoretical network developed in order to provide certain services according to an expected demand. “Long run” means in this case that the operator can adapt to changes in demand by dimensioning the network to the chosen level of output in the technically most efficient manner. It is assumed that the operator uses the best technology available at the best price and that it is not affected by past decisions: only present and future uses and policies of the operators are relevant (this kind of cost model can be coined “Forward Looking Long Run Incremental Cost”, FL-LRIC). Efficiency improvement comes from taking into account cooperation between end users and base stations or relays in the planning exercise. The structure of the model is shown in Figure 2-1.

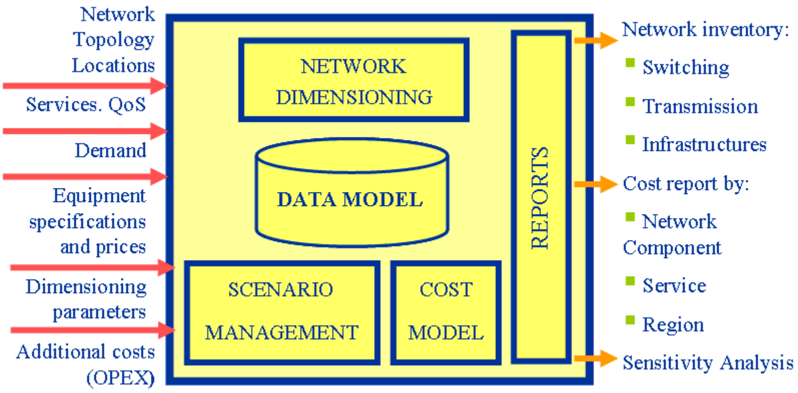

Figure 2-1: Cost model structure used for final business model of CODIV

In the proposed model we have made the following assumptions:

- Fixed and mobile operator offers voice, videoconference and data services.
- Reference demand is for main Spanish mobile operators in 2008, considering both UMTS R99 and HSPA demand.
- UMTS radio network deployment for the main cities in the country in the 2100 MHz band.
- Single failure link/node protection considered.
- Typical dimensioning and QoS parameters.
- Cost of capital considered using a WACC (Weighted Average Cost of Capital) of 10%.
- The costs of LTE and WiMAX, targeted systems by CODIV technologies, will be similar in the long run to current UMTS/HSPA cost per base station.

As a result, the model generates the following reports for a given scenario:

- Network inventory.
- CAPEX per network element for a Greenfield deployment.
- Annualized cost per network element considering typical asset life parameters.

Different models have been built for the different technologies, case studies and efficiency improvements being measured. Several simulations have been processed in order to calculate the sensitivity of the network cost to different relevant parameters. Given that CODIV techniques are radio techniques, they improve radio access network efficiency, which is the highest network cost for a wireless network operator. Cost models are restricted to radio access network and backhaul costs, since improvement in network efficiency will be limited to this network segment.

2.2 Cost Efficiency

In this deliverable it is assumed that network efficiency is a ratio of total traffic carried by the network and a cost measure like OPEX, CAPEX or annualized cost. LRIC model may be used to estimate network efficiency and measure its sensitivity to different conditions of spectrum availability and usage.

Roughly, there are two main cost components in network cost for a mobile operator **[Val09]**:

- A fixed cost (FC) component associated to the coverage target of the operator, and independent of the demand.
- A variable cost (VC) component, i.e., dependent on traffic demand from customers, containing all cost incurred by the operator in order to increase the network capacity, to cope with the demand while maintaining a certain quality of service.

Using this simple cost model (where VC is considered linearly dependent of traffic demand), cost efficiency (η_c) of a mobile network may be defined as:

$$\eta_c = \frac{D}{FC + VC \cdot D}$$

where D is the mobile traffic demand.

Thus, efficiency improves when demand increases. When demand tends to infinite, η_c will tend to its optimal value η_c* which is the inverse of variable cost as the equation below shows:

$$\lim_{D \to \infty} \eta_c = \frac{1}{VC} = \eta_c *$$

In case there is no demand, efficiency is zero, since total cost of the network is equivalent to fixed cost. The speed at which η_c approaches η_c* as demand increases, depends on the ratio between fixed and variable costs, as it is shown in Figure 2-2.

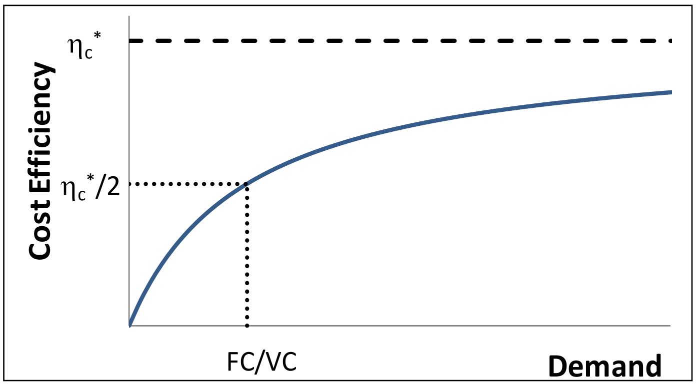

Figure 2-2: Typical cost efficiency curve (relationship with fixed and variable costs)

Network efficiency may be improved as shows Figure 2-3 by means of the following points:

1. By evolving network technologies and operation, and thus providing the same services to the same customers with lower variable cost.
2. Exploiting economies of scale, i.e. carrying more traffic or providing the same services to more customers with the same infrastructure.
3. Exploiting economies of scope, i.e. providing more services with the same network infrastructure. This finally translates into additional demand for the same infrastructure and has similar effects to economies of scale.

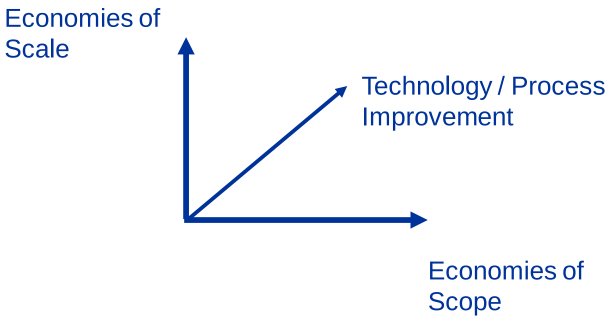

Figure 2-3: Possible ways for improving network cost efficiencies

It must be taken into account that there are substantial differences between network efficiency, as considered in this deliverable, and spectral efficiency, as a measure of the radio spectrum efficiency obtained by using a certain technology. Theoretical peak spectral efficiencies have contributed to increase the expectations posed on novel mobile technologies, and are usually far from mean spectral efficiency found in real network deployments. Moreover, better spectral efficiency may not translate into a better cost efficiency, for instance, in case that a new efficient technology is more expensive to be deployed.

LRIC bottom-up cost models may be used to estimate cost efficiency under different assumptions of demand, available technologies, service portfolio and spectrum available.

2.3 Cooperative-able terminals

In these scenarios, idle user terminals (UT) cooperate with active users. For this case cooperative diversity will allow:

- Higher throughput as a consequence of signal to noise ratio improvement between the end user terminal and the base station. End user may be connected to the BS using a more complex modulation technique through two radio links with better propagation conditions than direct connection. It is relevant in scenarios with high user and traffic density per cell.
- Improved coverage, especially in scenarios with coverage holes that can be avoided using an intermediate relay. This is especially interesting in urban and dense urban scenarios, where coverage holes are more frequent and at high frequencies, especially as we approach LOS frequencies. In this case, using intermediate relays may enable connection between BS and a user who is not “seeing” the base station, through two LOS radio links.
- Extended coverage as a consequence of the extra range added to the base station by terminals standing at cell- edge. In this case, terminals in the edge of the cells act as relays to end users out of range, thus improving total coverage of a given cell. If taken into account in radio planning, it may reduce the total number of cells in the network. This is especially useful in low traffic density per cell regions where planning is done according to base stations coverage.

In the following sections, cost efficiency improvement of cooperative diversity will be measured based on different models.

2.3.1 Higher throughput

A higher throughput can be obtained by using CODIV techniques. The bit rate that a mobile terminal can obtain in the network is determined among other things by the modulation scheme that is used. In our case (e.g. LTE for user channel PDSCH) three different modulations (QPSK, 16QAM and 64QAM) are used according to signal to noise ratio value(which depends on the distance to the base station, visibility, etc). Just as an example, in an additive white Gaussian noise channel and for LTE standard with 5 MHz bandwidth, the effective throughput changes in terms of the SNR according to Figure 2-4.

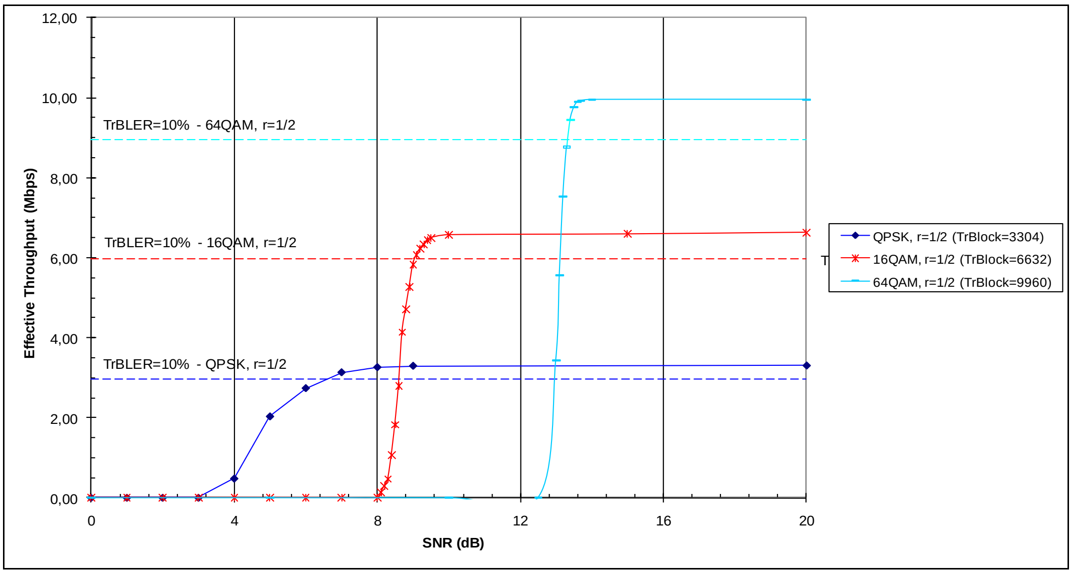

Figure 2-4: Example of effective throughput versus SNR in an AWGN channel

In this example, when the measured SNR at the mobile terminal is lower than 8.6dB, only QPSK modulation can be used. However, if SNR lies between 8.6 and 13.1 dB, 16QAM would be utilized to enhance the effective throughput. Finally, if signal to noise ratio is higher than 13.1 dB, 64 QAM must be used to achieve the maximum throughput.

This situation can be represented using the following simplified scenario (see Figure 2-4):

- Supposing that signal to noise ratio is function only of the distance between the user terminal and the base station. Other aspects as visibility, propagation losses, etc have been considered irrelevant in this particular case.
- SNR between a given user terminals and another one working in a cooperative mode is similar to signal to noise ratio between a base station and this given user terminal.
- Cellular layout has a circular grid; anyway the conclusions are valid also for hexagonal layouts.
- $d_{64QAM} < d_{16QAM} < d_{QPSK}$ are defined as the maximum distances to the BS at which communication is established with the different modulation techniques.
- r_{64QAM}, r_{16QAM} and r_{QPSK} are defined as the mean effective throughputs for each modulation techniques ($r_{16QAM} = 2\ r_{QPSK}$, $r_{64QAM} = 3\ r_{QPSK}$ approximately).
- Uniform user density of u users/Km^2. Each user will be using the best modulation technique possible depending on its distance to the base station.

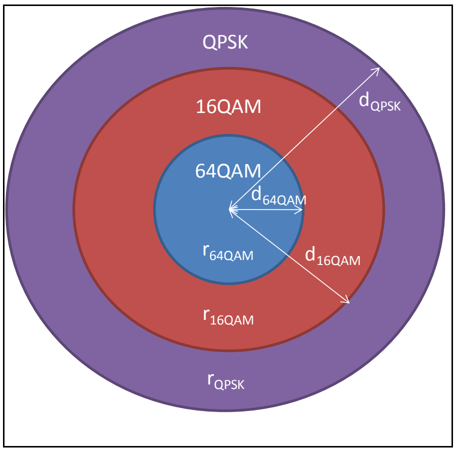

Figure 2-5: Adaptive modulation scenario

Effective capacity in the cell will be given by the following equation:

$$D=\pi\cdot u\cdot\left(d_{64QAM}^{2}\cdot r_{64QAM}+\left(d_{16QAM}^{2}-d_{64QAM}^{2}\right)\cdot r_{16QAM}+\left(d_{QPSK}^{2}-d_{16QAM}^{2}\right)\cdot r_{QPSK}\right)$$

If a user terminal is closer to a relay node (relaying-able terminal) than to a base station (and if the relay node is near the base station), this UT could use a modulation with more bits per symbol, and in this way it would increase its throughput. Thus, CODIV techniques allow for increasing the *d* factors and, as a consequence, increasing the percentage of users using modulation schemes with more bits per symbol. If CODIV techniques increase a percentage *b* the ranges d_{64QAM}, d_{16QAM}, the effective capacity of the cell will be increased according to the next equation:

$$\Delta D=\pi\cdot u\cdot\left(\left(b^{2}+2\cdot b\right)\cdot d_{64QAM}^{2}\cdot\left(r_{64QAM}-r_{16QAM}\right)+\left(b^{2}+2\cdot b\right)\cdot d_{16QAM}^{2}\cdot\left(r_{16QAM}-r_{QPSK}\right)\right)$$

For example, we can consider a cooperating-able dense urban scenario, with short range coverage and a high density of user terminals according to the following simulation conditions:

- 10 cooperative-able terminals which can be used by user terminals to establish a communication to the base station.
- 80 user terminals (which do not help others UTs).
- Random distribution in the layout.

Next, we make the following assumptions:

- UTs situated in 16 QAM region can use nearby cooperative-able terminals located in 64QAM region to increase their throughput.
- UTs located in QPSK region could use nearby cooperative-able terminals transmitting in a quadrature amplitude modulation.

According to the simulation assumptions above, 50 random scenarios have been simulated (one of the snapshots for this particular scenario is illustrated in Figure 2-6) and, as it was expected, the modulation distribution average is better using CODIV technologies than conventional deployments, as Table 2-1 shows.

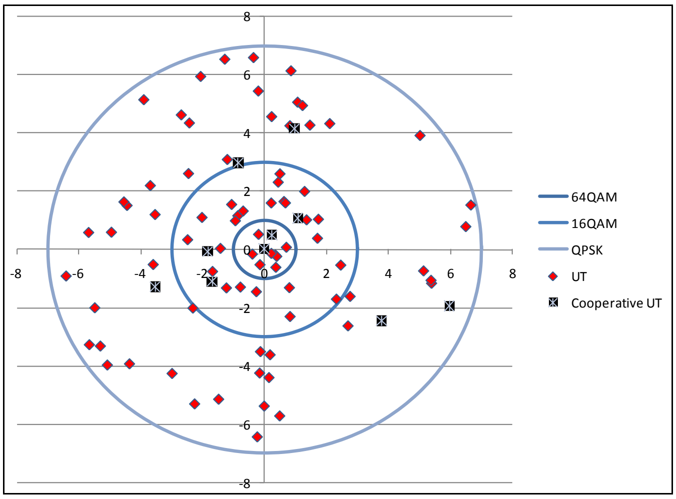

Figure 2-6: Example of snapshot obtained in the simulations for higher throughput scenario

Table 2-1: Simulation results for higher throughput scenario

Modulation scheme	% Modulation without CODIV	% Modulation with CODIV	% Variation
64QAM	14.53	16.23	+1.70
16QAM	28.08	39.23	+11.25
QPSK	47.40	44.55	-12.85

According to Figure 2-4, effective throughput average without CODIV would be around 5 Mbps, meanwhile using CODIV techniques, this number increases around 10% (up to 5,51 Mbps in average).

Note that one would require quite precise link budget calculations and simulations in order to make sure that the former hypotheses apply in a particular and real scenario.

This way, enhanced quality of service (QoS) may lead the service provider to develop new bandwidth-consuming services and increase competitiveness of an operator in mobile broadband services.

2.3.2 Improved coverage

In addition, an improved coverage will be obtained with relaying-able or cooperative-able terminals (fixed or nomadic) because user terminals located in coverage holes (shadowing from buildings, valleys, underground, tunnels, etc) will have an alternative way to connect to the base station. For a large number of final users of cellular networks, this increase of the grade of service (GoS) may represent a reason to change their current mobile network operator.

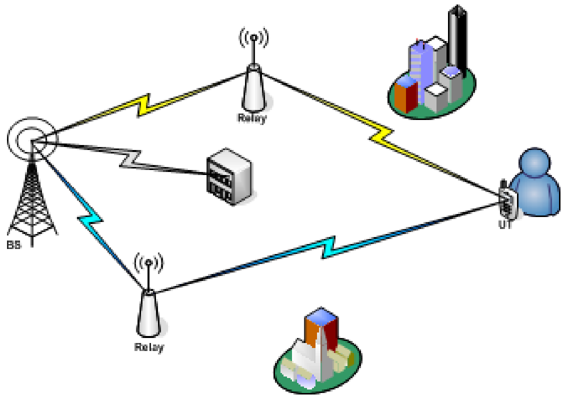

Figure 2-7: Increased grade of service (GoS)

For example, we can imagine an urban scenario, with a high blocking probability, long range coverage and a low density of user terminals according to the following simulation conditions:

- 5 cooperative-able terminals, 35 user terminals.
- All terminals have a 30% of possibilities of being in a coverage hole.

Figure 2-8 shows one of the snapshots obtained in the simulations carried out for the improved coverage scenario.

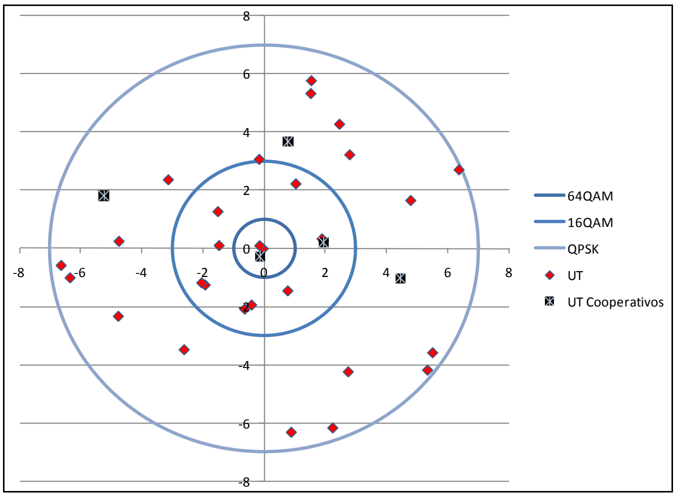

Figure 2-8: Example of snapshot obtained in the simulations for improved coverage scenario

CODIV technology allows terminals which do not have visibility to the base station to be connected to it using a cooperative or a relay node located in the same cell. Fifty random scenarios have been simulated, and the results have demonstrated that CODIV improves coverage considerably as Table 2-2 shows. Note that also, other simulations have been made, changing the number of cooperative-able terminals in the cell. As it was expected, the percentage of blocked terminals using the CODIV techniques decreases considerably, as the available number of cooperative terminals is increased.

Table 2-2: Simulation results for improved coverage scenario

Cooperative-able terminals	% blocked terminals without CODIV	% blocked terminal with CODIV
3	30.34	5.37
5	30.63	1.77
10	27.31	0.11

As in the previous case, one would need precise link budget calculations and simulations in order to make sure that the former hypotheses apply in a particular and real scenario.

2.3.3 Increased coverage extension

Finally, using relaying-able or cooperative-able terminals, the coverage extension will be increased, since users located beyond the boundaries of the cell coverage area will be able to use CODIV terminals as repeaters.

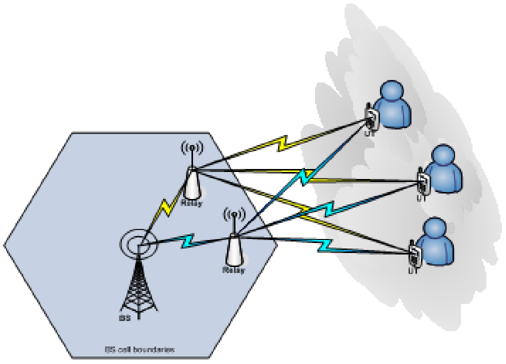

Figure 2-9: Increased coverage extension

This case can be analyzed using a similar model to the one described in the previous section. We assume:

- An ideal propagation scenario without obstacles.
- d_{QPSK} as the maximum distance to the BS at which communication is established with the different modulation techniques.

If d_{QPSK} is increased by a factor a = 1+b (d'_{QPSK} = a d_{QPSK} = (1+b) d_{QPSK}) the surface covered by the cell will be increased by b^2+2b, i.e. will be scaled by a factor a^2.

This coverage extension increase has a special importance in areas with low user and traffic density per cell, where network generally is built considering only coverage aspects. In these scenarios, it will have a direct impact to the investment and operational costs of the network. That means that the number of base stations in order to cover a low traffic density region, in which radio planning is done based on BS coverage range, would be lower, as shown in the Figure 2-10. An increment of 20% in cell range would move in 30% less BSs in rural low-density deployments.

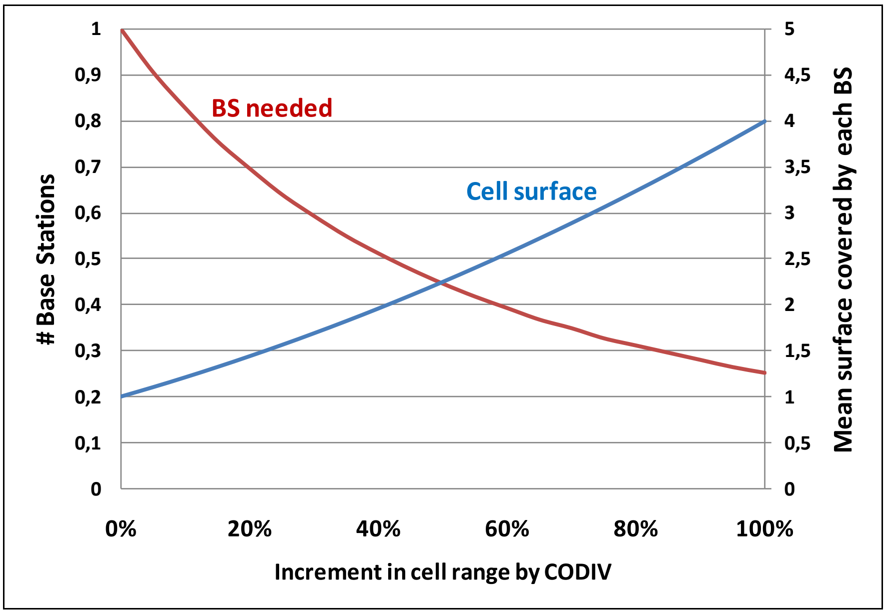

Figure 2-10: Evolution of cell surface and # of sites needed in rural low-density environments as a function of increment in cell range

Another consequence of this increment is that the demand covered by a single BS is also scaled by a factor a^2. In urban environments with high traffic density, which are limited by capacity, increment in cell range will only move into a lower number of sites if there is enough spectrum bandwidth available for the operator.

This decrease of the number of required BSs will have an economical impact in the investment cost. In order to illustrate this scenario, LRIC cost model has been parameterized with a low density rural scenario, and several simulations have been run for different ranges of current BS, achieved by CODIV cooperative techniques. CAPEX and cost results given are Greenfield cost figures, which calculates CAPEX and cost of building up a mobile network from scratch. Base station CAPEX result is broken into the following cost concepts:

- Radio site cost, acquisition and fit out.
- The radio equipment cost, BS, carriers, antennas, etc.

The effect of coverage increase on the investment cost is shown in the graph on Figure 2-11, together with the CAPEX breakdown.

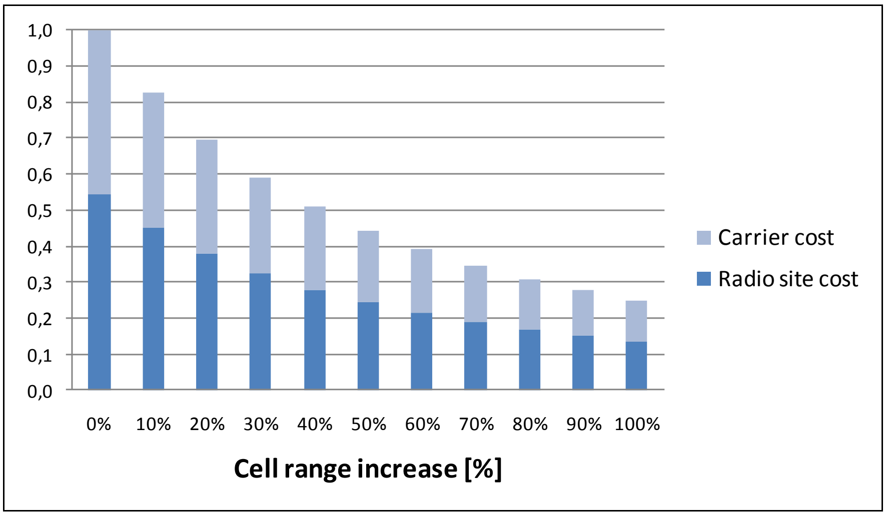

Figure 2-11: Base stations CAPEX versus cell range increase

CAPEX figures are normalized with respect to the CAPEX without CODIV techniques. As it is shown, the investment decreases when coverage is increased (for example, if cell range is duplicated, CAPEX decreases more than 70%). Radio site acquisition and fit out CAPEX is slightly higher than carrier cost, the CAPEX composition is independent of cell range increase.

CAPEX figures may be annualized using a WACC of 10%, and OPEX related to radio network may be added. The cost is calculated for each of the increments in range as the sum of the following components:

- Site cost, which includes annualized CAPEX associated to new sites, yearly leasing of macro sites, and backhaul connection of radio site.
- Macro carrier cost, which includes annualized CAPEX of radio equipment.
- Annual re-planning cost, which includes yearly cost of re-planning of a 5 % of radio access network.
- RAN operation and maintenance cost.

Final results and evolution with range increase through CODIV techniques are shown in Figure 2-12.

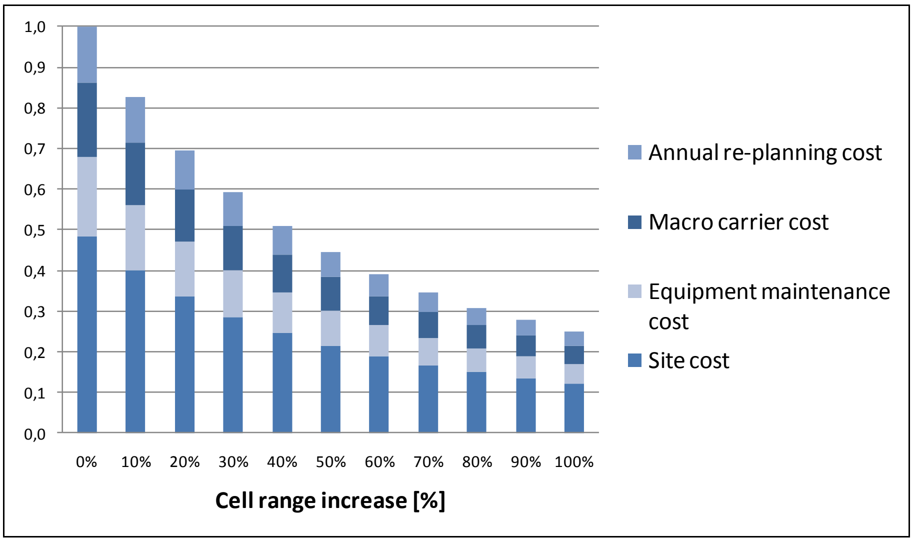

Figure 2-12: Operational cost versus cell range increase

In this case data were normalized value with respect to the operational cost of the radio access network without CODIV techniques.

It can be seen that the use of cooperative diversity technologies decreases the operational cost considerably. Site cost represents half of the total OPEX cost.

2.3.4 Economic considerations of cooperation

After analyzing the benefits of cooperation between terminals for the network operators, the main economic issues and impacts in business model derived from this cooperation will be discussed. Security issues and customer incentives to act as a cooperating relay will be discussed along with policies and recommendations. Practical applications or scenarios that operators may be pursuing in order to take advantage of cooperation will be presented.

From the point of view of the operator, the following issues must be taken into account when calculating the viability of cooperative-able terminals:

- It will be necessary to upgrade BS, which may include both hardware and software upgrades. BS upgrade may be performed only in those BS where CODIV benefits, in terms of coverage and capacity improvement, are useful to the operator, thus limiting total investment.
- Terminal upgrade. Cooperative-able terminals are different from standard terminals. It will be necessary to replace at least terminals which act as a relay in CODIV cooperative-able terminals scenario.
- Cross-subsidization of services may help deploying CODIV terminals. For example, one possible use case of mobile data is remote management of vending machines, to alert when something is going wrong or to inform about the activity of the machine. This remote management may be performed by mobile terminals. As a result, these terminals are often in the idle state. By using an agreement with the vending company, vending machines may be equipped with CODIV adapted terminals and they may act as a relay to other users.

Another aspect to be taken into account is the incentive of end users to act as a relay for some other users in the network, as well as the drawbacks of CODIV techniques.

- Confidentiality. As a result of the application of CODIV techniques to the end-user, if information sent by the end-user needs an intermediate user to reach the BS, confidentiality may be broken by the intermediate user.
- Power consumption. CODIV terminals will act as a relay if they are in the idle state. Thus, one visible effect that end users will experience if their terminal is CODIV-able is that battery is exhausted quickly and battery life will be lower.
- Security. Relaying through an intermediate terminal may result in security threats to the end user. It will be necessary to study in advance security risks of CODIV and prevent them in order to make this technology more attractive to the end-user.
- Specific terminal. CODIV relays require specific terminals. If the offer of CODIV-able terminals does not match the offer of non-CODIV terminals this represents a disadvantage for CODIV adoption.

One of the main problems of applying CODIV techniques (cooperative-able terminal approach) to end-user terminals is the lack of economic incentives for relaying. This is especially important taking into account that the advantages of the operator come from a network effect: the more CODIV-able terminals the more capacity and coverage improvement achieved.

Consequently, the main task of the operator regarding cooperative-able terminal deployment will be thinking of incentives in order to make CODIV technology attractive to the end-user. CODIV-able users may benefit from a better service only if they are able to use other CODIV terminals as relays. On the other hand, direct economic benefits for customers accepting CODIV-able terminals may be provided by the operators. These include at least:

- Terminal subsidization.
- Savings in voice/data charges.
- Prioritization in case of congestion (promotion to higher QoS classes).

2.4 Usage of dedicated relays

After studying the effects of cooperating terminals acting as relays when they are in idle mode, an operator may wonder whether a smart deployment of dedicated relays will allow also to lower deployment CAPEX and operational cost and which is the best policy to place these relays in order to achieve the different effects commented in the former section. In this section it will be discussed:

1. Expected differences in cost between a complete base station and a relay.
2. Economic analysis of the usage of relays in LTE and WiMAX access networks.
3. The economic analysis in this section has similarities with cooperative terminal analysis. However, as the operator has more control about how many relays are deployed and where to deploy them, it leads to the analysis of relay deployment policies and how to maximize the economic impact and the improvement in network efficiency.

2.4.1 Base station versus relay

In a previous deliverable of WP2 **[D2.3]** (section 5.1.2), the differences in cost of relays compared to BS according to the WINNER project **[WIN2D613]** were discussed and quantified. Although this information will be used in the cost analysis carried out for the deployment of relays in the system level simulation of urban scenarios and described in Section 3.3, here it is important to note that initially technological innovation may imply that the relay node cost will be higher than the cost of the equivalent BS in terms of transmitted power. However, it seems likely that the relay node cost in the long term will be lower if they are widely adopted, due to the lower complexity of the node hardware and software. Moreover, relays communicate with their parent BS using radio interface, thus there will be always a cost saving in the wire line backhaul.

2.4.2 Economic analysis of dedicated relays

Economic analysis of dedicated relays is similar to that of cooperative-able terminals made in section 2.3. However, the following differences must be taken into account:

- Relays may be considered to have the same range as the micro or pico BS. For example, macro relays (similar to micro BS), if implemented, will have approximately 18 dB more transmitted power than cooperative-able terminals. Consequently, range increments introduced by macro relays are much more important than those introduced by cooperative-able terminals.
- Increased power also benefits capacity improvement of relaying, as the modulation technique and obtained throughput is dependent on SNR at the receiver as shown in Figure 2-4. Cell capacity improvement through relaying is slightly different than in previous work, that was related to relaying in 3G, taking into account the different modulation techniques that end-user terminals may use depending on the SNR.
- There is always the opportunity to adapt relaying coverage to demand using relays at different levels (micro or pico).
- Cost of relaying. In this case relays are directly paid by the operator, thus ratio of relay versus BS cost is a key indicator, as commented before.
- Considerations made in Section 2.3.4 regarding incentives of the user to adopt CODIV terminals are not useful with dedicated relays. In this case, the operator exclusively must analyze and decide whether and when investing in relays is more profitable than investing in the deployment of additional BSs.

2.4.3 Deployment policies

There are different deployment policies depending on the effect we want to obtain:

- If we want to increase coverage, relays must be placed by the edge of the cell. Thus, coverage extension will be optimal although SNR obtained at the end-user receiver would not be sufficient to use the most efficient modulation techniques.
- If we want to increase throughput, relays must be placed by the edge of regions with more complex modulation techniques. Thus, SNR obtained at the end-user receiver may use the most efficient modulation techniques, although deployment will not be optimized for additional coverage extension.

Another possibility would be by means of using an outdoor antenna with an indoor repeater in buildings in order to increase throughput and improve indoor coverage. This may be useful in offices and business buildings taking advantage of existing communication infrastructure. Savings in link budget (3-21 dB) due to avoidance of wall losses may improve SNR in the building and thus increase throughput achieved by end-users inside it. This kind of deployment may be paid by the end-user (owner of the building) or by the operator to corporations or large enterprises.

2.4.4 Scenarios for dedicated relays

In conclusion, the deployment of dedicated relays by mobile network may be useful in the following scenarios:

- Macro relays in rural deployments with low traffic density in order to improve coverage of existing macro-cells.
- Micro–pico relays to improve throughput in urban scenarios with low or moderate density of users, in which there is no necessity to add a micro-pico base station to improve network capacity.
- Micro-pico relays in order to improve coverage in urban scenarios, especially shadowing of buildings or indoor coverage.

2.5 Multi-User MIMO scenarios

In Multi-User MIMO scenarios, the radio resources for the communication of different user terminals are shared in a more efficient way. If multi-user MIMO is applied, it will have a strong economic impact reducing expenditures, because capacity of the radio interface of a base station will be higher and thus the number of carriers and sites needed, will be lower. The objective of this section is to understand where Multi-User MIMO scenarios are useful and the impact of these techniques on the different environments of wireless access.

Suppose we have a network planned to cope with a demand D, and using an LRIC model we calculate its cost C, such as network cost efficiency is $\eta = D/C$. We have two alternatives to grow our network to meet demand expectations $D' = D+\Delta D$:

1. Continue growing the current network. In this case, assuming that cost efficiency is constant in the given interval, the cost will be $\Delta C_1 = \eta \Delta D$.
2. Growing the current network using multi-user MIMO. In this case, the cost will be ΔC_2.

Considering moderate increments of demand, rural low-density regions are often over dimensioned and, consequently, network operators are able to cope with the additional demand using the existing infrastructure or with small investments. In those regions if the hypothesis of constant network efficiency does not apply and multi-user MIMO extra-efficiency is not applicable: efficiency is improved by means of economies of scale and scope.

In high traffic density regions, efficiency improvement due to economies of scale and economies of scope is exhausted, and MIMO extra efficiency may be useful, as long as additional spectral efficiency translates into cost efficiency improvement. This occurs if cost of using multi-user MIMO is lower than cost of evolving current networking, i.e. if:

$$\Delta C_2 < \Delta C_1 = \eta \cdot \Delta D$$

If we think of an urban BS in a high traffic density area per cell, the increment of demand may cause additional carriers or additional spectrum being added to the existing equipment. In this case, which assumes that enough spectrum is available, multi-user MIMO would be useful if cost of multi-user MIMO is lower than cost of adding carriers or spectrum. It should be taken into account that multi-user MIMO force changes in number of antennas for BS. Considering only long-term variable costs, which are associated to BS upgrading and potential extra cost of multi-user MIMO-able terminals, this technology will be interesting if BS upgrading without using multi-user MIMO is more expensive. Several considerations may be discussed here:

- In case of spectrum bandwidth scarcity for a given level of demand, technologies like multi-user MIMO, which allows better spectral efficiency, are most valuable, since it prevents the operator from growing the number of sites. In this case, cost efficiency of the network may even increase if the additional cost for the implementation of MIMO techniques is lower than the cost of the extra sites.
- If MIMO is included in a standard, incremental cost of considering multi-user MIMO would be substantially lower since network nodes would fit multi-user MIMO hardware requirements. LTE standard is already considering the use of MU-MIMO strategies in particular scenarios (mainly urban dense, hot-spots and in-building) to enhance the cell capacity. On the contrary, this is not the case for WiMAX standard.
- Spectral efficiency improvement achieved by multi-user MIMO is a key indicator of its impact in network efficiency.
- Capacity improvement using this spectral efficiency and cost of upgrading to multi-user MIMO from an existing state-of-the-art is the key value to determine whether it allows decreasing global radio access network optimum efficiency.

To illustrate how spectral efficiency increase of MU-MIMO turns into cost savings, densely populated urban scenario with high-density traffic demand has been simulated using the LRIC model. Simulations have been run considering different spectral efficiency gains from MU-MIMO. Two different demand levels have been considered, D_2 and D_1 (where $D_2 >> D_1$). Cost results given are Greenfield cost figures, which calculates cost of building up a mobile network from scratch. The results of this simulation are showed in Figure 2-13 where the Y-axis represents the normalized cost value regarding the cost of the deployment for a demand level D_2. As can be seen, when the spectral efficiency increase is zero, the deployment cost for a demand level D_1 is around 33 % lower than for a demand level of D_2.

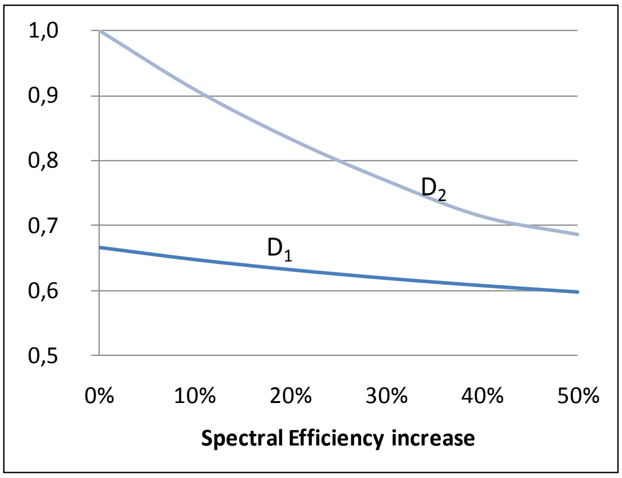

Figure 2-13: Reduction of costs with MU-MIMO

In the D_2 case, traffic density is high and the operator needs to increase the number of sites in order to cope with the demand. As a result, increment in spectral efficiency is more relevant, as it saves both in site and equipment cost. In the D_1 case, demand is lower and cost savings of increasing spectral efficiency impact only in the cost of BS. If MU-MIMO is used in cells of low demand density, we may reach the situation in which increment in spectral efficiency does not have any influence in network costs.

In summary, multi-user MIMO allows the network operator to increase the capacity of a cell, at the cost of extra CAPEX in BS and with specific terminals. One first consideration is that multi-user MIMO, as the rest of technologies that improve spectral efficiency of radio network, will be interesting only in areas with certain traffic density. In these cases, improved spectral efficiency increases theoretical capacity of existing network and postpones growth using additional carriers / spectrum or using additional sites. Due to the high costs of site acquisition and maintenance, it is likely that multi-user MIMO would be preferable to the alternative where one increases the access network capacity through new sites. Multi-user MIMO deployment costs and spectrum availability will determine whether it is preferable to add carriers using additional bandwidth to existing sites or upgrading them to multi-user MIMO.

3 Cost and deployment analysis

In Section 2, the predicted economic impact of the three main technical approaches contemplated in CODIV project (cooperative-able terminals, dedicated relays and MU-MIMO techniques) has been analyzed according to LRIC models. The purpose of current chapter is to estimate the costs of the particular deployments contemplated in the system level simulations (WP5) in order to know the additional expenses for the implementation of CODIV techniques in comparison with conventional deployments, and then to analyze whether or not the improvement of the performance achieved in the CODIV deployments in terms of the indicators used in the system level simulations, justify the costs increase necessary to implement the CODIV techniques.

In short, the main idea is to estimate the costs of the conventional deployment versus the CODIV approach used in the proof of concept (WP5) for a later analysis of costs and benefits associated to each deployment (conventional compared to CODIV). In this respect, Figure 3-1 outlines the methodology applied for the cost and performance analysis of the radio network deployments contemplated in the system level simulations accomplished by WP5.

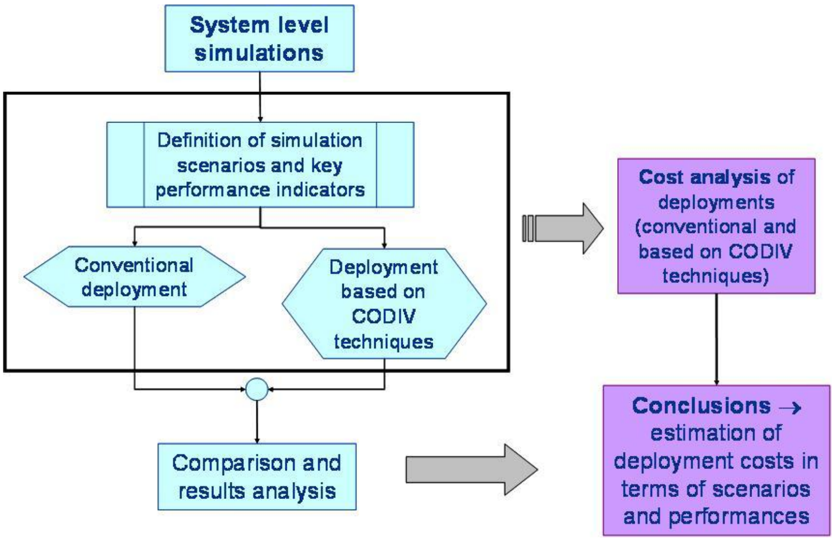

Figure 3-1: Flow diagram for cost and performance analysis of deployments contemplated in system level simulations of CODIV

Of all the technical approaches contemplated in CODIV, the most relevant and predominant from the deployment cost point of view is of course the one based on the usage of dedicated relays because with this option the operator would have to make the acquisition and planning of the dedicated relay nodes, modifying somehow the initial investments of the radio network deployment. The other two approaches, the relaying-able terminals and MU-MIMO schemes, will not have so much influence (at least in a direct way) on the initial costs of a given radio network deployment. However, as was explained in the previous chapter (Sections 2.3 and 2.5), these techniques may contribute significantly to improve the capacity and coverage of the deployments, so that in the long run it would be possible to get some saving in future investments that would achieve similar performance. For this reason, the current chapter is focused on the cost analysis of radio network deployments with dedicated relay nodes. It will concentrate on urban scenarios since the available results coming from system level simulations (WP5) at the moment of the preparation of this document were obtained for urban environments.

3.1 System level simulations in CODIV

According to the inputs coming from WP5, and in particular from the intermediate system level simulation tool reported in **[D5.3]**, in this section we will outline the assumptions, the key performance indicators used in the simulations and the results obtained in urban scenarios. For detailed information on the system level simulations of WP5 please refer to **[D5.3]**.

3.1.1 Simulation plan and definition

Figure 3-2 illustrates the radio network deployments for urban scenario contemplated in the system level simulations carried out in WP5 in order to analyze and compare the performance of a conventional deployment based only on the usage of base stations against CODIV deployment, with six fixed dedicated relay nodes per cell at 2/3 of the cell radius of the BS.

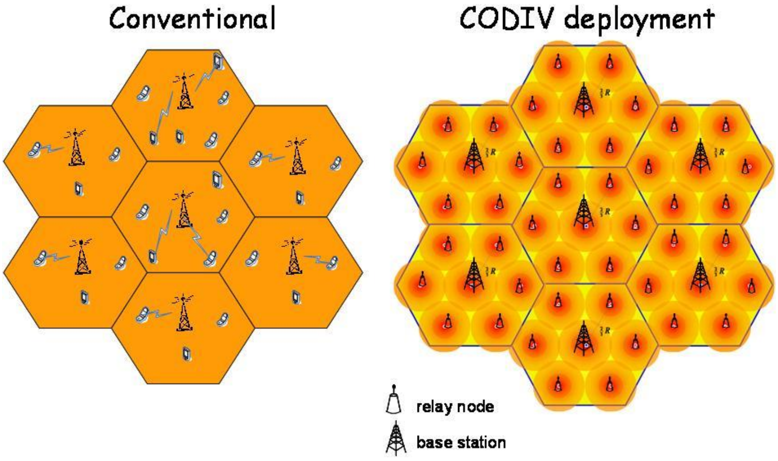

Figure 3-2: System level simulations plan according to CODIV approach based on the deployment of dedicated relay nodes located at 2/3 of the cell radius

The parameters used in the system level simulations (common to both deployments, conventional and CODIV) were the following (taken from **[D5.3]**):

- Simulation environment: urban.
- Number of cells: 19.
- Number of mobile users: 200 (parameterized).
- Cell size: 1000 m (parameterized).
- Traffic: full queue.
- BS power: 12.3 dbw (about 42 dBm).
- Scheduling: max C/I.

The following list shows the particular parameters assumed for the cooperative case of the system level simulations.

- Type of relay: fixed relay.

- Number of fixed relays per cell: 6.
- Position of fixed relay: 2/3 of cell radius.
- RF power of relay: parameterized (in principle 0.3 power of BS → about 12.6 dBm).
- Operation of fixed relay: half duplex.
- Number of antennas.
    - BS: 2 receive antennas.
    - Relay node: 2 receive antennas.
    - Mobile user: simple terminal with 1 antenna.
- Criterion for relay selection: best SNR.
- Resource allocation: one user per TTI (per frame).
- Physical layer algorithm: virtual MIMO according to IT (Instituto Telecomunicacoes) proposal.

Figure 3-3 shows the definition of the frame structure used in the system level simulations as well as the composition of the resource unit. For the full queue traffic model contemplated in the simulations total RUs were assigned to one user per TTI.

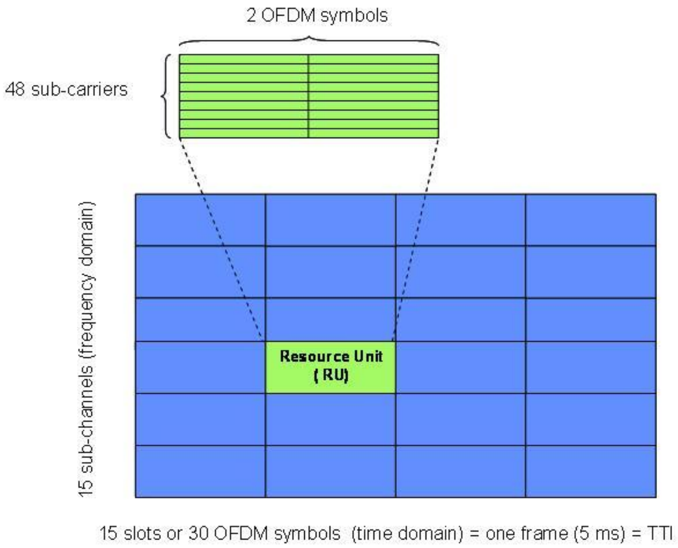

Figure 3-3: Frame structure used in the system level simulations of CODIV

According to the frame structure used in the simulations, Table 3-1 shows the peak bit rate which can be achieved for different modulation and coding schemes.

Table 3-1: Numerical examples of peak data rate achieved for different MCS in the system level simulations of CODIV

Modulation and Coding scheme	Theoretical throughput (Mbps)
QPSK ½	4.32

QPSK ¾	6.48
16QAM ½	8.64
16QAM ¾	12.96
64QAM ½	12.96
64QAM ¾	19.44

In the simulations for the CODIV deployment, since it is assumed that the relays are half-duplex, the communication requires two phases as shown in Figure 3-4. So the relay-assisted scheme for downlink is as follows:

- In the first one, the BS broadcasts its own data at full power to UT, and also to the relay node, which does not transmit data during this stage.
- During the second phase, the relay node can help the BS by forwarding the information, also at full power, to the UT, whereas the BS is idle.

Likewise in the uplink the communication cycle requires also two phases:

- In the first one, the UT broadcasts its own data at full power to BS, and also to the relay node, which does not transmit data during this stage.
- During the second phase, the relay node can help the UT by forwarding the information, also at full power, to the BS, whereas the UT is idle.

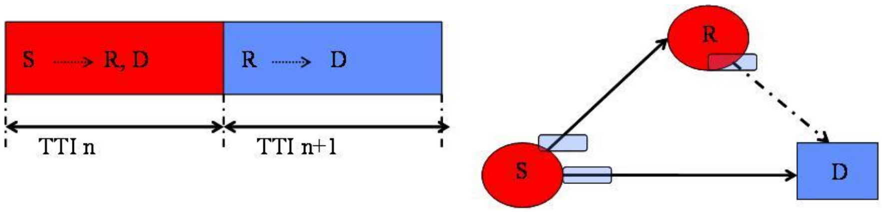

Figure 3-4: Scheme of half duplex operation in CODIV system level simulations

The relay selection algorithm implemented in the intermediate version of the system level simulations (results are included in the current deliverable) was based on SINR measurements according to the following steps:

- From among the six relays (RN1... RN6) in the cell in which the user camps, the two closest to the user (RN1, RN2) are selected.
- The SINR between the two closest relays and the user; and between the BS and the user is computed.
- The network node (relay or BS) with the maximum SINR will be responsible for transmitting signals for the user.

So the selection of the relays was performed according to the following expression:

$$R^{(k)} = \arg\max_{i=0:N_R}\left(SNR_i^{(k)}\right)$$

where $SNR_i^{(k)}$ is the SNR measured between relay *i* and user *k* (index 0 refers to the BS), and N_R is the total number of relays

It is important to clarify that if a user terminal has a SNR value from BS better than the SNR value from RN, the user chooses direct link, otherwise, it chooses cooperative link.

The criterion to position the fixed relays in the cell consisted simply in placing the nodes at a distance from the BS so that the average SINR was the maximum.

3.1.2 Metrics used in the system level simulations

The key performance indicators used within the system level simulations for evaluating and comparing the efficiency of each of the contemplated deployments were the following:

- Average service throughput.
- Percentage of satisfied users.
- Fairness according to Gini index.

The average service throughput is defined as the ratio of the number of bits transmitted in sector over the time required to transmit them according to the next equation.

$$AverageThrougput = \frac{\sum Number\ of\ successful\ bits\ transmitted}{\sum total\ time}$$

For the metric percentage of satisfied users, the next definitions are applied.

- One user is considered unsatisfied if its communication is dropped.
- It is considered that a user will be dropped if the SINR falls below a predetermined threshold (SNR<-10.15dB), or one packet is un-successfully transmitted for *k* attempts.

So the expression for the percentage of unsatisfied users becomes as follows:

$$Percentage\ Unsatisfied\ User = \frac{number\ of\ drop\ users}{total\ number\ of\ users}$$

Finally, the measure used to quantify the fairness in the system level simulations was based on the Gini index. The Gini coefficient is defined graphically (see Figure 3-5 from **[D5.5]**) as a ratio of two surfaces involving the summation of all vertical deviations between the Lorenz curve and the perfect fairness line (A) divided by the difference between the perfect fairness and perfect unfairness lines (A+B). The Lorenz curve tells us how much data is deviated from the line of perfect fairness. As can be seen the Gini index value lies between 0 and 1. If we go toward line of perfect fairness (closer to 0, perfect fairness) our fairness increase. However if we go away from line of perfect fairness (closer to 1, perfect unfairness) our fairness decreases. Note that the variable used in the Gini index was the SINR calculated in the simulations.

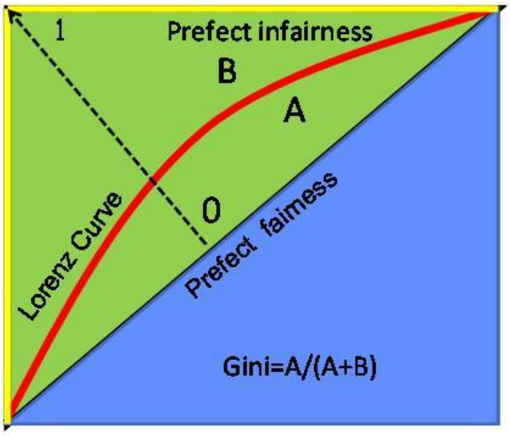

Figure 3-5: Gini index definition used for the fairness metric in the system level simulations of CODIV

Therefore the expression to calculate the Gini index in the system level simulations was as follows:

$$G = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left|SNR_i - SNR_j\right|}{2n^2 \cdot \overline{SNR}}$$

where ‘*SNR*’ is the value of signal to noise ratio observed, and ‘*n*’ is the number of SNRs observed

3.1.3 System level simulations results for urban scenarios

We present in the following a summary of the results obtained in the system level simulations for urban scenarios according to the assumptions explained previously and coming from WP5.

Figure 3-6 illustrates the comparison of the average service throughput observed in conventional and CODIV (dedicated relay approach) deployments simulations for different number of users. Regardless of the number of users, the deployment based on the use of dedicated relays according to CODIV approach shows a better performance than the conventional deployment (only BSs). Nevertheless, the improvement detected in the simulations was not so much significant, the maximum observed increase being of 6 % for the case of 100 users.

Likewise Figure 3-7 illustrates the comparison of the average service throughput observed in conventional and CODIV (dedicated relay approach) deployments simulations for different cell sizes. As in the previous case the average service throughput of the CODIV deployment was better than in the conventional deployment. In these simulations, for cell sizes equal or greater than 2000m, the improvement was quite significant between 16% and 30%, while for 1000m cell size the improvement was almost negligible around 1.5%. Note however than the maximum throughput was reached in both deployments, conventional and CODIV, in a cell radius of 1000m with a value around 8.5 Mbps.

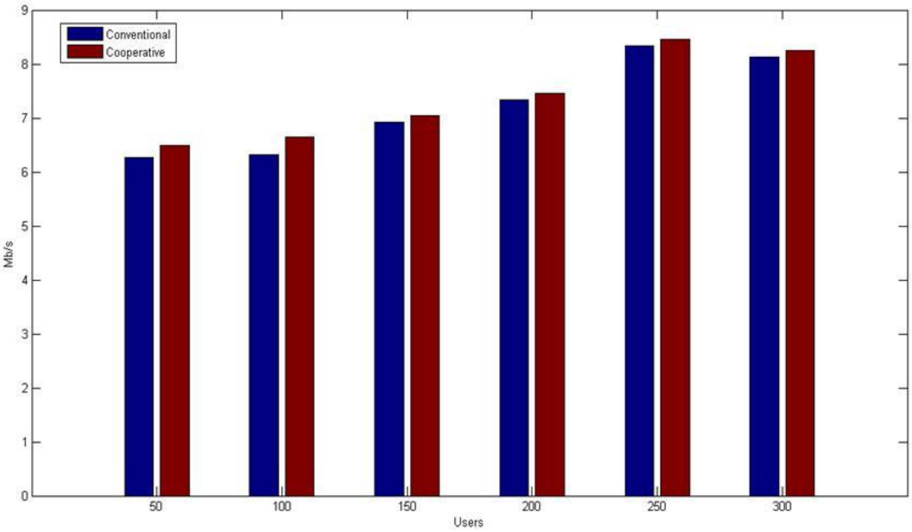

Figure 3-6: Average service throughput versus number of users

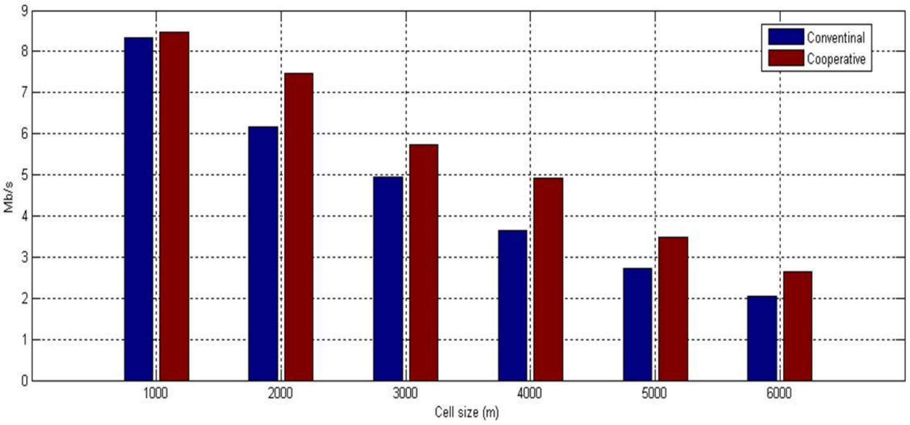

Figure 3-7: Average service throughput versus cell size

Figure 3-8 shows the percentage of unsatisfied users for different cell radius obtained in the system level simulations for conventional and CODIV deployments. The improvement of this parameter for the CODIV deployment was growing according to the cell radius, although for cell sizes equal or lower than 2000 m was not so much significant (below 2%). The maximum improvement was reached for the larger cell size (3000 m) of the simulations with a reduction about 10% in the percentage of unsatisfied users for the CODIV case against conventional deployment (without relays).

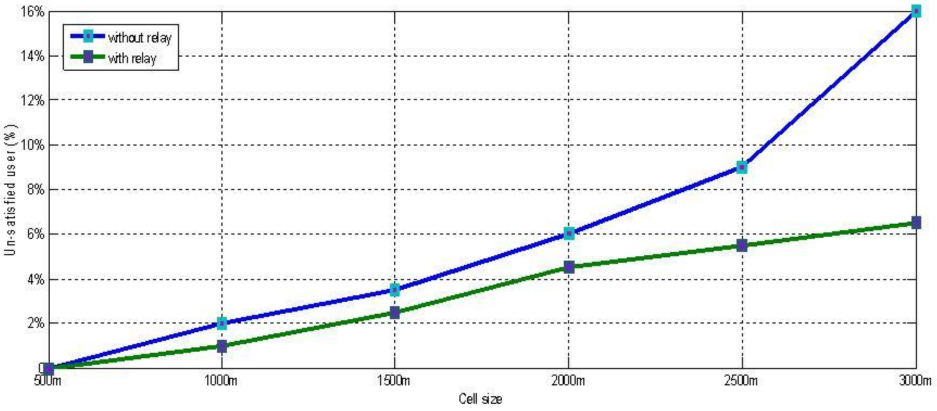

Figure 3-8: Number of unsatisfied users versus cell size

Finally, concerning the Gini index used to estimate the fairness of the system (remember that 0 means perfect unfairness, and 1 means perfect fairness), Figure 3-9 shows the evolution of this index for conventional and CODIV deployments in terms of the cell radius. As can be observed, the fairness is increasing when the cell size is growing, and the improvement reached with the CODIV deployment in comparison to conventional case (without relays) was practically kept constant with an increase around 0.05 in the Gini index.

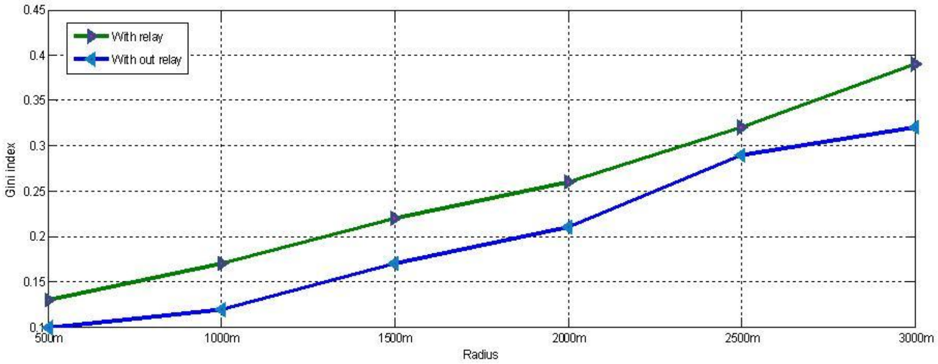

Figure 3-9: Fairness measurement according to Gini index versus radius of cell

3.2 Analysis of the deployment costs

Within this section certain aspects and topics related to the analysis of deployment costs of current and future cellular radio networks will be reviewed and outlined, including several cost analysis models from literature as well as an example of deployment cost structure for 3G systems in accordance with the methodology of Telefonica.

3.2.1 Radio network deployment issues

One important characteristic of any radio network deployment is that operational and transmission costs tend to dominate over radio equipment and site costs when the site density is increased (see example of UMTS deployment in Section 3.2.4). That is, the maintenance costs are the dominant factor for network deployment with higher site density. So in order to minimize the radio network expenditures, an important aspect to analyze is the inclusion of an efficient supervision and control system, as well as the use of equipments with easy and cheap maintenance.

Besides, for a given cellular system it is generally accepted that the capacity is proportional to the base stations density. However, the infrastructure costs seems to increase approximately in a linear way with the capacity needed in a certain network deployment, and then a low degree of economies of scale exists. This problem was treated in **[Jen97]** and the conclusion was that the network cost rises linearly with the data rate per user. Also in this paper a simple infrastructure cost model was presented,, stating that total infrastructure costs of a wireless system is modeled like an expression linearly proportional to the number of base stations. This model was further developed in **[Jen02]**. Nevertheless, in an empirical system, the operator in charge of a certain deployment usually distinguishes between different types of base stations and other nodes as relays from different points of view such as capacity, coverage and reliability, depending on particular characteristics of scenario where is desired to provide a given service.. Therefore the total cost per base station and relay node, including capital investments and operational expenditures, is greatly affected by the type of access point (BS and RN) used for a particular deployment scenario.

Other important aspect to consider in any radio network deployment from a mobile operator point of view is the overall cost structure. Usually the investments of a mobile operator amount to radio and transmission equipment, license fees, site build outs and installation of equipment. The running costs, in turn, consider mainly transmission, site rentals, marketing, terminal subsidies, and operation and maintenance cost (O&M). The exact breakdown of those costs is of course case specific, and it may vary significantly between different countries and operators. For instance in the TONIC project **[Loi02]** several cost figures for western European operators were used. In this project the cost structure was estimated for operators providing UMTS services in small and sparsely populated countries, and in large countries with denser population. For example Figure 3-10 reproduces graphically the data managed in this project. From these results it is clear that cumulated running costs dominate the total cost structure of a mobile operator, and according to **[Loi02]**, they correspond to roughly 75% of the total costs for a large country. More specifically, the running costs are dominated by non-technical costs, such as marketing, terminal subsidies and wages which can be seen in Figure 3-10. Note also that transmission constitutes a significantly higher portion of the running costs in the small country. This since “last mile” transmission is priced per kilometer in the model used in **[Loi02]** and the distance between base stations is higher in the small country example, due to its lower population density.

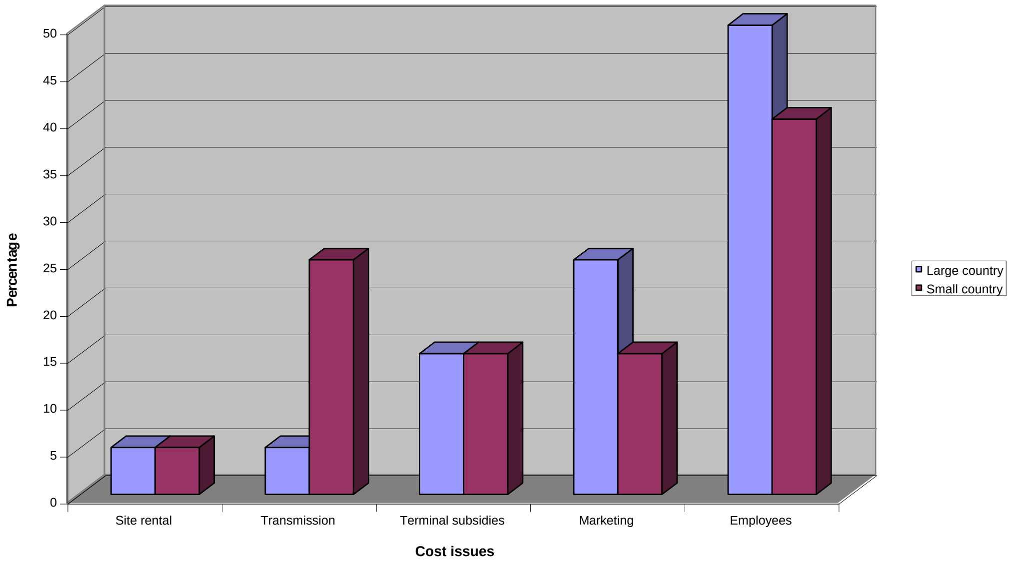

Figure 3-10: Typical running cost structure based on TONIC project results [Loi02]

Another interesting problem analyzed in **[Loi02]** which was taking the overall network deployment into account, was that the main part of the infrastructure costs comes from the radio access network (including radio network controllers, base stations or access points, sites, and “last mile” transmission). Core network equipment such as backbone transmission, switches, routers, charging functionality, and subscriber registers only contribute to 10-30% (small and large countries respectively) of the overall network costs. Likewise in several publications (**[And04]** and **[Kla04]**) it was demonstrated that the site-related costs are the dominant part when a macro base station is deployed, and so it is not expected that a cost reduction in base stations deployment occurs at the same rate as equipment costs.

Finally, one important characteristic to take into account for the cost analysis in any radio network deployment is the great variability of prices that the network equipments experience in a very short time. For instance Figure 3-11 (thanks to Visiongain Group) shows the price evolution of a node-B (macro base station) from 2002 to 2004. As can be seen this price experienced a somewhat 70% decrease, in only two years.

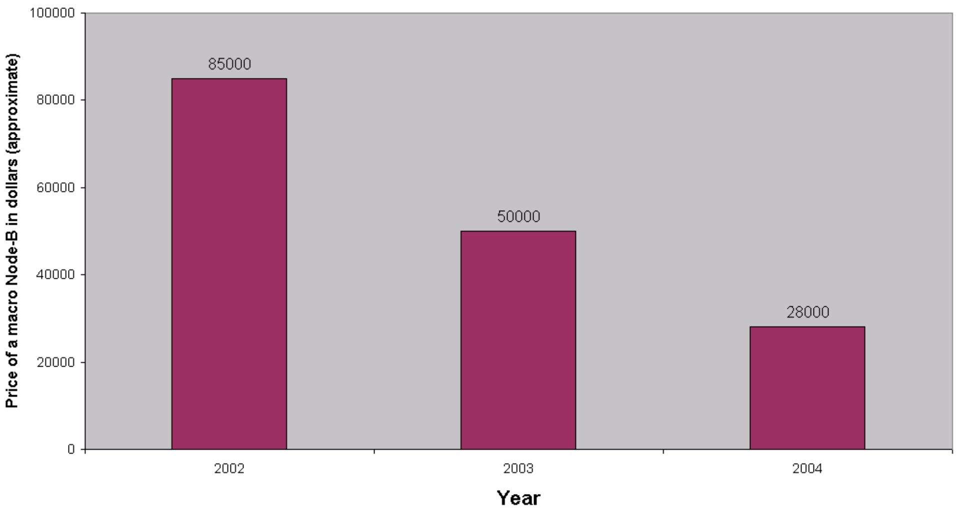

Figure 3-11: Example of falling prices for UMTS macro base station (source: Visiongain group)

Therefore it is important to take into account this fact when a cost analysis of a particular deployment is carried out, and so the CAPEX and OPEX data showed in Section 3.2.4 should be considered only as a guideline of the authentic expenditures which will depend on a diversity of factors such as the law of supply and demand, special discounts, type of vendor, size of the order and so on.

3.2.2 Cost analysis models

The intention of this section is to provide some insights concerning models proposed in literature for cost analysis of radio network deployments of current 3G systems.

In this way for example in **[Jen97]** the infrastructure cost analysis is performed through the following linear cost model:

$$C_{system} = c_1 + c_2 \cdot B + c_3 \cdot W_{system}$$

where B is the number of base stations in the system and W_{system} is the bandwidth used by the system

This model has the drawback to use very simple assumptions such as:

- the base station has a fixed cost,
- the system operates in a licensed band,
- and other aspects which may affect the overall infrastructure costs are negligible.

A more detailed analysis proposed in **[Pie04]** for the infrastructure costs in a cellular system using relay nodes, takes into consideration the type of base station (for example in **[And04]** the characteristics and costs structure of different base stations is analyzed (an important difference between the equipment/site costs of a macro node-B and a pico node-B of around 5 % is remarked), the difference between the running costs and the capital expenditure (the fact that sometimes maintenance costs may exceed the equipment costs), and other important aspects. In this work the infrastructure cost per unit of area (km^2) is defined by means of the following linear model:

$$C = c_b \cdot \lambda_b + c_r \cdot \lambda_r$$

where c_b and c_r are the cost of a base station and of a relay respectively, whereas λ_b and λ_r are the base station and the relay density respectively

Besides c_b and c_r include the equipment and the site acquisition costs, but a similar expression can be written for the running costs too. It is important to note that there is no term for reflecting the extra costs due to the bandwidth licensing, since the aim of this work, like in CODIV case, is to perform a comparative study. Therefore, similar to the cost analysis model proposed in **[Pie04]**, we will compare the infrastructure cost with and without relaying technologies. Taking into account that the system level simulations carried out in CODIV **[D5.3]** seek to estimate the performance improvement due to the inclusion of a certain number of relay nodes over a conventional cellular deployment, the cost assessment used in CODIV will be also the relative infrastructure cost, in which the cost is not expressed in absolute terms, but only relatively to specific single hop architecture (conventional deployment) like following equation shows.

$$\frac{C_{Enhanced\_Deployment}}{C_{Conventional\_Deployment}} = \frac{c_b \cdot \lambda_b + c_r \cdot \lambda_r}{c_b \cdot \lambda_b} = 1 + \frac{c_r \cdot \lambda_r}{c_b \cdot \lambda_b}$$

3.2.3 Relevance of cost analysis

Nowadays the multi-hop techniques are recognized as a way to improve the coverage and the capacity of any cellular system. However from an economic perspective, the gain obtained through the use of a certain multi-hop technology in a cellular network is yet an open issue. For instance in **[Pie04]** an infrastructure cost analysis was performed on two different hybrid cellular architectures, one of them using terminals as relays, and another one using fixed relays. For the first architecture, numerical examples were presented, in which the infrastructure cost was from 20% to 40% higher when multi-hopping is not used, depending on the density of relaying-able terminals. For the second architecture,, the cost ratio between deploying a new macro base station and deploying a wireless relay was analyzed for different examples. The conclusion was that the infrastructure cost is between 25% and 100% higher when multi-hop is not used, for a cost ratio between a macro base station and a relay varying from 20 to 34.

From an operator point of view, the main drive for the use of dedicated relays in a certain area is the reduction of deployment costs. In the initial stage of a radio network planning, as was explained in **[D2.3]**, one of the objectives is to estimate the amount of access points to be deployed over the targeted area in order to provide the engaged goals of capacity and coverage. Of course, the final objective of the optimization process is to reach the target capacity and coverage with the minimum costs, both capital and operational expenditures (CAPEX and OPEX).

Hence, the cost analysis of relay-based deployments is a fundamental issue to decide when and where the use of different kind of relays can be advantageous and profitable in terms of performance and/or costs. In this case, there are two possibilities; one is to fix the capacity and coverage demanded for a certain deployment and then to estimate the number of needed access points (only base stations or a combination of base stations and relay nodes) and lastly the total costs to achieve these objectives. The second option (and the one adopted by CODIV) consists simply of including, upon a given deployment based only on the use of base stations, an amount of relays located in the more appropriate places to increase the performance of the deployment in terms of certain indicators. Therefore the comparison methodology assumed in CODIV has to calculate in the first instance the costs of a conventional scenario based only on the deployment of base stations and the additional costs of the cooperative scenario including relay nodes. Once the total costs of conventional and cooperative deployments have been established, finally one should determine whether the gained performance in the deployment justifies the additional cost or not.

3.2.4 Example of UMTS deployment cost breakdown in Telefonica

[WIN1D31] proposed a methodology for comparing new and conventional deployment concepts. This methodology was referred to as Weighted Spectral Efficiency (WSE), and the network deployment total cost was broken down into three general items: (i) equipment cost, (ii) antenna system cost, and (iii) connection cost with fixed network. In order to get a more detailed distribution of cost for current radio network deployment, in this section is described the breakdown of costs for UMTS network deployment used by Telefonica.

First of all, whenever a network deployment is planned, the total cost is divided as Figure 3-12 shows, i.e., in initial capital investments and in maintenance/operational costs. It is habitual to denominate these two parts as CAPEX (CAPital EXpenditures) and OPEX (OPerational EXpenditures). Capital expenditures are expenditures used by a company to acquire or upgrade physical resources such as equipment, property, and industrial buildings. In accounting, a capital expenditure is added to an asset account (i.e. capitalized), thus increasing the asset's basis. OPerational EXpenditure is defined as expenditure for the purpose of operating something, in our case the UMTS radio network.

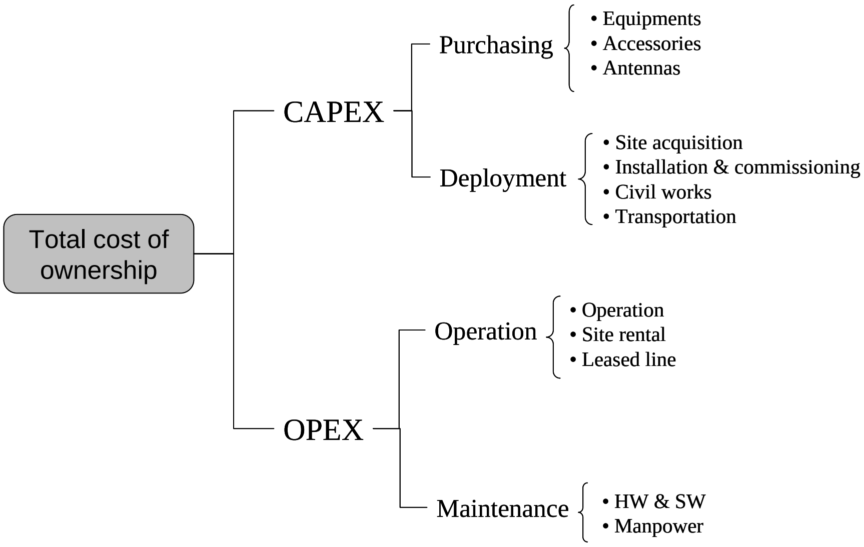

Figure 3-12: Example of cost breakdown for cellular network operator

For the OPEX part, we use a combination of multiple factors (based on incomes, number of subscribers, type of network, etc), reference levels of very confirmed operators (applicable to long term margins after a stable phase is reached), and estimations of initial OPEX necessary to produce some OPEX structure to be developed during the planning phase.

Commonly the CAPEX are determined using numerical data on network elements coming from representative and optimized network planning, along with prices information, in order to define an investment plan. The CAPEX are based on coverage (usually for first years) and capacity (in general long-term) requirements.

We now describe an example of the general costs structure associated to a typical radio network deployment for 3G systems carried out by Telefonica.

- CAPEX
    - 1A: radio frame cost.
    - 1B: costs of radio frequency distribution system, and RF cable.

    - 2B: rest of implantation costs.
    - 3A: acquisition costs.
    - 4A: cost of connection to transmission system.
    - 5A: cost of planning of network deployment.
- OPEX
    - 5B: optimization costs.
    - 1C: cost for preventive and corrective maintenance of radio part of the deployment.
    - 2B: cost for preventive and corrective maintenance of other parts of the deployment.
    - 3B: leasing cost of site.
    - 4B: leasing cost of transmission lines.

In Telefonica the 1A and 1B items are designated as specific work, whereas 2B item is so-called associated work. The specific work includes all items related to radio system such as equipments (cards and racks), RF distribution system, RF cables and antenna system. The associated work is usually formed by everything that is not included into the specific work. So in a rural environment for instance, the associated work would be formed by the costs of the tower, the stall, the electric drop wire, the fence and so on, while in an urban scenario the item 2B would be formed by the expenses relating to issues such as the enabling of the site, the current tap installation and the ground connections. In any case, the expenses of item 2B are in general terms minimal compared to specific work costs.

Regarding the items 3A, 4A and 5A it is important to note that these costs are usually fixed. Nowadays, due to population concerns about the radiation problem, site acquisition (item 3A) uses to be a very tough negotiation process with neighbors group, in particular for acquisition of access (installation of antennas and radio equipments) to flat roofs in buildings of populated cities. Some prospector usually carries out these negotiations with the corresponding commission cost (in some cases up to 3000 €) in addition to the site rent. The cost of connection to transmission system depends on the number of required transmission lines, and the cost (initial fee) is around 750 € per E1 (line of 2 Mbps for 30 traffic channels). It is necessary to have at least one E1 per sector. The planning costs (5A) are relatively low compared to total expenses, and they consist in the hours devoted by the contractor for planning the deployment (when there are more deployments, the planning costs decrease).

Similarly to this last item of the CAPEX part, the optimization costs (5B) although assumed to be an annual expense, are low and the repercussions over total cost, due to operation (OPEX), are minimum. The preventive and corrective maintenance (1C and 2B) uses to be carried out by the equipment manufacturer by means of some supervision and control platform belonging to him. Depending of course on the type of base station the maintenance cost may vary perceptibly. The leasing cost of site (3B) uses to be a monthly payment, and the expenses are between 9000 € per year for an urban macro base station, and 1200 € for a micro base station. Finally the leasing cost of transmission lines use to be around 470 € at month per E1 line.

Summarizing, among the total expenses in infrastructure, the interconnection of base stations or access points with the rest of network elements constitutes one of the most relevant. At the moment the operator costs are basically distributed between the equipment cost and the leasing cost. This last concept is the prevalent component and it represents approximately 90% of the total of annual costs. In particular, when the site density is enlarged, the operational and transmission costs become dominant factor over initial expenses for radio equipments. In addition, for keeping a certain QoS level, a high availability is needed, that is, the percentage of time in which the system is active should be maximized, optimizing MTBF (Mean Time Between Failures) and MTTR (Mean Time to Repair).

3.3 Performance and cost for CODIV urban scenarios

This section is devoted to analyze the costs of the deployments associated to the system level simulations carried out in WP5 for urban scenarios. The short description and results were outlined in Section 3.1.

The goal here is first to estimate the additional costs needed to achieve the performance improvement of the deployments based on the inclusion of dedicated RNs according to the CODIV techniques over conventional deployments. The final goal is to establish those conditions for which the CODIV deployment could be more appropriate and profitable than the conventional one. In other words, a detailed analysis of deployment costs along with capacity/coverage studies, will allow us to justify the use of relay-based network deployment in certain cases.

Already in **[D2.3]** the cost analysis of relay-based deployments was considered and the comparisons of costs between different types of base stations and relay nodes were justified and established. Likewise, CAPEX and OPEX tables for different cost components coming from WINNER project **[WIN2D613]** were included there, emphasizing the fact that the cost structure of future cellular systems can be very complex since a number of uncertain factors (i.e. relation between companies, legislative regulations and so on) should be included in a detailed analysis. Nevertheless due to the fact that CODIV deals with radio access network, the focus of the analysis was exclusively placed on the costs of RAN elements, and not towards complex business models including external elements to the radio access network. Among the main elements for the cost estimation of a RAN **[WIN2D613]** mentioned gateways, radio access points such as base stations and relay nodes, and terminals. Anyway the main interest in our case is the cost structure of the radio access points which somehow determine the total deployment cost of a RAN, as was concluded in WINNER project **[WIN2D613]** pointing that the total deployment cost of a radio access network scales linearly with the number of access points.

So, in order to compare the costs associated to the different deployments contemplated in the system level simulations provided by WP5, example figures of CAPEX and OPEX for different network nodes according to the data already included in **[D2.3]** are shown in Table 3-2 and Table 3-3. These tables serve as an example, and should not be considered to be more than demonstrative values. A reason for the difficulty of estimating general deployment cost values of an access point is that the cost is strongly dependent on the particular scenario. Anyway, it is important to note that the cost of the elements included in both conventional and relay based deployments was focused on the urban environment which has been the one contemplated in the feedback received from WP5 (proof of concept and system level simulations).

Table 3-2: CAPEX values used in the deployment analysis for CODIV urban scenario

Cost element	**Estimated unitary cost (k€)**	**Assumptions**
Macro BS equipment (43 dBm)	50	Three sectors, includes air conditioning, batteries, container, antennas, cables, etc.
RN equipment (17 dBm)	3	Low-cost, low capacity
Macro BS site acquisition and deployment	60	Office, coffee bars, waiting halls, hotel reception, vending machines
RN site acquisition and deployment	0.1	
Macro BS fixed line connection	0.15	Connection to fibre optic access network
Total CAPEX macro BS	110.15	
Total CAPEX RN	3.1	

Table 3-3: OPEX values used in the deployment analysis for CODIV urban scenario

Cost element	**Unitary cost (k€/year)**	**Net Present Value (k€) for 10 years**	**Assumptions**
Macro BS Site Rent, Maintenance, Power and Operation	17	132.63	Includes software upgrades
RN Site Rent, Maintenance and Power	0.5	3.9	No back-up batteries
Macro BS Fixed line Connections	20	156	Professional high-capacity backhaul line, failsafe
Total OPEX macro BS	37	288.63	
Total OPEX RN	0.5	3.9	

It is important to remark that, as was pointed before, the prices of base stations and other network nodes are usually very variable, since the market is continuously trying to reach its equilibrium price as the demand and supply statistics change. So the prices included in the previous tables should be considered only as guidelines. Besides as a general rule, considering a 10 year depreciation value, OPEX should be higher than annualized CAPEX, i.e., CAPEX divided by 10 years. So the OPEX costs are also represented by their net present value, assuming a lifetime of ten years and a discount rate of 6%.

Taking into account the characteristics of the deployments included in the system level simulations reported by WP5, Table 3-4 summarizes the total expenditures for each of the deployments contemplated in these simulations, showing the increase of cost due to the incorporation of dedicated fixed RNs in the CODIV deployment.

Table 3-4: Increase of costs (CAPEX and OPEX) of CODIV deployment for urban scenarios

Expenditures	**Conventional deployment (19 BSs)**	**CODIV deployment based on the use of dedicated relays (19 BSs + 114 RNs)**	**Cost increase (%)**
CAPEX (K€)	2092.85	2446.25 (2092.85 + 353.4)	17
OPEX (K€ per year)	703	760 (703 + 57)	8

On the other hand, from a capacity point of view the results of the system level simulations presented in Section 3.1.3 and related to the average service throughput in terms of the number of users and cell size (repeated here in Table 3-5 and Table 3-6 respectively), showed that:

- Regardless of the number of users, the deployment based on the use of dedicated relays provided a better performance than the conventional deployment, although the improvement detected in the simulations was not so much significant, the maximum observed increase being 6% for the case of 100 users.
- The improvement of the average service throughput observed in the CODIV deployment for cell sizes equal or greater than 2000 m was quite significant, between 16% and 30%, while for 1000 m cell size the improvement was almost negligible around 1.5%. However the maximum throughput was reached in a cell radius of 1000 m with a value near 8.5 Mbps.

Table 3-5: Improvement in urban scenarios of average service throughput versus number of users for CODIV deployment compared to a conventional one

Number of users	**Increase of average service throughput for CODIV deployment (%)**
50	3.936
100	6.027
150	2.013
200	1.579
250	1.758
300	1.810

Table 3-6: Improvement in urban scenarios of average service throughput versus cell size for CODIV deployment compared to a conventional one

Cell size (m)	**Increase of average service throughput for CODIV deployment (%)**
1000	1.466
2000	20.664
3000	16.571
4000	35.659
5000	30.662
6000	27.556

So taking into account the capacity results coming from system level simulations, it seems that the improvement of performance noted for CODIV approach based on the use of dedicated RNs, depends mainly on the cell size, achieving a maximum increase in the average service throughput around 36% for a radius of 4000 m. Therefore, as long as the operator can get somehow more benefits with the increase of capacity in a deployment based on RNs than the additional costs (17% of CAPEX and 8% of OPEX per year), the CODIV solution will be more profitable than the conventional one. Of course, the way for getting more benefits will depend on the business model assumed by the operator. For example if the incomes are in terms of the bit rate provided to the final user (on-demand rate), the profits coming from the gain of capacity for a certain deployment (considering the foreseen users density and cell size) will have to be estimated, and then the benefits increase will have to be compared with the additional deployment costs in order to determine the more appropriate solution. In the case of business models based on flat rate, the decision would be more difficult since the profits are not directly related to the increase of capacity. In this case, other criteria such as user fidelity or possibility to obtain more users should be applied to find the best deployment for each condition.

Other interesting analysis could be as follows. Figure 3-7 shows the average service throughput versus cell size for conventional (19 BSs) and CODIV (19 BSs plus 114 RNs) deployments. As we can see in this figure, the average service throughput for a conventional deployment of 3 Km cell radius was about 5 Mbps, the same as for the CODIV deployment of 4 Km cell radius. If we assume that the number of BSs needed to reach the same throughput in a conventional deployment of 4 Km cell radius as for the case of 3 Km cell radius CODIV deployment is proportional to the ratio between the areas of these two deployments, we could compare the deployment costs of different solutions (conventional and CODIV) to achieve a certain target throughput which in our case is 5 Mbps. Assuming circular approach for the area of the cell, this factor would be around 1.77. So, in order to reach an average service throughput of 5 Mbps in a conventional deployment of 4 Km cell radius, we would need 1.77 times more BSs (19 x 1.77 ≈ 34 BSs) than in a conventional deployment with cell size of 3 Km (19 BSs). However this throughput can be also achieved with a CODIV deployment using 19 BSs and 114 RNs according to the results of the system level simulations. In short, Table 3-7 shows the total CAPEX and OPEX associated to each of the solutions (conventional and CODIV) for a deployment of 4 Km cell size with a target average service throughput of 5 Mbps, indicating the costs saving which could be achieved with the CODIV deployment based on the use of dedicated fixed RNs.

Table 3-7: Costs savings of CODIV deployment for 4 Km cell radius

Cost element	**Possible solutions for deployments of 4 Km cell radius and a target average service throughput of 5 Mbps**		**Costs saving (%)**
	Conventional (34 BSs)	**CODIV (19 BSs + 114 RNs)**	
Total CAPEX of deployment (K€)	3745.1	2446.25	34.7
Total OPEX of deployment (K€ per year)	1258	760	39.6
Total OPEX of deployment for net present value (k€) in 10 years	9813.42	5928.57	39.6

Concerning the other two metrics used in system level simulations, Table 3-8 and Table 3-9 show the percentage of unsatisfied users and Gini index respectively for conventional and CODIV deployments. As in the case of capacity, the CODIV solution provides more improvement for big cell sizes than short radius. The analysis to determine the best deployment strategy is similar to the previously performed and so as long as the increment of profits that can be derived for the reduction of unsatisfied users and best fairness (increase of Gini index), are higher than the additional costs due to the inclusion of dedicated RNs, the CODIV deployment will be more convenient than the based only on the use of BSs.

Table 3-8: Improvement in urban scenarios of percentage of unsatisfied users versus cell size for CODIV deployment compared to a conventional one

Cell size (m)	Percentage of unsatisfied users	
	Conventional deployment	CODIV deployment
1000	2	1
1500	3.5	2.5
2000	6	4.5
2500	9	5.5
3000	16	6.5

Table 3-9: Improvement in urban scenarios of Gini index versus cell size for CODIV deployment compared to a conventional one

Cell size (m)	Gini index	
	Conventional deployment	CODIV deployment
500	0.1	0.13
1000	0.12	0.17
1500	0.17	0.22
2000	0.21	0.26
2500	0.29	0.32
3000	0.32	0.39

In short, the question is to assess the economical benefits which can be derived by the improvement of performance (in terms of the defined metrics) achieved thanks to the additional investment in the CODIV case. It is clear that as long as the increment of benefits are higher than the increment of costs, as the next expression shows, the deployment based on the used of RNs could be more beneficial and interesting as compared with the conventional one.

$$\Delta\_Benefits > \left(\Delta\_CAPEX + \Delta\_OPEX\right)$$

4 Impact of CODIV techniques on business and deployment models

One should not neglect the tight interconnections between the business and deployment models implemented and adopted by a certain cellular network operator, sometimes being very difficult to analyze business models without taking into account the deployment models and vice versa. Anyway, the current chapter has been split in two parts; the first one devoted to highlight the main conclusions about the impact of CODIV techniques on deployment models, and the second one to review from the literature some business models outlining the foreseen impact of CODIV solutions on future business models of cellular network operators.

4.1 Impact on deployment models

In the previous WP2 deliverable **[D2.3]** we have discussed and analyzed the possible impact of CODIV technologies on planning and deployment methods, concluding that the integration of the cooperative techniques investigated and developed in CODIV on future WiMAX or LTE deployments will allow the possibility to increase the performance of the network, the capability to make an unplanned rollout, the improvement of the QoS (better and more fair), and significant cost savings. Also, we have pointed out some of the disadvantages of the integration of CODIV techniques based on relaying approach in future deployments such as more complex schedulers, increased overhead, difficulty to find suitable cooperative terminals, accommodation of extra relay traffic, an increase of extra end-to-end delay, and need to provide sufficient synchronization. All these issues should be taken into account when one performs a certain radio network deployment in order to make an impartial and fair comparison between conventional deployments and others based on the extensive use of cooperative techniques (i.e. fixed and dedicated relays, and/or relaying-able terminals).

As it was mentioned in **[D2.3]** already, the driven force for future deployment models is service-oriented (each of them with its own quality of service requirement), and the CODIV techniques integration will impact and lead to greater or lesser extent the modification of the planning process from the dimensioning of the deployment to the establishment of the final radio network plan. Here are repeated the deployment tasks where the CODIV techniques (mainly those based on the relaying approach) could have some impact:

- Pre-planning phase to establish the coverage and capacity plan according to the types of nodes or access points (BSs and RNs) available for the deployment.
- Site survey and site selection of the different network elements, identifying the more adequate position and type of node (BS or RN) for each of the sites included in the deployment. This will involve the estimation of the number of BSs and RNs needed for better performance.
- Interference analysis for the calculation of C/I values and implantation of frequency plan taking into account all the effects due to the integration of relaying devices (probably less interference level per element will be produced but more interferers are present). Note that power control functions are fundamental for interference analysis. Thus, for deployments based on CODIV techniques, the power control module should contemplate the lower levels of transmit power needed for the relaying approach proposed by CODIV.
- Parameter planning for the link and system level simulations considering the presence of relay nodes and multi-user MIMO strategies in the link budget calculation process as well as in the abstraction model used for the system level simulation. The link budget will compute the cell size for the most constraining service.

Concerning the multi-user MIMO techniques it is important to note that they have already been considered in advanced LTE systems and so it is envisioned that the MU-MIMO approach proposed in CODIV does not require important changes in future deployments. Nevertheless as was mentioned in **[D2.3]**, the particular RRM algorithms and criteria for clustering the more suitable terminals in the cooperative scheme considered in CODIV, could involve the modification of some parameters of the simulations carried out by the RNP tool and / or the integration of some module of this simulator as long as the RNP tool allows it. In other words, the MU-MIMO adaptation encompasses the algorithms/mechanisms used to dynamically select the receiving terminals and the spatial stream to be scheduled for them in the conditions of full spatial multiplexing on the same time-frequency resources.

Finally, it is important to note that in the next mobile communications generation (4G), it is envisaged that the cell radius of the base stations will be smaller than in previous generations, so the use of both relaying-able terminals and relay nodes could become an interesting solution to increase the coverage area as well as the capacity and the fair distribution of resources in the cell. Besides, the initial deployment of relays and cooperative techniques investigated and developed in CODIV for next generation of cellular networks will provide an important business opportunity from an operator point of view since the current cell sites could be reused by 4G base stations (LTE and WiMAX), keeping the requirements of coverage and capacity thanks to the implementation of these new devices and diversity cooperative technologies. Likewise as was explained in **[D2.3]**, RNs can be used in places where access to backhauling for micro or pico stations is not cost-effective (costs of wire line infrastructure or building restrictions), and they can be mounted on street furniture such as towers, poles, tops or sides of buildings, lampposts or any other location (e.g. vending machines). In the same way, depending on the class of operator, the deployment of RNs might be random as a method of network optimization (mature operators), or pre-planned (Greenfield operators). Definitively the use of RNs can be considerably cheaper than deploying pico/micro BSs as there are no extra costs for backhauling.

4.2 Impact on business models

This section is devoted to analyze the impact of CODIV techniques in current telecommunication business models.

4.2.1 Revision of business model components

In the following the main components of several business models for Cellular Network and Telecommunication Operators (CNTO) available in the literature are reviewed and analyzed.

The business model concept is becoming one of the important domains in the field of Information Technologies. The design and implementation of a business model for a CNTO is a complex and tough task since it requires multiple actors to balance different and often conflicting requirements **[Haa06]**. For this topic, it is clear that the main concern of any CNTO is to determine the optimal and most viable business model to meet the diverse goals for these operators.

The provisioning of new technologies such as the ones investigated within CODIV for the fourth generation cellular phone services has become one of the most important and exciting areas for research purposes as was outlined in **[Pan05]**.

In spite of the increasing emphasis in the literature on the importance of the business model on the success rate of the operator, there has been a lack of consensus regarding its definition and its components. In this respect, researchers in **[Kal06]** have depicted business models from different perspectives, proposing certain classification of business components as a basis on which to develop a more comprehensive definition in order to reach a consensus.

Another example of a business model analysis from literature was proposed in **[Van03]**, who argued that the business model for CNTOs consists of four main components. Figure 4-1 illustrates schematically these four pillars for the business model of any operator.

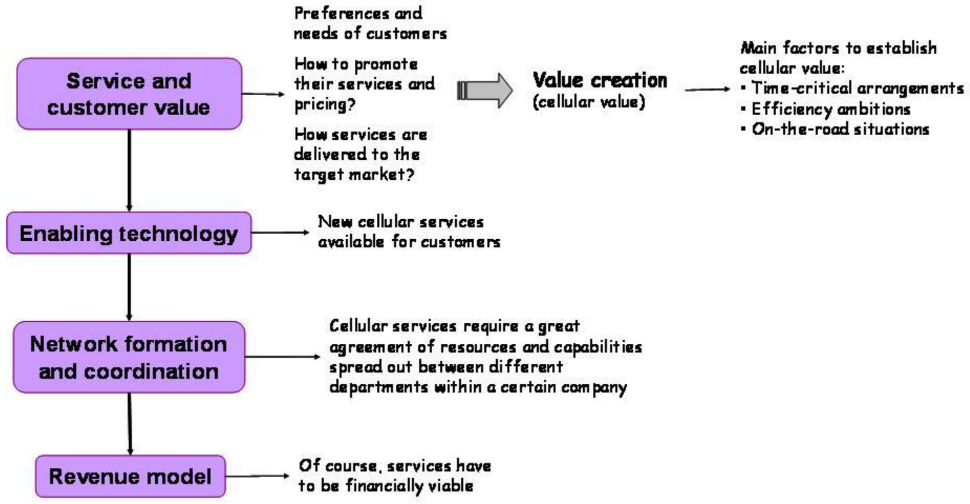

Figure 4-1: Main components of business model for CNTOs according to [Van03]

In a similar way the authors in **[Cam03]** suggest that the business model for CNTOs has the following four components:

- Value proposition. The manner in which a CNTO provides physical connectivity, access to other networks, and access to the internet for its customers.
- Target customers. Individual customers, businesses, virtual CNTOs.
- Core activities. For this component, three tasks are identified:
  1. Network promotion and contract management (customer service, invoicing).
  2. Service provisioning (service development and quality assurance).
  3. Infrastructure operation (network deployment, maintenance, management).
- Revenue flows. Subscription fees, transaction fees, volume-based fees.

In **[Tay06]** the business model for CNTOs is discussed, identifying four business model pillars: the value proposition (offered services), the technology solution (influences the price of the service), the cooperation platform (describes the cooperation among value network players) and the financial design (describes costs and revenues distribution among the value network players).

Other exploratory research in the business model topic is to define the critical success factors (CSF) that allow the operator to analyze the business possibilities. Typical CSFs usually contemplated by the operators are network coverage, capacity, reliability and interoperability. However for example researchers in **[Kal06]** focus the investigation on particular factors, that are conforming and shaping the emerging market of cellular data services, arranging them in internal and external factors as illustrated in Figure 4-2.

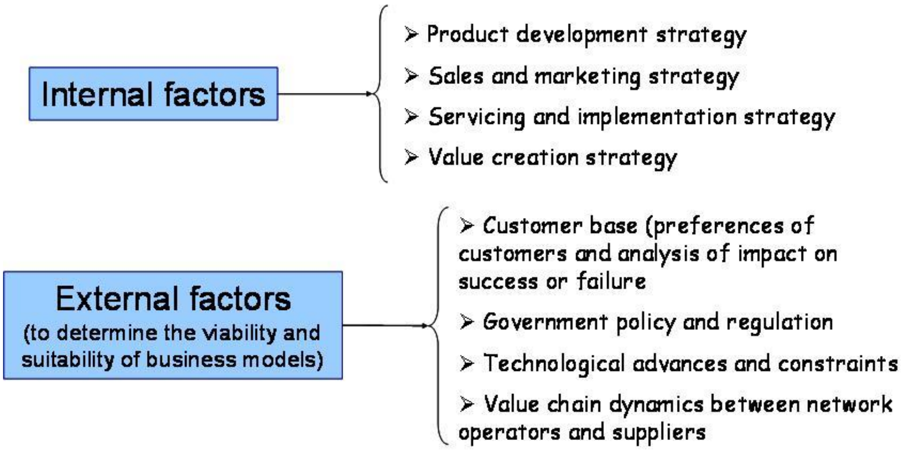

Figure 4-2: Factors shaping the emerging market of cellular data services according to [Kal06]

Finally in **[Mut08]** an attempt is made to align different approaches from literature which show somehow a fuzzy and inconsistent understanding of business models for technology companies. **[Mut08]** proposes a generic business model for CNTOs based on value proposition, value architecture, value network and value finance, as Figure 4-3 shows. It is important to note that these components are all interrelated with each other.

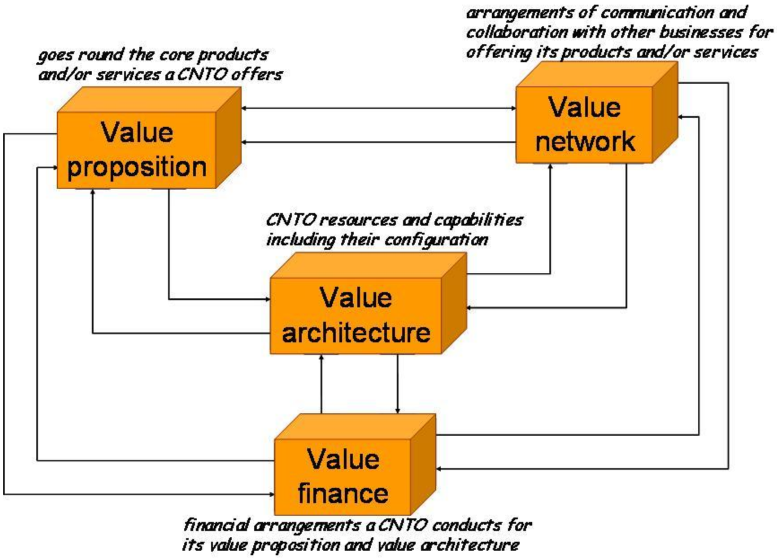

Figure 4-3: V^4 business model components according to [Mut08]

4.2.2 Particular case of CODIV techniques

The previous review of business models from the literature has provided a general vision of the main components or pillars in any business model adopted by cellular network operators. On the other hand the technical approaches investigated in CODIV will contribute to improve the capabilities and resources of the operator (value architecture) in terms of coverage, capacity and/or QoS. Therefore, the CODIV techniques will allow offering products and services (value proposition) with higher requirements so that the value finance of the operator could be increased. Of course, the decision to implement or not the cooperative solutions developed and proposed by CODIV project (dedicated relays, relaying-able terminals or MU-MIMO) will depend on the estimation of the cost efficiency (demand Mbps/cost) which could be reached with the different alternatives contemplated in a particular deployment.

For the particular case of the CODIV solution which is based on the deployment of dedicated relays (the approach with more important investment for the operator) the use of these new nodes will provide a valuable flexibility and may reduce the risk associated with high uncertainty about future demand. Besides, temporary use of relays may be economically viable, especially when the costs for backhaul transmission is a significant part of the total cost of a new BS. In other words, economic gains with the deployment of relay nodes could be obtained because operators may postpone investments in the backhaul transmission lines.

Other important consideration regarding the CODIV solution based mainly on the use of dedicated RNs is that usually the operators think of incremental network deployment for their business models according to the predicted traffic demand increase, and so it is likely that this technical solution impacts to a great extent in the comparison process of the investment needed to achieve a new performance target. Therefore, the CODIV techniques should be considered when the operators have to estimate the cost of providing services not contemplated in the first roll-out as well as the timing of the decision to increase the performance of the actual network with different technologies (i.e. cost, quickness and ease of conventional solutions adding more BSs or deployments using CODIV solutions). Besides, one should take into account that the best suited solution will depend greatly on the particular characteristics of the deployment, and the cost structure of the diverse competitive solutions may be quite different, changing considerably the business case.

It is obvious that there is always a trade-off between the installation / maintenance costs needed to assure a certain QoS, and the revenue coming from the customers. Another of the technical approaches of CODIV proposes the use of terminals in idle status as relay nodes in order to improve the connectivity of the active terminals without the necessity to install more infrastructures. Note that the reticence of the users for letting their terminals being used as relays comes mainly from the battery autonomy and security issues. Among the different alternatives studied in literature (**[But03]** and **[Jak03]**), the most promising solution for the reticence problem of the customers is to consider a given subscription discount for users who accept to relay traffic to other users.

The incentive mechanism proposed for CODIV solution based on relaying-able terminals is aligned with the one developed and investigated in **[Pat05]**, and it consists simply of providing certain subscription discount to those customers who accept to transfer packets from other terminals.

The price deduction could be fixed or variable depending on the traffic amount relayed from other users. Regardless of the type of fee discount, the main issue here is to estimate for a particular deployment, the economy in terms of CAPEX and OPEX due to the implementation of relaying-able terminals, and then to determine the optimal price deduction which can be offered to the cooperative users in order to improve the net benefit of the operator in charge of the deployment. In short, the saving produced in terms of installation and maintenance costs should exceed the reduction of income because of fee discounts necessary for persuading at final customers to let their terminals being used as relays for other users. This way, the areas not covered in a conventional cellular deployment can be included, providing the operator an additional benefit if the possibility of relaying-able terminals is contemplated and offered. So, the technical approach developed by CODIV based on the possibility of UTs serving as relays in future cellular networks (i.e. LTE and WiMAX) is a solution that the operator in charge of the deployment should seriously consider in the dimensioning phase of its network.

CODIV solutions as emerging cellular technologies for future radio network deployments (LTE and WiMAX) will make possible the availability of new cellular services for customers, opening the door to new opportunities of business. In short, CODIV technologies will mainly influence in the accessibility or the ability of customers for accessing the offered services thanks to the deployment of dedicated relays, cooperative terminals and MU-MIMO techniques.

5 Conclusions

Since the analysis of the integration of CODIV techniques in radio resource planning was developed and explained in the previous deliverable of WP2 **[D2.3]**, the current document has been focused on the analysis of the predicted impact and possible influence of these cooperative technologies on the business and deployment models associated to the radio network operators. In order to fulfil this objective, the economic impact for the different technical solutions contemplated in CODIV (relaying-able terminals, dedicated relays and MU-MIMO strategies) has been analyzed, emphasizing the business opportunities of CODIV solutions on future business models for LTE and WiMAX deployments. Likewise, taking into account the results of the system level simulations performed within WP5 for deployments with dedicated relays in urban scenarios, the benefits in terms of deployment costs have been estimated, comparing the performance and costs of conventional and CODIV deployments. As a result of this work, the main conclusions of the final WP2 deliverable about the impact of CODIV techniques on business and deployment models are summarized in the following points below:

- The performance improvement in terms of average effective throughput and coverage extension observed in the simulations according to LRIC models of deployments based on the cooperative-able terminal approach of CODIV, may lead to the service provider to develop new bandwidth-consuming services and increase the competitiveness of an operator in mobile broadband services.
- The incentive mechanism proposed for CODIV solution based on relaying-able terminals consists in providing certain subscription discount for those customers who accept to relay/transfer packets from/to other terminals.
- Smart deployment of dedicated relays will allow also to lower deployment CAPEX and operational cost. Depending on the objective of the radio network planning, relays must be placed by the edge of the cell (coverage increase) if the SNR at the end-user receiver is not high enough to permit the use of the most efficient modulation schemes, or by the edge of spatial regions where the system uses more complex modulation mode (throughput increase) so that the SNR at the end-user receiver may use the most efficient modulation scheme.
- Although initial technological innovation may cause the relay node cost to be higher than the cost of the equivalent BS in terms of transmitted power, it is foreseen that the relay node cost in the long term will be lower if they are widely adopted, due to the lower complexity of the node and cost saving in the wired line backhaul.
- In case of spectrum bandwidth scarcity for a given level of demand in areas with certain traffic density, CODIV approach based on the use of MU-MIMO techniques will allow a better spectral efficiency and it may prevent the operator from growing the number of sites, due to the high costs of site acquisition and maintenance.
- If MIMO is included in a standard, the incremental cost of considering CODIV multi-user MIMO would be substantially lower since BSs and potentially user terminals would fit MU-MIMO hardware requirements.
- The cost analysis of relay-based deployments is a fundamental issue to decide when and where the use of different kinds of relays can be advantageous and profitable in terms of performance and/or costs.
- The analysis of the performance and cost of the urban scenario used in the system level simulations performed within WP5 has shown that as long as the additional costs due to the inclusion of dedicated RNs are lower than the profits derived by the improvement of the

performance (in terms of capacity, reduction of unsatisfied users and fairness), the CODIV deployment will be more convenient than the one based only on the use of BSs.

- Assuming that in 4G systems the cell radius of the base stations will be smaller than in previous generations, the initial deployment of relays and cooperative techniques investigated and developed in CODIV could provide an important business opportunity from an operator point of view since the current cell sites could be reused by 4G base stations (LTE and WiMAX), keeping the requirements of coverage and capacity thanks to the development of new devices which incorporate diversity cooperative technologies.
- The technical approaches investigated in CODIV will contribute to improve the capabilities and resources of the operator (value architecture), making easier to provide new products and services (value proposition) with higher requirements so that the financial value of the operator could be increased.

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