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Abstract

This deliverable presents the initial results from the system level simulation of two technical components (Centralized multi-cell scheduling and Component carrier management) and the qualitative techno-economic studies. The simulator is developed to reflect the network and user conditions envisaged in the two technical components and the initial results indicate the likely gains from these. Four use cases (Automotive, Smart city IoT, Long range connectivity and NTN for disaster and emergency communications) are covered in the techno-economic analyses and the C-RAN centralization themes adapted from 3GPP are used to model these deployments. The main cost factors are discussed in detail, laying the groundwork for future work in quantitative studies.

Keywords

5G, Cloud RAN Component Carrier, Drone based communications, Long range connectivity, Multi-cell scheduler, System Level Simulator, Smart cities, Techno-economic analysis

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[1] CO = Confidential, only members of the consortium (including the Commission Services)

PU = Public

Executive Summary

This deliverable from the WP2 (System Requirements, Integration, and Evaluation) of the ONE5G project contains the initial results from the system level simulation of selected technical components (from WP3 (End to End multi-service performance optimization)) and the qualitative techno-economic analysis of selected use cases. The work here reflects the major part of the research and development effort from WP2 in the first year of the project.

A system level simulator is developed as to be compatible with the 3GPP Release 14 and 15 as a baseline and then to be capable of demonstrating the combined gains of selected technical components from WP3 and WP4 (Multi-antenna access and link enhancements). The features and functionality of the simulator are outlined here, with complete details made available in the previous WP2 report IR2.1. Two technical components (TeCs) from WP3 have been selected for evaluation and reported here with some initial results. Full details of these TeCs are available in the recent D3.1 deliverable. The outline of these TeCs is as follows:

- Centralized multi-cell scheduling
  The heterogeneous multi-cell layout is considered as a super cell and the radio tasks above the MAC layer (including scheduling) are conducted by a central unit (CU). This CU will contain a scheduler, which will develop a 3D Table containing all the Channel Quality Indicators (CQIs) reported by the users to the respective multiple cells which it can potentially connect to. The scheduler will allocate cells and resources to the active users in a proportional fair (PF) manner on a sub-frame resolution. Two modes of random access to request resources from either the Macro cell and/or small cell(s) are considered in this heterogeneous cell layout. The fairness of the scheduling is ensured by considering the average throughput values from the reported CQI instances.

- Component Carrier (CC) management
  The dynamic assignment of multiple component carriers to the users is considered, as an extension to the dual connectivity concept. The assignment is governed by input parameters including network conditions, service category and UE context information. Both enhanced Mobile Broadband (eMBB) and Ultra-Reliable and Low-Latency Communications (URLLC) services are enabled, with CC manager focusing on data aggregation for eMBB and data duplication for URLLC. The CC manager will compute a score for each carrier per each active user based on the above input parameters. The dynamic assignment is based on this score.

The system level simulator is configured to truly reflect the conditions considered in the TeC development in WP3. Further 4 TeCs from both WP3 and WP4 will be evaluated with the simulator in the project’s second year. The first results presented here only consider the TeCs in isolation and only for eMBB data, but combined analysis will be developed in the second year to reflect the potential overall gains from these TeCs and different data types. The initial results for the centralized multi-cell scheduler show significant increases in downlink for both the average throughputs per user and per km2 area with the proposed scheme, when compared to round-robin scheduled default scheme. Also the use of PF scheduler elements ensures that notable percentages of low CQI users are captured even with high user densities. The initial results for the CC manger demonstrate that for a dual connectivity system the downlink average user throughputs remain similar with the proposed scheme, but the average latencies are significantly reduced.

The simulation results also contain validation results for the test cases of eMBB, massive Machine-Type Communications (mMTC) and combined URLLC/mMTC traffic types. The appropriate traffic models (as discussed in IR2.1) have been utilized in generating these results. This validation work demonstrates that the simulator can handle any type / combination of traffic types to reflect 5G advanced scenarios.

The second part of the deliverable is dedicated to the techno-economic analysis of four selected use cases. These use cases are selected from the total of nine developed use cases by WP2 (as reported in D2.1) to fairly reflect the Mega cities and Underserved areas scenarios and the 3 services types (eMBB, URLLC and mMTC). The qualitative analyses provided in D2.2 for the selected use cases can be summarized as follows:

- Assisted, Co-operative and Tele operated driving:
  To support the strict requirements in latency, reliability and availability in this use case, the deployment of dedicated Multi-access Edge Computing (MEC) nodes at the network edge are considered. The deployment costs depend on the architectural model (Distributed Radio Access Network (D-RAN) or C-RAN options) envisaged and these options are discussed in line with the 3GPP developments.

- Smart cities
  This analysis will consider large scale, non-time critical MTC type applications for city wide deployments – in line with NB-IoT and LTE-M standards. The technical capabilities supported by NB-IoT and LTE-M standards are discussed. The deployment of these technologies would necessitate only a software upgrade to existing LTE networks, making many of the traditional deployment costs non-relevant. The options for sharing the OPEX with the eMBB services once an MTC network is deployed are also discussed, with more in-depth analysis to follow in D2.3.

- Long range connectivity in remote areas
  The technologies and associated costs in providing 5G connectivity (voice and some basic data services) to the rural and remote areas are discussed. These technologies focus on increasing the cell coverage footprints from 50 km up to 100 km cell range and include increasing the tower mast height, greater number (up to 18) of sectorisations, higher diversity with 4 vertically positioned antennas and MIMO configurations.

- NTN for disaster and emergency communications
  A rapidly deployable drone based 5G communication service is proposed for supporting emergency crews in localized incidents. Selected 5G and 4G small cells (on the ground) will be equipped to provide the fronthaul relay capability for these drone RRHs. The main deployment costs, incremental costs of provisioning fronthaul and backhaul with C-RAN architecture options and the spectrum usage costs are discussed.

While the four use cases are analyzed quite independently in this first stage of the techno-economic study, we aim to align them through the common threads in the second year, leading to D2.3. One of these common areas is the network centralization options (C-RAN) as per the recommendations of 3GPP. We plan to explore similar C-RAN options, which will enable us to evaluate comparable costs for these different use cases and also explore the possibilities of supporting these multiple use cases through a common network employing network slicing.

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Acronyms and Abbreviations

3GPP	Third Generation Partnership Project	**MIMO**	Multiple Input Multiple Output
5G	Fifth Generation	**mMTC**	Massive Machine Type Communication
ARPU	Average Revenue Per User	**mmWave**	Millimeter wave
BBU	Base Band Unit	**NB-IoT**	Narrow Band Internet of Things
CA	Carrier Aggregation	**NGMN**	Next Generation Mobile Network
CAPEX	Capital Expenditure	**NOMA**	Non Orthogonal Multi-Access
CC	Component Carrier	**NFV**	Network Function Virtualization
CCM	Component Carrier Manager	**NR**	New Radio
CQI	Channel Quality Indicator	**OSS**	Operations Support System
C-RAN	Centralized Radio Access Network	**OPEX**	Operational Expenditure
CU	Centralized Unit	**PAL**	Priority Access Licenses
CoMP	Co-ordinated Multi-Point	**PDCP**	Packet Data Convergence Protocol
CP	Control Plane	**PF**	Proportional Fair
D-RAN	Distributed Radio Access Network	**PHY**	Physical layer
DU	Distributed Unit	**PRB**	Physical Resource Block
E2E	End to End	**QoE**	Quality of Experience
EC	European Commission	**RAT**	Radio Access Technology
eMBB	Enhanced Mobile Broadband	**RBG**	Resource Block Group
eNB	evolved Node-B	**RLC**	Radio Link Control
ESN	Emergency Services Network	**RRM**	Radio Resource Management
FH	Fronthaul	**RRC**	Radio Resource Control
Fe-MTC	Further enhanced Machine Type Communication	**RRH**	Remote Radio Head
Fe-NBIoT	Further enhanced NB-IoT	**RRU**	Remote Radio Unit
FD-FDD	Full Duplex - Frequency Division Duplexing	**RSRP**	Radio Signal Received Power
FTP	File Transfer Protocol	**RSU**	Road Side Unit
GAA	General Authorized Access	**RU**	Remote Unit
gNB	5g Node-B	**SAS**	Spectrum Access Systems
GPP	General Purpose Processor	**SINR**	Signal to Interference plus Noise Ratio
GUI	Graphical User Interface	**SLS**	System Level Simulator
H2020	Horizon 2020	**SoTA**	State of The Art
HD-FDD	Half Duplex - Frequency Division Duplexing	**TCO**	Total Cost of Ownership

ICT	Information and Communication Technologies	**TeC**	Technical Component
IP	Internet Protocol	**TETRA**	TErrestrial Trunked RAdio
KPI	Key Performance Indicators	**TTI**	Transmit Time Interval
KQI	Key Quality Indicators	**UC**	Use Case
LPWA	Low Power Wide area Access	**UE**	User Equipment
LSA	Licensed Shared Access	**UP**	User Plane
LTE-M	Long Term Evolution – Machine Type	**URLLC**	Ultra Reliable Low Latency Communication
MAC	Medium Access Control (layer)	**V2X**	Vehicle to Everything
MC	Multi-Connectivity	**WP**	Work Package
MEC	Multi-access Edge Computing		

1 Introduction

The ONE5G project aims to provide innovative solutions to move the current baseline of 5G SoTA to '5G Advanced', covering all 3 pillars of eMBB, URLLC and mMTC service categories. The System Level Simulation (SLS) based evaluation of the technical components (TeCs) developed in the project and the techno-economic analysis of selected use cases are important stepping stones to achieve this objective. The simulator used in the SLS, when fully developed, will capture the overall performance gains when the selected TeCs are implemented together, over a baseline 3GPP release 14/15 system. The techno-economic analysis will look at critical deployment aspects for the selected use cases, with some '5G-advanced' network features. This deliverable documents the initial results from these two work areas, covering the first year of the project.

The technical work packages of the project (WP3 and WP4) have proposed a total of 6 TeCs to WP2 for SLS based evaluation. This deliverable details the simulator developments to support 2 of these TeCs and the initial results from these simulations. Also, the simulation results from the individual and combined eMBB, URLLC and mMTC test cases are presented, showcasing that the simulator is capable of handling the technical complexities of the 5G service categories. The initial simulation results are presented independently for each of the TeCs. In the second year of the project we'll aim to evaluate the combined gains from multiple selected TeC based simulations.

The techno-economic analyses cover four use cases (out of 9) developed by WP2 earlier in the project. The use cases are selected to represent two main scenarios (Mega cities and under-served areas) and the eMBB, URLLC and mMTC service categories in equal measure. These use cases are analyzed qualitatively, aligned to the current developments in the 3GPP and commercial network domains. The analyses include the architectural options (in line with 3GPP) and the main cost factors for these individual use cases. During the second year, full quantitative analyses will be provided, with commonalities through the centralized (C-RAN) implementations highlighted.

The remainder of this deliverable is structured as follows. In chapter 2, the basic outline of the system level simulator is provided (full details are presented in IR2.1 [ONE18-IR21]). Then overviews of the two selected TeCs are presented (again, full details available in D3.1 [ONE18-D31]), leading to the initial simulation results from individual evaluations. The two selected TeCs are both from WP3, with higher layer impact. The first is a centralized multi-cell scheduler and the second is a Component Carrier manager for multi-connectivity deployments. Simulation results for eMBB, mMTC and combined URLLC/mMTC test cases are also provided, mainly to illustrate the functional capabilities of the simulator.

In chapter 3, the qualitative techno-economic analyses are presented. The use cases of Assisted, co-operative and tele-operated driving (Automotive), Smart cities based non-time critical communications, Long range connectivity provision and Drone based communications for disaster and emergency services are covered. C-RAN based architectural options are considered explicitly for the Automotive and Drone based use cases and it is expected that as the other use case centered analyses develop further, these C-RAN options will be taken up by them as well. 3GPP architectural split options are considered, where the associated cost models are taken from previous work in the mmMAGIC project [mmM17-D14].

Chapter 4 provides the conclusions from the two study items and also looks into the future related work for the second year of the project.

2 Simulator overview and initial simulation results

2.1 Simulator overview

System level evaluation through simulations needs to take into account different aspects related to configuration, environment models, network (simulated system) models, analytics and event handling. All of these are accessible in a user-friendly graphical user interface (GUI). The structure is illustrated in Figure 2-1 and the components are described as follows. The figure is a high-level representation of the aforementioned components without showing further details, since these components are analysed in dedicated sections of ONE5G Internal Report 2.1 [ONE18-IR21].

Environment models and configuration: A first step of system-level simulations is to specify the simulated system (i.e., define the considered parameters), designate the environments and select analytics. Environment concerns aspects related to traffic (e.g. proper modelling of eMBB, mMTC etc., anticipated load, mobility and radio conditions (e.g. propagation models). The aforementioned parameters and details have been reported also in the project’s deliverable [ONE18-IR21]. This is triggered by the fact that project use cases deal with megacities and underserved areas and as a result, different traffic characteristics apply depending on the use case. Such aspects will be properly documented for the considered use cases in order to consider them in the simulations later on.

Network/ Simulated System models: System aspects include network deployment (e.g. small cells and macro cells for use cases in underserved and megacities). Also, spectrum aspects are considered for utilization of bands below 6GHz and to be expanded in mmWave as well. For instance, which bands are allowed to be used, how many channels, bandwidth etc. Abstraction of PHY/MAC is taken into account and Radio Resource Management (RRM) algorithms are also considered.

Analytics: The simulation results will be evaluated against the Key Performance Indicator (KPI) targets (e.g. in terms of throughput, latency). The results are analyzed and visualized. KPIs are carefully elaborated in WP2 as well as related standards. Key Quality Indicators (KQI) are also studied in the context of WP2 and WP3 in order to offer a framework to reflect objectively the service performance and quality, inherently from an E2E perspective.

Event Handling: An event may be distinguished by time, location, type (e.g., session set up, call request, packet transmission), services, devices, users and supplementary info. Details on event handling are provided later on in this document.

Graphical User Interface (GUI): A user-friendly GUI is essential for easy handling of simulations and demonstrations. The GUI consists of user friendly tabs, text boxes and input fields in order to create an easy to use environment for data input as well as extraction of results by visualizing results in graphs and charts.

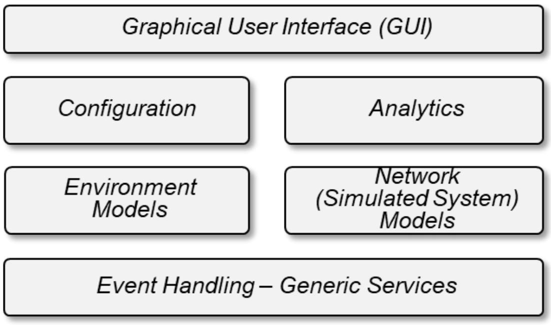


Figure 2-1: Overall features of system level simulation platform.

2.2 Evaluation methodology approach

The defined scenarios and use cases as described in the project’s deliverable [ONE17-D21] provide the essential information for building environment models and KPI targets. Technical components are developed in WP3 and WP4 and indicate promising performance gains. In the first phase of the development of the technical components in WP3 and WP4, initial evaluations via system level simulations are performed. Then and finally, in the second phase, comprehensive system level simulations are conducted in the context of WP2 to analyse in more details focused technical components, which are being developed in achieving its technical goals and KPI targets. The aforementioned approach is depicted in Figure 2-2.

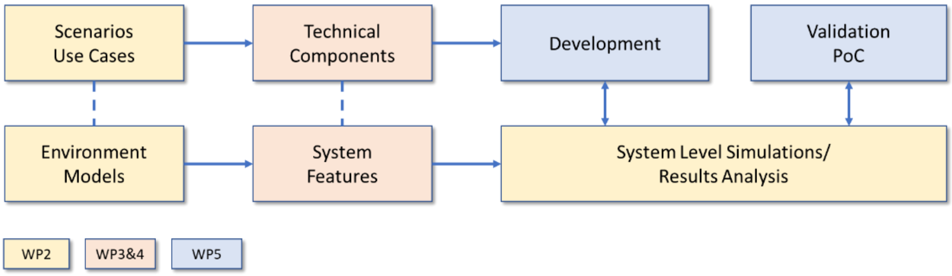


Figure 2-2: Evaluation methodology approach.

2.3 Focused technical components

This section presents a brief overview of the considered technical components related to centralized multi-cell scheduling as well as Component Carrier management. In the following subsections ,we present a brief description of the focused components. Further details are provided in the relevant subsections in D3.1 [ONE18-D31] and D4.1 [ONE18-D41]. In this section, we mainly focus on the modelling aspects of the components in order to integrate them in the 5G system-level simulator and produce the related results.

2.3.1 General modelling considerations for the system level simulations

In order to proceed to system-level simulations, it is essential to model the main functionality of the technical components based on certain specifications. Figure 2-3 illustrates a functional overview for discrete event handling and more specifically by assuming the simulated serving areas $i \dots N$ with a set of traffic sources (e.g. eMBB, mMTC, URLLC –depending on the scenario) in which extracted events are handled by a macro cell serving area i. Initially, the simulated UEs are attached to their nearest macro cells. Message requests are generated by UEs at certain points of time based on the traffic model. A decision making mechanism designates the assignment of the UE to nearby small cells. Depending on the type of scenario or the technical component we intend to evaluate, each small cell will prioritize the transmissions and schedule the most important ones. The centralized scheduler as described in subsection 2.3.2 will be provided, or simpler Round Robin scheduler can be utilized.

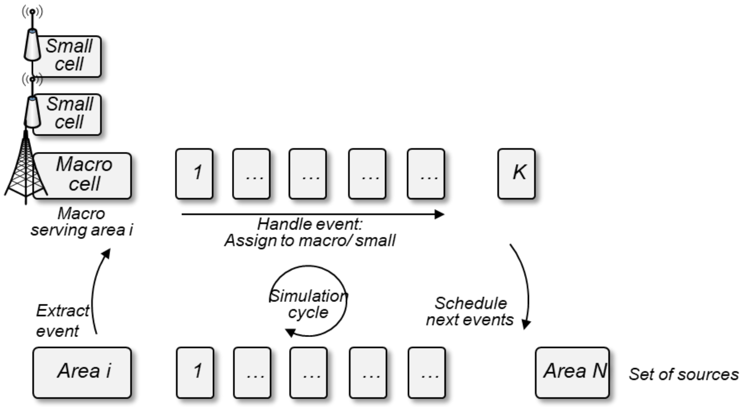


Figure 2-3: Functional overview for event handling

2.3.1.1 Scheduling

Specific input/output parameters are taken into account for scheduling algorithms (Figure 2-4). In each cell, the scheduling process is executed in each Transmission Time Interval (TTI) (1ms). Scheduling algorithm inputs are:

- Available Physical Resource Blocks (PRBs) per TTI.
- Scheduling requests (in a queue sorted based on the time the request arrived in the queue)
- User request message size (in bytes)
- User request priority (based on the assigned service type): the priority of the request (if it exists)
- Resource Block Group (RBG) Size: minimum number of PRBs that can be assigned in each user
- Maximum PRB allocation per user: maximum number of PRBs that can be assigned in each user
- Effective bandwidth per PRB calculated based on SINR and spectral efficiency curves
- Available carriers
- CQI

The outputs are:

- Number of assigned PRBs per user
- Position of each assigned PRBs into the subframe (1ms)

The system-level simulator, supports 3 types of scheduling: a) Round Robin; b) Priority Scheduling; c) Scheduling based on Spectrum Access System (SAS) as described in the subsections that follow.

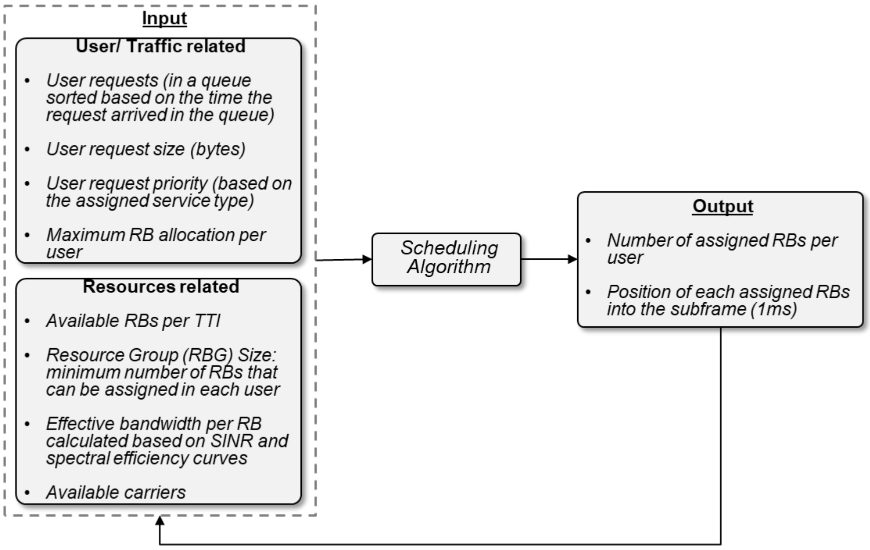


Figure 2-4: Scheduling input/output

2.3.1.1.1 Round Robin algorithm

Initially, we assign PRBs to the first N users in the queue. N = min {Number of users, Available PRBs / Resource Block Group (RBG) Size}. If the required PRBs for a user are less than the initially assigned, then the extra PRBs are assigned to other users. This is realized by marking the user which needs more PRBs, and in the second iteration the unassigned PRBs are assigned to these users. The algorithm terminates if there are no available PRBs or all the requests from the N users are fully satisfied.

2.3.1.1.2 Priority scheduling algorithm

All the users are sorted in the request queue based on their priority (highest priority users go first). Then the algorithm makes a first assignment by taking into consideration only the first priority users. The assignment of PRBs among the first priority user is realized using the aforementioned Round Robin algorithm applied only for the first priority requests. If there are available PRBs after this first round of assignment, then the algorithm continues with the second priority users, using Round Robin and then third priority, and so on.

2.3.1.1.3 Scheduling based on Spectrum Access System (SAS) algorithm

Each base station is able to acquire information about the spectrum bands, channels and UEs and choose which band can be selected at any time either by utilizing licensed or unlicensed channels or by selecting the 3.5GHz band. Then, the SAS mechanism is enabled in order to provide information about the availability of channels and select the proper channel. In addition, after the step resulting in a 3.5 GHz channel being utilized, the algorithm will keep checking for any information about the channel that is given to a specific tier. In particular, the Priority Access Licenses (PAL) and General Authorized Access (GAA) users may receive instructions to change channel (or even band if no channels are available) whenever a higher tier user needs to use the specific channel.

Apart from the aforementioned scheduling algorithms, ONE5G has proposed also a centralized multi-cell scheduling technical component as described in the following section.

2.3.2 Centralized multi-cell scheduling

2.3.2.1 Overall description of the component

The basic idea of the Centralized multi-cell scheduling is that a “super-cell” being managed by a Central Unit (CU) will perform all the radio tasks above the MAC layer corresponding to the different cells. This CU will perform all the scheduling decisions and allocate the users to the resource blocks and RU where the channel conditions are the best by taking advantage of the CQIs reported by the users. More details can be found in D3.1 [ONE18-D31].

Using channel conditions represented by CQI values, the centralized multi-cell scheduler will create a 3D-table populated with Proportional Fair (PF) metrics that it will be used to schedule users at the available sub-bands and RUs. The 3D-table contains the metrics from all the crossing links, i.e. from each UE to each RU. Thethe centralized scheduler will rely on this table to decide which RU has to transmit to a certain UE at some certain sub-bands in every subframe, TTI – 1ms.

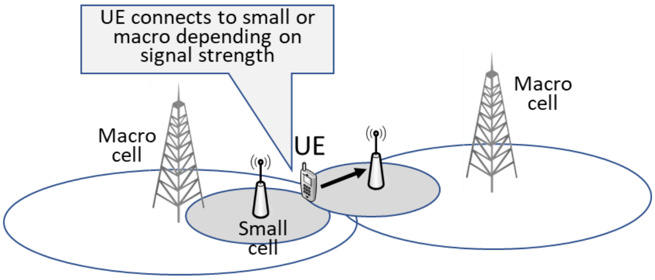
In order to be more flexible, the centralized multi-cell scheduler allows frequency reuse by means of applying techniques such as Coordinated MultiPoint (CoMP) and Non-Orthogonal Multiple-Access (NOMA). These techniques are not considered in the current evaluation of this deliverable. The occasion to apply these techniques is controlled by a threshold that the SINR values between different RUs must fulfil at certain sub-bands, and by the cluster size which limits the maximum number of RUs which can be coordinated.

2.3.2.2 Modelling considerations for the system level simulations

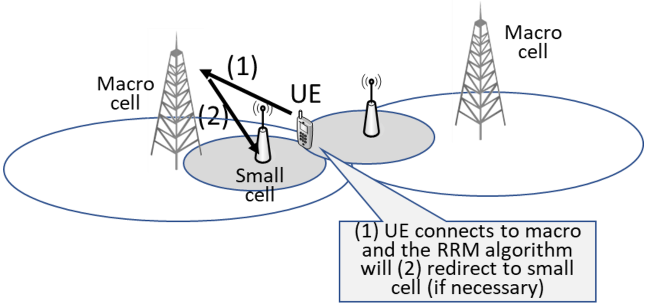
Apart from the general modelling considerations for the system level simulations, we have proceeded to modelconsiderations for specific technical components. For the evaluation of this technical component two modes of operation for random access process are assumed. Mode 1 assumes that the UE selects a cell according to signal strength and the generated event is handled by the cell. Mode 2, assumes that the UE initially goes to the macro cell which acts as an event handler. The macro cell then decides which cell (macro or small) to handle the events.

- Request is generated by UE at time t_1 and location (x, y)
- At time t_2 (new TTI), the UE will be attached to a macro cell and assigned to a small cell
    - Each cell will schedule the transmissions according to the used scheduler.
- At t_2, the next request generation of UE will be scheduled (according to the traffic model)

Figure 2-5 illustrates the aforementioned functionality.



(a)



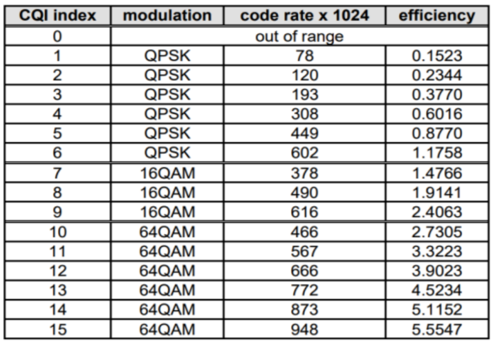
(b)

Figure 2-5: Illustration of (a) Mode 1 and (b) Mode 2

2.3.2.2.1 CQI estimation and PF

There is a modeling for the mapping of efficiency to CQI based on the 3GPP table in [3GPP-36213], as illustrated in Table 2-1 and Figure 2-6. In order to provide a CQI value and proceed to the selection of cells according to the methodology considered in the technical component, we use the SINR value which is provided by the simulator and map it to a spectral efficiency value, based on [3GPP-36942]. Then, the efficiency value is mapped to a specific CQI according to [3GPP-36213] in order to select the best possible values as per Table 2-1. In order to provide a CQI value and proceed to the selection of cells according to the methodology considered in the technical component, we use the SINR value which is provided by the simulator and map it to a spectral efficiency value, based on [3GPP-36942]. Then, the efficiency value is mapped to a specific CQI according to [3GPP-36213] in order to select the best possible values.

Table 2-1: CQI Table based on 3GPP TS36.213



CQI index	modulation	code rate x 1024	efficiency
0	out of range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

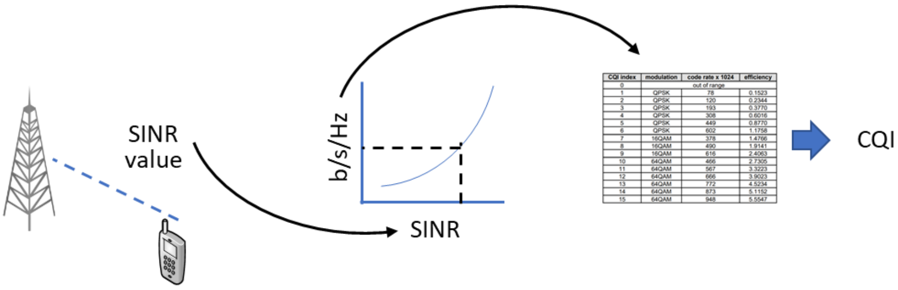


Figure 2-6: CQI estimation

Furthermore, the centralized multi-cell scheduling algorithm applies PF metrics based on CQI measurements which are used as input to the considered algorithm for multi-cell scheduling which is described in [ONE18-D31] and also taking into account, besides the achievable throughput (get from CQIs), the average throughput of an user. This is important, since the proposed approach is not to penalize the users which have not so good channel conditions, and make them eligible in some sub-frames.

2.3.3 Component Carrier management (MC & CA)

2.3.3.1 Overall description of the component

Several techniques for component carrier management have been proposed, each of them following different criteria [WAN10, LEE17]. The most immediate research line could be the load balancing among component carriers. In the same way, dual connectivity has been addressed in recent works, showing its advantages and capabilities in different scenarios [ROS16, LEM16], for example, regarding its ability to reduce radio link failures given a fast-moving UE. Finally, some recent works propose addressing multi-connectivity through the 3G concept of active set management [TES16]. However, in these works, only the radio channel conditions are considered as their input for the component carrier management.

The aim of this work is to dynamically assign Component Carriers from multiple (more than two) nodes (extending dual connectivity) according to the network state (e.g., network load or coverage hole), as well as the service category and context information. In this study, only eMBB and URLLC are considered (i.e. ONE5G use cases no. 2, 5 and 6 [ONE17-D21]) and managed in a different way considering their different requirements. For URLLC, the reliability will be addressed through data duplication. For eMBB, given its need for higher throughput, a data aggregation scheme will be followed. To this end, a Component Carrier (CC) manager is proposed to determine the number of carriers to be assigned to a user, as well as the carrier indices and the source nodes, and flow. Different types of inputs are considered, such as: (a) metrics reported by the user, like the Reference Signal Received Power (RSRP); (b) metrics from the carriers (like their load); (c) metrics from end-to-end information (like throughput or latency) and (d) information from the context (like the user position). Based on these inputs, the CC manager computes a score for each of the available carriers indicating the carrier suitability for a specific user. This score can be computed in different ways depending on the target criterion (e.g. if a load balancing approach is followed, those CC with a lower load will receive a higher score).

2.3.3.2 Modelling considerations for the system level simulations

2.3.3.2.1 Component Carrier management

For this technical component, the following modelling considerations are taken into account. Each base station has a set of Component Carriers. Component Carriers have schedulers for handing packets. Each packet may be split intoportions in order to be handled by different Component Carriers (dual-link or multi-link approach), depending on the links that a UE has established with available Component Carriers. Figure 2-7 illustrates the aforementioned considerations with respect to Component Carrier modelling.

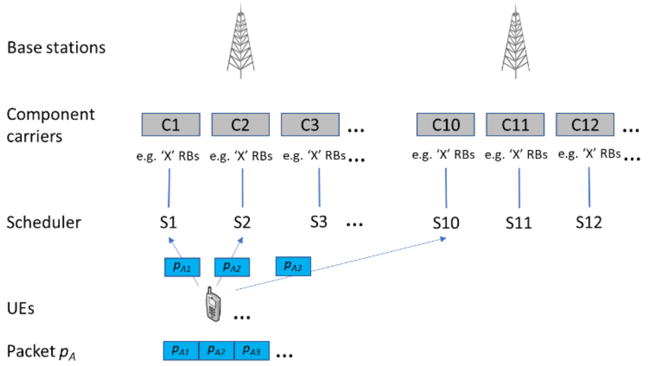


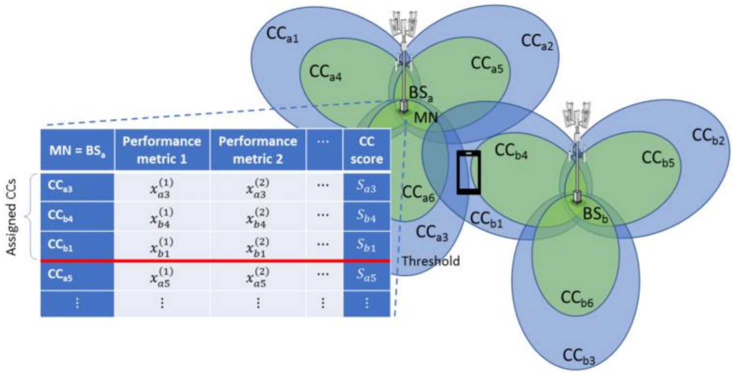
Figure 2-7: Component carrier management modelling aspects

The CC manager aims at determining:

- The number of CCs to be assigned to a UE. In general, a higher number of CCs for a given user implies enhanced performance, i.e. higher throughputs or higher values of reliability.
- The carrier indices. In order to fairly share the time and frequency resources among the different users, as well as to fight time-varying fading effects, each user is assigned not only a number of CC, but also its absolute radio frequency channel number.
- The specific usage of the CCs that were assigned. In principle, carriers for eMBB users will be used to aggregate and increase their accessible bandwidth, whereas carriers for URLLC users will be used to add redundancy in the form of carriers holding a duplicated data flow.
- The source nodes providing the CCs.

A score is periodically computed for both the CCs managed by a node and those managed by its neighboring nodes, where each score stands for the suitability of a CC according to previously defined network experts' policies. For these scores to be computed, several sources of performance information are used. The current physical location of the CC manager (CCM) depends on the network architecture. In case that a centralized radio access network (C-RAN) is deployed, the CCM will be located at the baseband unit (BBU), taking advantage of its ability to steadily monitor the performance of every node through low-latency and high-capacity backhaul links. On the contrary, if a distributed RAN (D-RAN) is deployed, each node would have its own CCM. In this case, each node should exchange its performance information with its neighboring nodes, so that every node always has an updated vision of its neighbors' performance. Despite performance data are periodically stored in the OSS (Operations Support System), the storage period usually ranges from fifteen to sixty minutes, which makes these data to become obsolete for short-term RRM functionalities, like the CCM. The required mechanism for the exchange of performance information should be frequent enough to provide a reliable vision of each node current status, but slow enough not to incur excessive signaling load in the backhaul links or computational cost at the nodes.

For the evaluation of the component, UEs can be distributed in an uneven way along the scenario, thus creating some load imbalance. That is, some CCs would be more saturated than others assuming either an RSRP-based or a random UE-to-CC allocation. As such, CCs can be allocated to UEs after first having sorted these CCs according to their current load level with a certain periodicity.



$MN = BS_a$	Performance metric 1	Performance metric 2	⋯	CC score
CC_{a3}	$x_{a3}^{(1)}$	$x_{a3}^{(2)}$	⋯	S_{a3}
CC_{b4}	$x_{b4}^{(1)}$	$x_{b4}^{(2)}$	⋯	S_{b4}
CC_{b1}	$x_{b1}^{(1)}$	$x_{b1}^{(2)}$	⋯	S_{b1}
CC_{a5}	$x_{a5}^{(1)}$	$x_{a5}^{(2)}$	⋯	S_{a5}
⋮	⋮	⋮	⋮	⋮

Figure 2-8: Example of the operation of the CC manager.

2.3.3.2.2 Carrier Aggregation

In Carrier Aggregation, a component carrier is often referred to as a serving cell, is assigned its own cell identifier, and is managed as a serving cell by the higher layers, based on 3GPP procedures. Each individual RF carrier is known as a component carrier. A component carrier can be used on downlink and uplink. The component carrier can have configurable bandwidths. A management entity for resource assignment is used for allocating RBs to users based on various metrics such as SINR, throughput, load, service type (e.g. eMBB, URLLC) and having as input available carriers.

For instance, Figure 2-9 illustrates the utilization of different RBs between users (Intra-band). Intra-band carrier aggregation uses a single frequency band. User A utilizes a set of RBs (grey colored), while User B utilizes a different set of RBs.

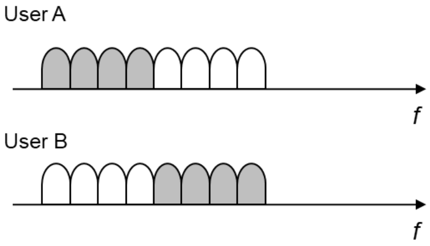


Figure 2-9: Utilization of RBs between users (Intra-band)

Figure 2-10 illustrates the inter-band carrier aggregation. User A may utilize a set of RBs (grey colored) and a different set is utilized by users B and C. In the example, f_1, f_2, f_3 may have different values for monitored metrics (e.g. different SINR etc.). Round Robin can be utilized for assignment of resources to similar type of users (e.g. eMBB users etc.) Also, the assignment of resources to critical services e.g. URLLC can be prioritized.

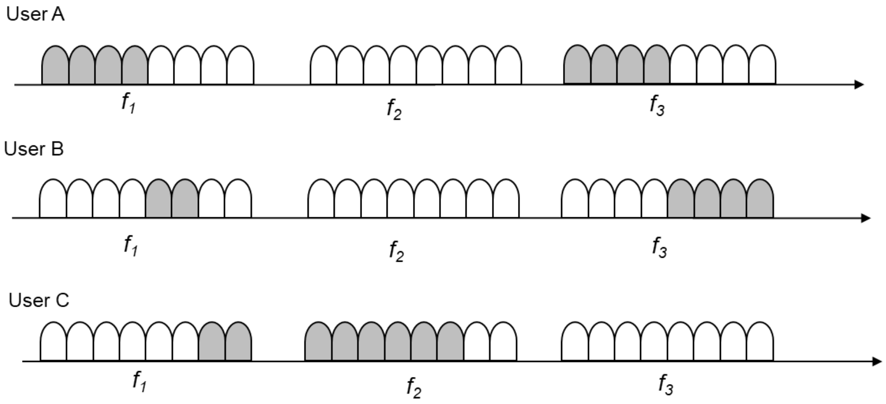


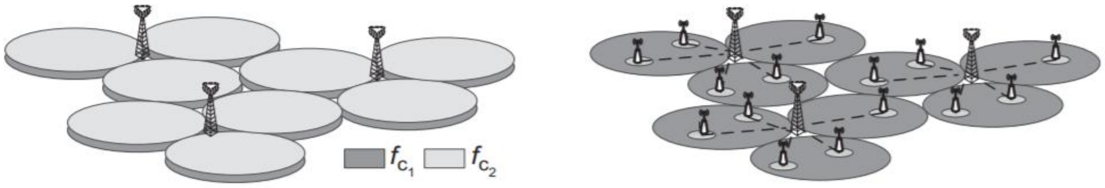
Figure 2-10: Utilization of RBs between users A, B, C (Inter-band)

The assignment process is as follows:

- A request is generated by UE;
- Getting as input the available carriers depending on the service type;
- Clustering of requests based on service type;
- Prioritization of requests according to the criticality (e.g. URLLC will be prioritized compared to eMBB);
- Assigning the most appropriate RBs for each cluster by utilizing Round Robin;

With respect to deployment scenarios [AHM14] in **Figure 2-11(a)** cells with carrier frequencies f_{c1} and f_{c2} are geographically collocated. They provide approximately the same coverage due to similar path loss characteristics within the same band. This carrier aggregation scenario achieves higher data rates throughout the cell where both layers provide sufficient coverage.

In the case of **Figure 2-11(b)** the cells associated with carrier frequency f_{c1} provide macro coverage and small cells may correspond to carrier frequency f_{c2}. Small cells can be used to improve throughput at hotspots (currently this is considered). The carrier frequencies f_{c1} and f_{c2} can be at different bands. The carrier aggregation is applicable to users within the coverage of small cells and the underlying macro-cells.



(a) (b)

Figure 2-11: Potential deployment scenarios [AHM14]

2.3.4 Preliminary results

2.3.4.1 Results related to centralized multi-cell scheduling

In this subsection, we provide some preliminary results which take into account the implementation in the system-level simulator of the centralized multi-cell scheduling technical component. The results have been validated by the respective technical component owner who is a member of the project's consortium. In this respect, the implementation takes into account the described procedure and principles for multi-cell scheduling without NOMA and CoMP, and compares it to a baseline scheduling algorithm such as Round-Robin. Also, **Figure 2-12** illustrates the antenna pattern for 3-sector cells as described in [3GPP-36942] and this is followed in our antenna modelling as well.

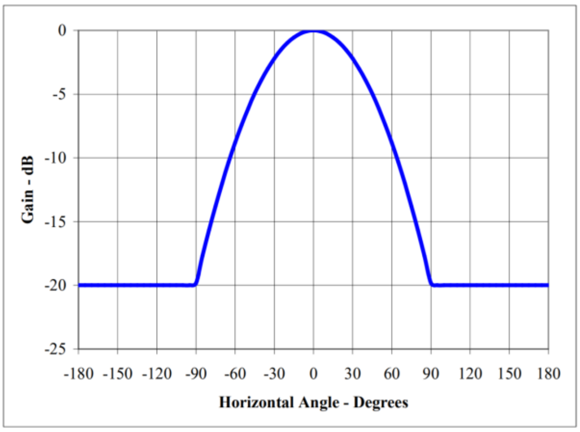


Figure 2-12: Antenna Pattern for 3-Sector Cells [3GPP-36942]

Table 2-2 presents the simulation parameters that were considered for the preliminary evaluation of the technical component.

Table 2-2: Simulation parameters

Number of cells	21
Base station Tx power	46 dBm
ISD	500 m
Type of environment	Urban
Location of base stations	Rooftop (10 m)
MIMO scheme	2x2
Total number of UEs	300, 600, 1200
UE Tx power	23 dBm
Height of UEs	1.5 m
Location of UEs	Uniform
Path loss	L = 128.1 + 37.6 log10(R), R in kilometers
Bandwidth	10MHz downlink and 10MHz uplink
Frequency	2 GHz
Traffic type and model	eMBB, 3GPP FTP Model 1
Simulation time	60s

In **Figure 2-13,** we evaluate the downlink average throughput per UE which shows that better performance is achieved when the TeC implementation is considered compared to a case in which the TeC's algorithm is not taken into account. Also, **Figure 2-14** shows the downlink average throughput per km^2 in which better performance is achieved when the TeC implementation is considered as well.

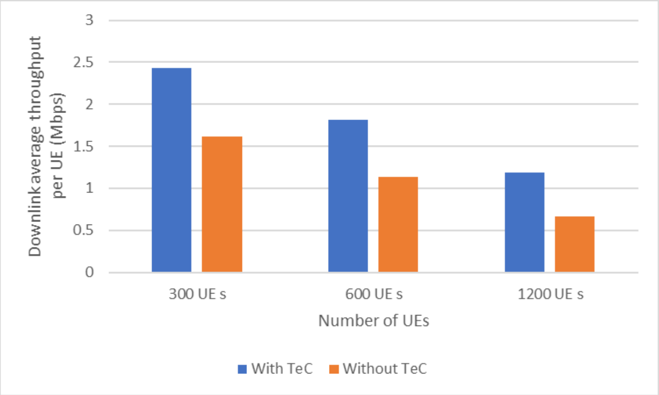


Figure 2-13: Downlink average throughput per UE

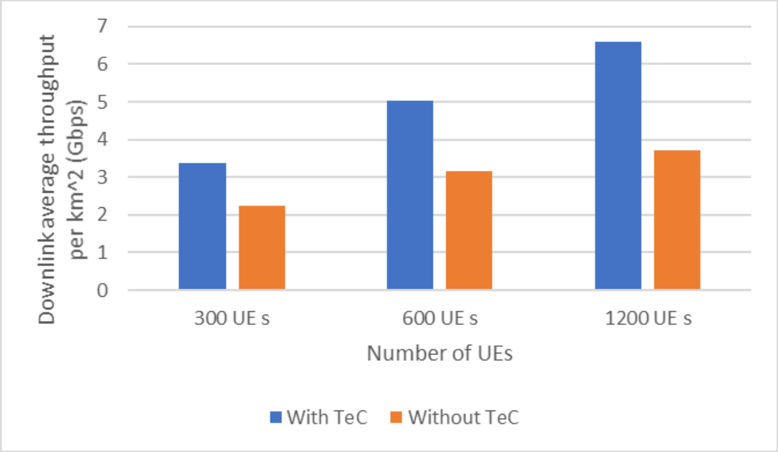


Figure 2-14: Downlink average throughput per km2

In the following figures, the CQI distribution is illustrated in order to capture the impact of the increase of UEs as well. In all cases, the TeC implementation is considered.

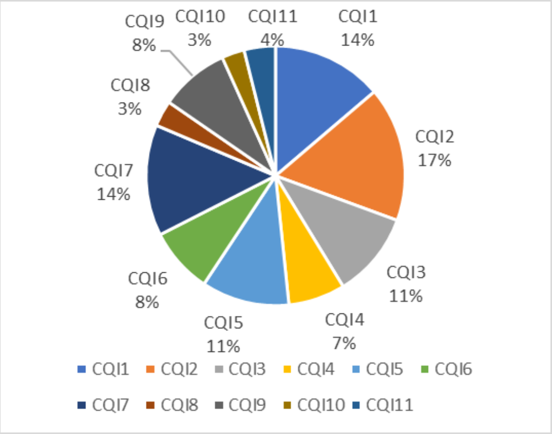


Figure 2-15: CQI distribution percentages (average) with 300 UEs

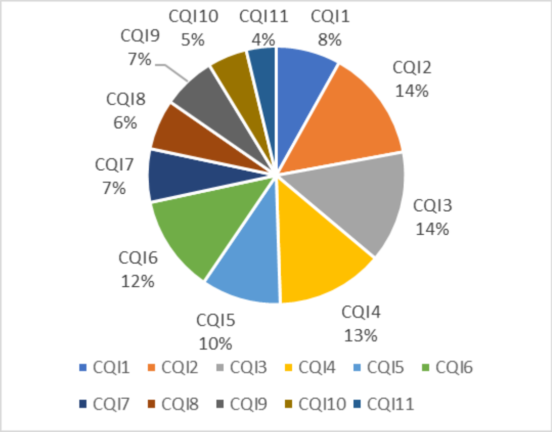


Figure 2-16: CQI distribution percentages (average) with 600 UEs

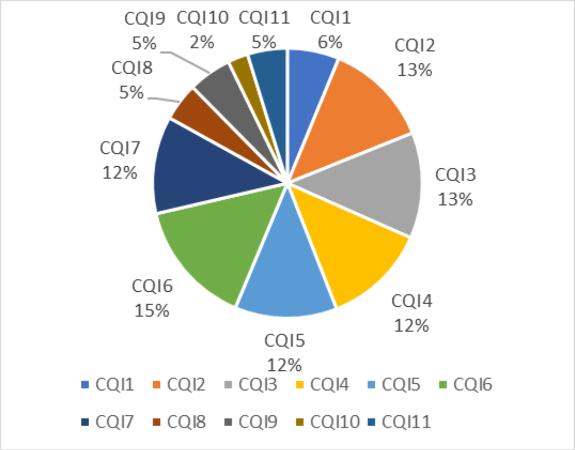


Figure 2-17: CQI distribution percentages (average) with 1200 UEs

An updated implementation of the centralized multi-cell scheduler will be also depicted in next deliverable, D2.3, where the proposed scheduler will be extended to the uplink side and different methods to allow frequency reuse among cells such as CoMP, NOMA and RF isolation can be considered.

2.3.4.2 Results related to Component Carrier management

In this subsection, we provide some preliminary results which take into account the implementation in the system-level simulator of the component carrier management technical component. The implementation takes into account the described procedure and principles for component carrier management which will be expanded for the handling of multi-link connectivity. In this specific evaluation, we consider only eMBB traffic and selecting cells with the criterion of signal strength. We assume 10 MHz (50 RBs) in downlink and the same bandwidth in uplink. UE distribution is mainly uniform in this simulation.

Table 2-3: Simulation parameters

Number of cells	21
Base station Tx power	46 dBm
ISD	500 m
Type of environment	Urban
Location of base stations	Rooftop (10 m)
MIMO scheme	2x2
Total number of UEs	300
Sessions/day/UE	1140, 2880
File sizes	1 MB, 2 MB
UE Tx power	23 dBm
Height of UEs	1.5 m
Location of UEs	Uniform
Path loss	$L = 128.1 + 37.6 \log10(R)$, R in kilometers
Bandwidth	10 MHz downlink and 10 MHz uplink
Frequency	2 GHz
Traffic type and model	eMBB, 3GPP FTP Model 1
Simulation time	60 s

In **Figure 2-18,** we evaluate the downlink average throughput per UE which shows that the performance achieved when the initial TeC implementation is considered which is comparable to cases in which the TeC's implementation is not taken into account. Also, **Figure 2-19** shows the downlink average latency (in our case it is radio access latency for transmitting the whole size of a file) in which better performance is achieved when the TeC implementation is considered as well.

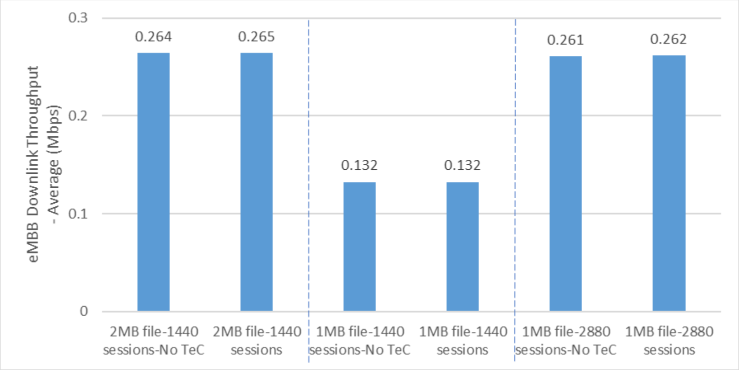


Figure 2-18: eMBB downlink average throughput for cases with/without CCM

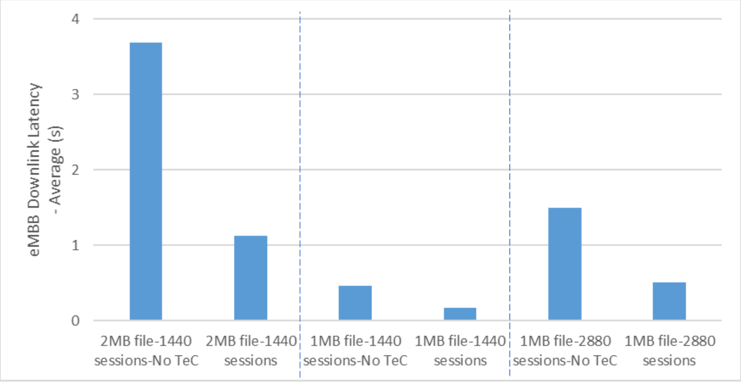


Figure 2-19: eMBB downlink average latency for cases with/without CCM

2.3.4.3 Further results from project's use cases

Further preliminary results are already available and will be further enhanced for D2.3 at the end of the project, by integrating also more technical components as they become available. For the simulations, we have used 19 3-sectorized base stations, which correspond to 57 macro cells. The number of devices is configurable depending on the scenario. Also, one small cell per macro cell is provided. The following results in sub-sections 2.3.4.3.1-2.3.4.3.3 take into account the prioritization of traffic depending on the criticality (e.g. URLLC traffic is prioritized before others). Hence, a different scheduler rather than the centralized multi-cell scheduler is utilized.

2.3.4.3.1 mMTC-related test case

This test case is related to use case "Non time-critical processes and logistics (factories and smart cities)" -Megacities case (simulating up to 200000 devices) and is related to the evaluation of mMTC service [ONE17-D21]. Small packets of 20 bytes are transmitted. More detailed parameters are provided below.

Table 2-4: Simulation parameters

Number of base stations	19 3-sectorized (57 macro cells)
Number of small cells	57 (1 small per macro cell)
Base station Tx power	46 dBm
ISD	500 m
Small cell Tx power	30 dBm
Type of environment	Urban
Location of base stations	Rooftop (10 m)
MIMO scheme	2x2
Total number of devices	1000, 2000, 5000, 10000, 20000, 50000, 100000, 200000
UE Tx power	23 dBm
Height of UEs	1.5 m
Location of UEs	Uniform
Path loss	L = 128.1 + 37.6 log10(R), R in kilometres for macro cells L = 140.7 + 36.7 log10(R), R in kilometres for small cells
Bandwidth	10 MHz downlink and 10 MHz uplink
Frequency	2 GHz
Simulation time	60 s

Figure 2-20 shows the mMTC uplink average latency (latency is related to the radio access part of the network) which is increased as the number of devices increases from 1,000 to 200,000 in a simulation area of 4 km^2. Accordingly, Figure 2-21 shows the average throughput per device which is not much affected as the number of devices increases.

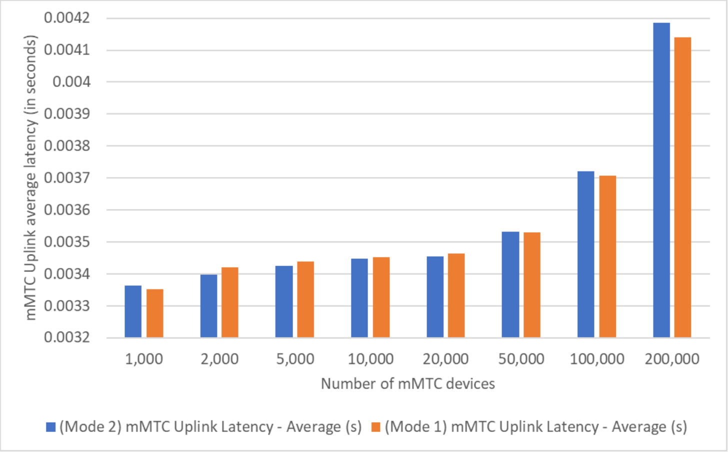


Figure 2-20: mMTC uplink average latency of Mode 1 and Mode 2

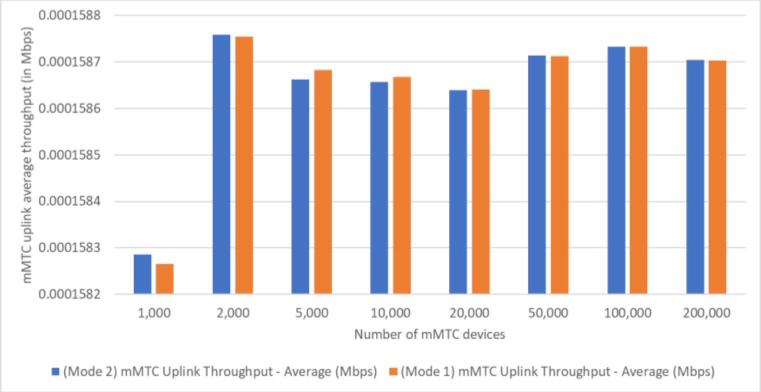


Figure 2-21: mMTC uplink average throughput of Mode 1 and Mode 2

2.3.4.3.2 eMBB-related test case

This test case is related to use case “Outdoor hotspots and smart offices with AR/VR and media applications” which is defined in [D2.1] and is related to the evaluation of eMBB service in urban environment. FTP traffic model 3 as defined in 3GPP is assumed with file sizes of 2048 and 512 bytes. More detailed parameters are provided below.

Table 2-5: Simulation parameters

Number of base stations	19 3-sectorized (57 macro cells)
Number of small cells	57 (1 small per macro cell)
Base station Tx power	46 dBm
ISD	500 m
Small cell Tx power	30 dBm
Type of environment	Urban
Location of base stations	Rooftop (10 m)
MIMO scheme	2x2
Total number of UEs	798, 1254, 2508, 4959, 9975
UE Tx power	23 dBm
Height of UEs	1.5 m
Location of UEs	Uniform
Path loss	L = 128.1 + 37.6 log10(R), R in kilometres for macro cells L = 140.7 + 36.7 log10(R), R in kilometres for small cells
Traffic model	eMBB, FTP Model 3 (file sizes of 0.5 and 2 MB)
Bandwidth	10 MHz downlink and 10 MHz uplink
Frequency	2 GHz
Simulation time	60s

Figure 2-22 and Figure 2-24 show the eMBB uplink average latency (related to radio access part of the network) which increases as the number of devices increases from 798 to 9,975 in a simulation area of 4 km^2. Figure 2-23 and Figure 2-25 show the average throughput per device which is more affected in file sizes of 2,048 bytes compared to file sizes of 512 bytes.

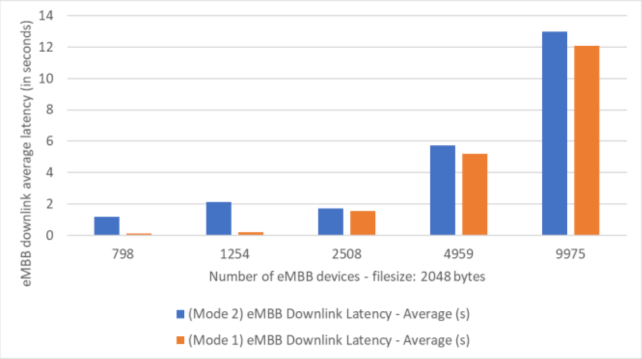


Figure 2-22: eMBB downlink average latency of Mode 1 and Mode 2 (file size: 2048 bytes)

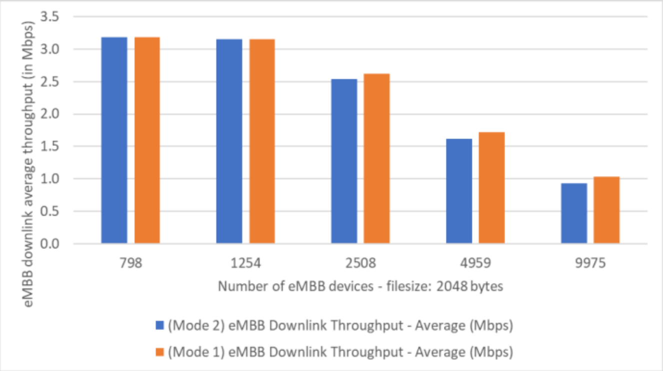


Figure 2-23: eMBB downlink average throughput of Mode 1 and Mode 2 (file size: 2048 bytes)

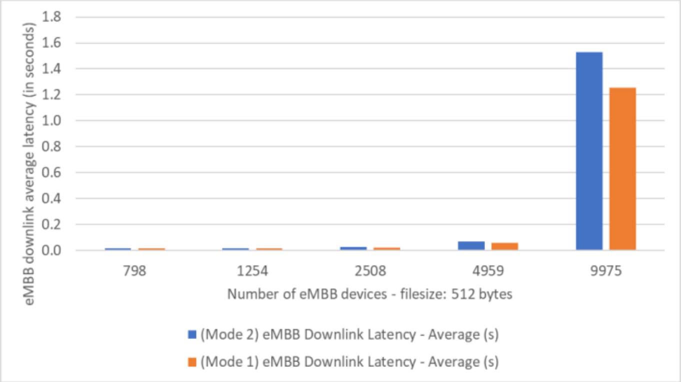


Figure 2-24: eMBB downlink average latency of Mode 1 and Mode 2 (file size: 512 bytes)

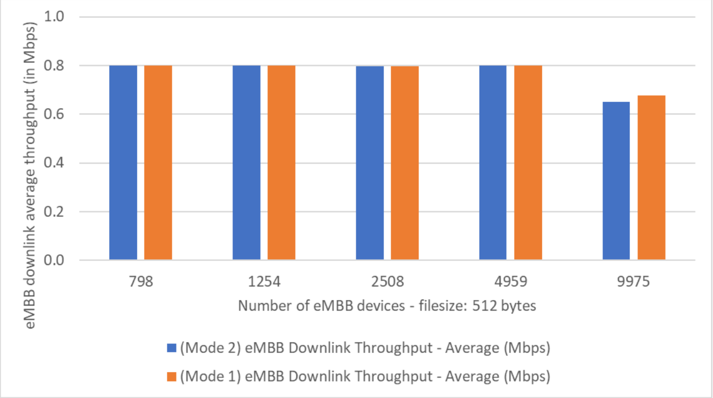


Figure 2-25: eMBB downlink average throughput of Mode 1 and Mode 2 (file size: 512 bytes)

2.3.4.3.3 Combined URLLC/mMTC-related test case

This test case is related to the use case "Smart grid, connected lighting and energy infrastructure" which has been defined in [ONE17-D21] and is related to the evaluation of combined critical URLLC and mMTC services. Files of 20 bytes are assumed and the traffic mix is 30% URLLC files and 70% mMTC files. More detailed parameters are provided below.

Table 2-6: Simulation parameters

Number of base stations	19 3-sectorized (57 macro cells)
Number of small cells	57 (1 small per macro cell)
Base station Tx power	46 dBm
ISD	500 m
Small cell Tx power	30 dBm
Type of environment	Urban
Location of base stations	Rooftop (10m)
MIMO scheme	2x2
Total number of devices	798, 1254, 2508, 4959, 9975
UE Tx power	23 dBm
Height of UEs	1.5 m
Location of UEs	Uniform
Traffic distribution	30% URLLC files (which are prioritized in the scheduler) and 70% mMTC files
Path loss	L = 128.1 + 37.6 log10(R), R in kilometres for macro cells L = 140.7 + 36.7 log10(R), R in kilometres for small cells
Bandwidth	10 MHz downlink and 10 MHz uplink
Frequency	2 GHz
Simulation time	60s

Figure 2-26 shows the uplink average latency which increases as the number of devices increases from 1,000 to 200,000 in an area of 4 km^2. Accordingly, Figure 2-27 shows the uplink average throughput per device which tends to remain the same as the number of devices increases from 1,000 to 200,000 in an area of 4 km2.

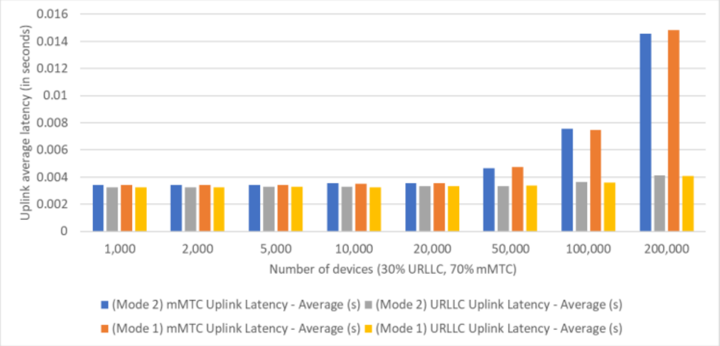


Figure 2-26: Uplink average latency of Mode 1 and Mode 2

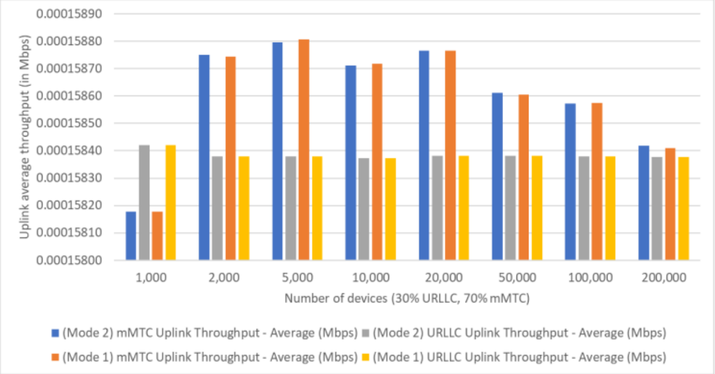


Figure 2-27: Uplink average throughput of Mode 1 and Mode 2

3 Techno-economic analysis

Business considerations and techno-economic aspects need to be analyzed whenever a new network is about to be deployed. The foreseen explosion in new digital services, new markets and diverse applications will make 5G networks unique in many aspects. The techno-economic analysis of such unique and complex networks is of greatest importance, as it assesses the economic viability of new services, where the cellular networks have not been ventured before. In ONE5G in particular, the aim of developing a flexible air-interface able to be efficient in both megacities and underserved areas scenarios comes with the objective of identifying the cost driving elements for the roll-out and operation of systems in such scenarios.

A broad set of use cases has already been developed in a previous stage of the project [ONE17-D21], representing multiple verticals (such as automotive, factories, transport and logistics, smart cities and energy, agriculture, media entertainment and eOffice, eHealth and wellness, disasters and public safety), covering the three categories of services that are eMBB, mMTC and URLLC. This variety of services and use cases make it necessary to assess the economic viability of their deployment in challenging areas like megacities and/or underserved areas. That’s why business aspects need to be taken into account to select the most adequate network deployment options for each case. To do so, the most important drivers for CAPEX (capital expenditure) and OPEX (operational expenditure) in future 5G network deployments will have to be properly modeled, including all the relevant access and transport elements, with a strong presence of network virtualization.

A first stage of this analysis is proposed in this section, dedicated to the qualitative analysis of a selected set of use cases defined in the project [ONE17-D21], considering a representative set of 5G vertical applications and services while balancing the coverage of both megacities and underserved areas scenarios.

3.1 Selected use cases for studies

Nine use cases were developed in a first stage of the ONE5G project [ONE17-D21]. Six of them are considered as the most attractive for 5G and then called “core use cases”. They are planned to be further technically studied in the project, for instance with simulations and proof of concepts. The three others are called “associated use cases” and comprise very interesting services that will still be technically covered in ONE5G but with a lower depth and without any related PoC.

Table 3-1 summarizes the nine use cases developed in the project [ONE17-D21] and highlights (in green) the selected four use cases to be techno-economically studied. They are:

- *Use Case 1 (UC1): Assisted, cooperative and tele-operated driving*, studied in section 3.2. Assisted/cooperative driving enables vehicles to interact with each other, as well as with the network architecture and any roadside unit (RSU) in order to avoid potential collisions and improve driving safety.
  Tele-operated driving involves a human driver physically located outside of the vehicle.
- *Use Case 3 (UC3): Smart cities*, studied in section 3.3. Smart cities consist of non-time-critical processes aimed at providing the required connectivity to sensors, actuators and various connected things that will help improve IoT device management such as traffic, waste collection, parking detection and information, air monitoring, etc.
- *Use Case 4 (UC4): Long range connectivity in remote areas*, studied in section 3.4.
  The goal here is to provide minimal voice and data services over long distances (up to 50 km in rural and 100 km or more in -ultra-rural) in low to very low density areas, without strict requirements on throughput.
- *Use Case 9 (UC9): Ad-hoc airborne platforms for disasters and emergencies*, studied in 3.5. This case considers the rapid deployment of airborne platforms like drones in

disaster and emergency situations. The ability to rapidly deploy these platforms and connect them to the wider core networks and rescue command centers are the key attributes here.

The selection of the use cases to be studied in this techno-economic analysis was realized considering the need to keep a strong emphasis on 5G vertical applications while properly balancing between megacities and underserved areas scenarios. The representation of the three categories of services targeted by 5G (e.g. eMBB, URLLC, mMTC) was taken into account. In addition, multiple deployment options were considered, either based on 3GPP Rel.15 network and using additional equipment adapted to the specificity of each use case (such as MEC for UC1, specific antenna masts for UC4 or drones for UC9) or using 4G-based network (UC3).

Table 3-1: Selected use cases for techno-economic analysis.

	N°	Use case	Vertical business	Level of standard maturity w.r.t. 3GPP/other	Service categories	Scenario
Core use cases	**1**	**Assisted, cooperative and tele-operated driving (between vehicles, and between them and infrastructure**	**Automotive**	**High (TR 22.886)**	**all**	**Megacities, Underserved Areas**
	2	Time-critical factory processes and logistics optimization (industry and smart airports)	Factories, Transport and Logistics	High (TS 22.261)	all	Megacities
	3	**Non time-critical processes and logistics (factories and smart cities)**	**Smart cities and energy**	**High (TR 45.820 and TR 38.913)**	**mMTC**	**Megacities, Underserved Areas**
	4	**Long range connectivity in remote areas with smart farming application**	**Agriculture**	**High (TR 38.913)**	**eMBB, mMTC**	**Underserved Areas**
	5	Outdoor hotspots and smart offices with AR/VR and media applications	Media, Entertainment and eOffice	High (TR 38.913, TS 22.261, ...)	eMBB	Megacities
	6	Live event experience	Media, Entertainment and eOffice	High (TR 38.913, TS 22.261, ...)	eMBB	Megacities, Underserved Areas
Associates use cases	7	Health / wellness monitoring	eHealth and wellness	Low	mMTC, UR(LL)C	Megacities, Underserved Areas
	8	Smart grid, connected lighting and energy infrastructure	Smart cities and energy	Med (e.g. TR 45.820 and TR 38.913)	mMTC	Megacities, Underserved Areas
	9	**Ad-hoc airborne platforms for disasters and emergencies**	**Disasters and Public Safety**	**High (Study Item on NR to support non-terrestrial networks)**	**eMBB / mMTC**	**Megacities, Underserved Areas**

3.1.1 Terminology

For the sake of clarification, we define below the terminology that will be widely used in this chapter. A full explanation of each of these elements is available in D3.1 [ONE18-D31] and the mmMAGIC D1.4 [mmM17-D14], which we use as the basis to define network centralization options.

Centralizing RAN functions can be done in a progressive manner:

- A D-RAN (Distributed RAN) is a totally distributed network where RAN processing is performed entirely at the site, like in 4G.

- A C-RAN (Centralized RAN) is a centralized network where some or all of RAN processing is performed at the data centre. Two additional key features are then used: pooling of baseband which means the ability to reduce the amount of computing resources when aggregating a number of cells (pooling) and general-purpose-processor (GPP), a virtualization technique aimed at exploiting hardware pooling gains.

Figure 3-1 illustrates those varying degrees of centralization in the network. This is a sub-set of the 8 split options defined in 3GPP and are selected on the basis of relevance to our work.

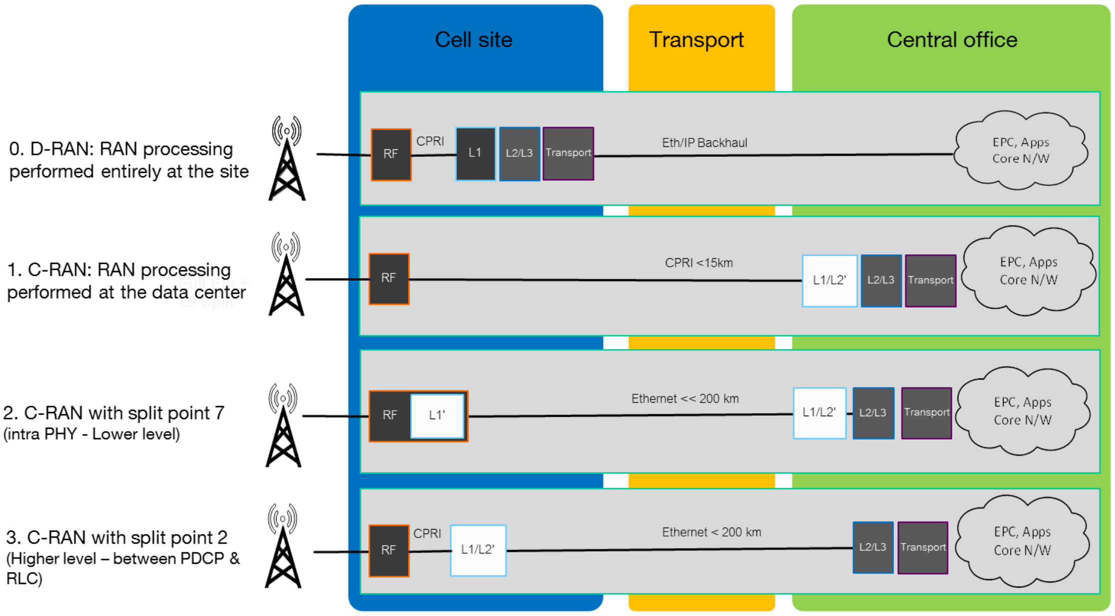


Figure 3-1: Deployments with varying degrees of centralization.

Between the cell site and the core network, some key elements of the transport network architecture need to be defined:

- The remote radio unit (RRU) / remote radio head (RRH) comprise the analogue–processing part of the nodes which are always close to the users (i.e. distributed).
- The baseband unit (BBU) is located in the central unit; it is in charge of the communication through the physical interface between the central unit and the RRU / RRH. BBU size ranges from a few cells to thousands of cells, depending on the level of aggregation and distance to the sites.
- The remote unit (RU) comprises the lower layers baseband processing required by the split point in use. It is located either with the RRH/RRU or in an aggregation point (thus controlling a number of cells).
- The fronthaul is the link between the remote sites RRU/RRH and the central unit hosting the BBU. It can be based on owned fibre lines or leased fibre lines or even self-backhauling through microwaves.
- The backhaul is the transport network connecting the sites with the core network in D-RAN or the BBU with the core network in C-RAN. Backhaul network is always IP-based Ethernet links.

Network slicing is the ability to logically transform the network into a set of multiple independent networks, tailored to the specific needs of customers and running over a common physical infrastructure [ONE18-D31].

3.1.2 3GPP Rel.15 reference architecture

The starting point of the techno-economic study is to consider the existence of an already existing 5G Rel.15 based network as defined in section 2.2.1 of IR3.1 [ONE18-IR31].

The agreed architecture in 3GPP Rel.15 is reminded in **Figure 3-2**. It follows a hybrid model where the gNB can be either aggregated in a single node or disaggregated into three logical nodes comprising the RRH, the distributed unit (DU) and the centralized unit (CU). The CU can be decomposed into CU-CP for control plane and CU-UP for user plane.

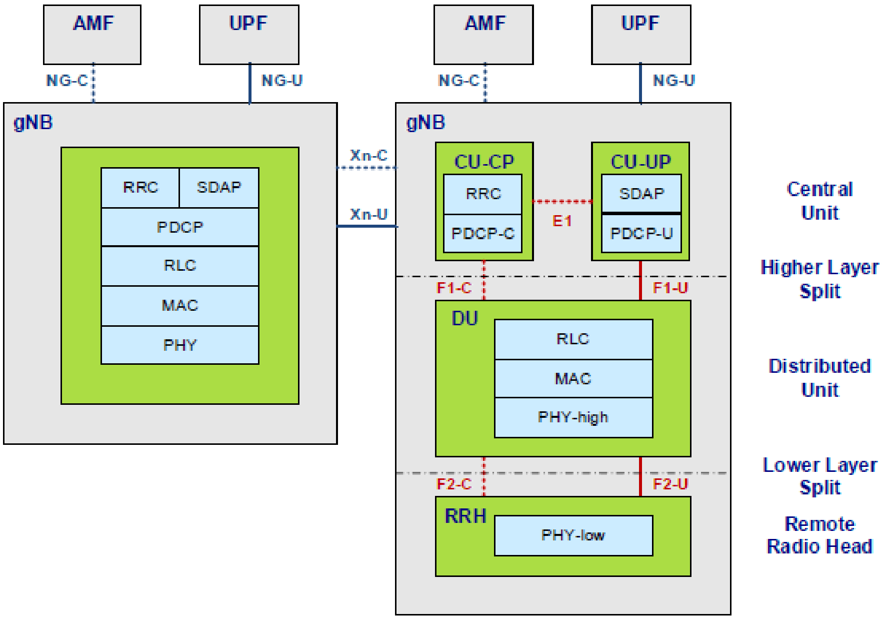


Figure 3-2: Schematic network architecture in 5G [ONE18-IR31].

For simplicity, the split between DU and CU will follow one of only two possible options, foreseen as the most interesting ones for 5G by 3GPP:

- Higher level split = split 2, agreed to be standardized between PDCP and RLC,
- Lower level split = split 7, agreed to be at intra-PHY level but still pending discussions for future eventual standardization. 3GPP Study Item on CU-DU lower layer split for New Radio has been stopped in the last RAN#80 Plenary Meeting and no normative continuation is planned.

Figure 3-3 illustrates the options analysed in 3GPP for the transport requirements in each case.

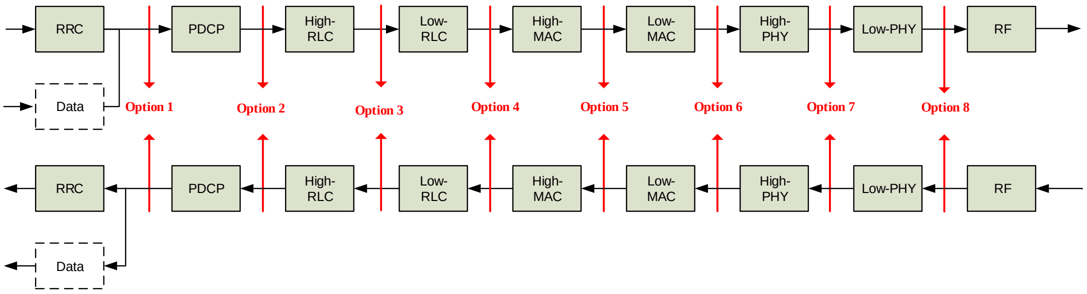


Figure 3-3: Functional split options in 3GPP NR [3GPP TR 38.801]

The use cases to be further analyzed in this techno-economic study will consider either a split 2 or split 7 option for network deployment.

3.1.3 Cost assumptions in centralized and distributed deployments

Fronthaul and / or backhaul network deployment options have been studied in mmMAGIC 5GPPP project [mmM17-D14] with numerous possibilities for the position of the split point. mmMAGIC (Millimetre-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications) was an EU funded 5G-PPP project, whose overall objective was to research and propose design concepts for a mobile radio access technology (RAT) operating in the 6-100 GHz range, focusing on extreme Mobile Broadband. A model had been created for the techno-economic analysis of mmWave deployments in both leased lines and owned lines cases, with several split options. The multiple cost models considered previously in [mmM17-D14] are summed up in this subsection and in 3.1.4.

3.1.3.1 Hardware pooling gains

As mentioned in subsection 3.1.1, the pooling of RAN functions higher in the network than having a dedicated one for each cell site leads to some hardware pooling gains for the BBU when compared to the use of dedicated hardware. An estimation for the hardware pooling gain is taken as a function of the number of sectors. Savings from resource pooling only impact the fraction of hardware that is required for GPP, not dedicated hardware.

Hardware pooling gains are taken from [LZG+14] and illustrated in **Figure 3-4**. It appears that little gain is expected beyond 32 sectors while complexity can grow exponentially.

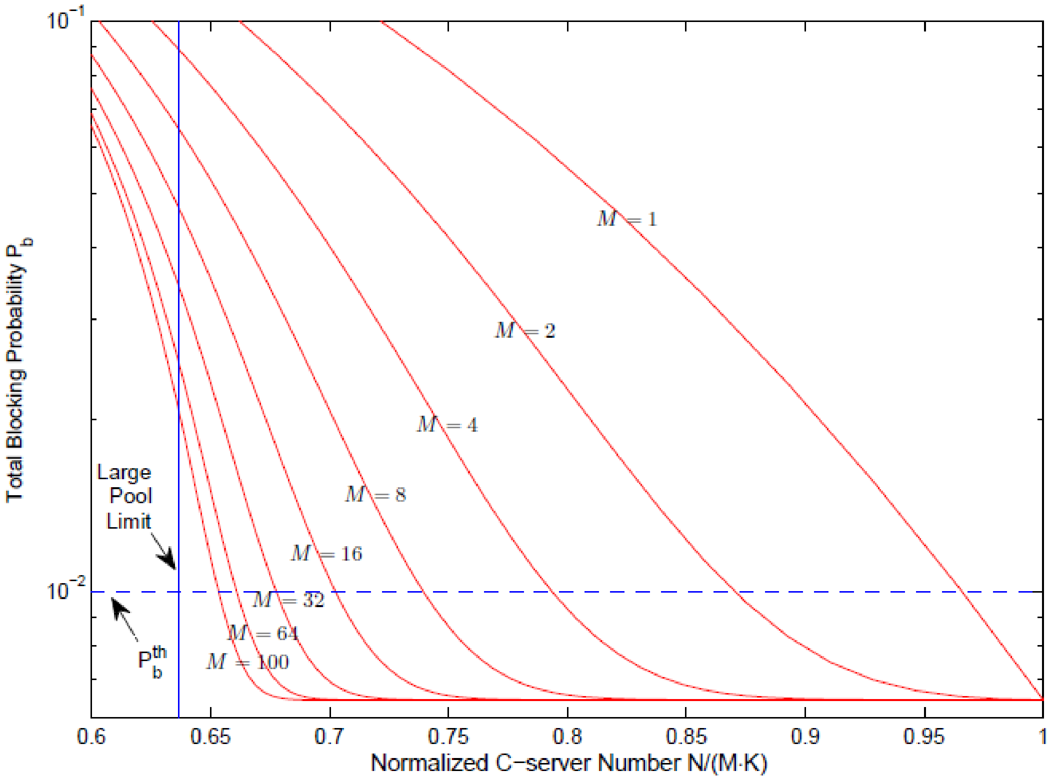


Figure 3-4: Hardware pooling gain (in x axis) as a function of the number of sectors (M) for a given blocking probability as taken from [LZG+14] (N is the number of virtual base stations, K is the number of units of radio resources).

3.1.3.2 Power consumption

Power consumption calculations comprise of the power consumption of the RRH which is a configurable fraction of the total power consumption in a base station (between 50% and 80% typically) and the power consumption of the GPP that is higher than dedicated hardware.

Power consumption linked to air conditioning and rectifiers does decrease in the case of C-RAN thanks to the centralization of equipment that enables the use of more efficient cooling facilities and power supplies for the equipment racks.

3.1.3.3 Number of sectors

The number of sectors controlled by the BBU is configurable. BBU sectors are grouped into racks, each supporting a given number of cells. The cost of holding the racks at the BBU is modelled by means of a hosting CAPEX per rack and per year.

3.1.4 Transport network cost model

The transport network generally comprises three segments, as pictured in **Figure 3-5** [NGMN11] where the progressive aggregation of links toward the core is highlighted.

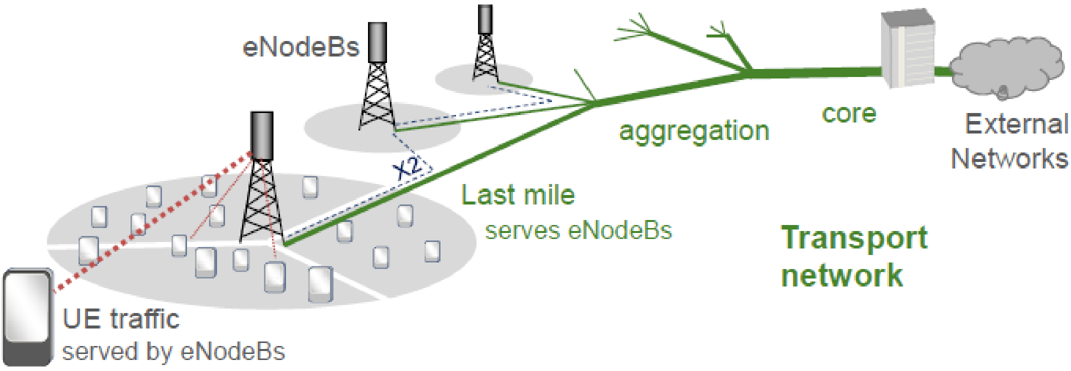


Figure 3-5: Schematic architecture of the transport network according to NGMN [NGMN11]

The last mile has a relatively low length of a few hundred meters and is dimensioned to carry the maximum data rate of the cell. It is usually served through either dedicated fiber or self-backhauling (microwave, mmWave). It ends at the nearest point of presence where it connects to the metropolitan network. The civil work such as digging trenches and laying fibers may not be needed when such last mile is already available from previous deployments.

The metropolitan network is a high capillarity network providing IP/Ethernet traffic towards the sites while benefiting from *several levels of traffic aggregation*. Such network is dimensioned while considering some statistical multiplexing gain that reduces the actual capacity needed.

The IP backbone is an even higher capacity transport for the transport of large amount of IP/Ethernet data toward the core. The multiplexing gains are higher than those from the metropolitan network thanks of its *higher level of traffic aggregation*.

mmMAGIC [mmM17-D14] took into account such architecture and proposed multiple models adapted to the different options selected for the deployment of D-RAN or C-RAN networks. These formulations are reminded in the following subsections.

3.1.4.1 Backhaul cost model

In D-RAN, the backhaul comprises all three segments which are based on IP/Ethernet fibers. The gNB comprises a gateway terminal, the baseband hardware, the RRH and the associated antennas. No virtualization or centralization capabilities are exploited; hence all baseband processing is assumed to run on dedicated hardware.

In C-RAN, the last drop can be based either on fibers or on self-backhauling. Backhaul only involves the IP backbone as per direct connection of the BBU to the nearest point of presence towards the core. gNB comprises the gateway terminal, the RRH, antennas and baseband hardware for the RAN processing functions below the split point. The BBU performs the RAN functions above the split point mostly with GPP.

Different possibilities can be envisioned for the backhaul deployment, based on owned microwave, leased or owned fiber. In all cases the cost is dependent of the backhaul capacity.

3.1.4.1.1 Owned microwaves case

A linear model is proposed for the backhaul owned microwave case, to represent the royalty fee of frequency using and associated equipment. The OPEX here comes from the spectrum license cost, which is flat with usage:

$$CAPEX = A$$

$$OPEX = B\ (frequency\ license)$$

3.1.4.1.2 Leased lines case

The operator uses a leased line according to a commercial offer from a third party. The inner structure of the transport network is therefore invisible to the operator, who is charged of a certain monthly/annual fee that depends on the amount of traffic disregarding any statistical multiplexing gain. A non-linear model is then proposed for the D-RAN OPEX, taking into account the projected evolution of the cell traffic in 5G. The D-RAN CAPEX is supposed to be fixed, corresponding to service fees:

$$\mathrm{CAPEX} = \mathrm{C}$$

$$OPEX = A \cdot \left(backhaul\_capacity(Mbps)\right)^{B}$$

In C-RAN backhaul, however, given that a single connection is required to transport the traffic of all the cells under control of the BBU, connectivity benefits from statistical aggregation and therefore lower data rates are considered as per the statistical multiplexing gain:

$$OPEX = A \cdot \left(backhaul\_capacity(Mbps) \cdot \frac{1}{mux\_gain}\right)^{B}$$

The same labels A, B and C are used in the coming formulations but they are in general different for the different cost models (backhaul, fronthaul) in leased lines and owned lines.

3.1.4.1.3 Owned lines case

A linear cost model is proposed, based on the actual backhaul capacity, the overall network costs and the amortization period. Coefficient B integrates the net reduction in network resources as a result of aggregation (multiplexing gain):

Once the network is built, and given the amortization period and the total capacity of the network, a monthly OPEX is derived by dividing the overall cost by the amortization period (in months) and in turn divide by the total capacity of the network – this gives an equivalent “monthly cost per Mbps”, which is the constant B. The final OPEX will be linear with data usage, with an initial constant A to model any additional fixed cost.

$$OPEX = A + B \cdot backhaul\_capacity(Mbps)$$

3.1.4.2 Fronthaul cost model in C-RAN

Fronthaul comprises only the last drop and the metro segment between the BBU and the RRH.

3.1.4.2.1 Owned microwaves case

A linear model is proposed, similar to the D-RAN backhaul case:

$$CAPEX = A$$
$$OPEX = B\ (frequency\ license)$$

3.1.4.2.2 Leased lines case

The model used for the fronthaul follows the same approach than for the D-RAN backhaul. A non-linear model is proposed for C-RAN, considering no multiplexing gain in the OPEX as no aggregation is yet present:

$$CAPEX = C$$

$$OPEX = A \cdot \left(fronthaul\_capacity(Mbps)\right)^{B}$$

3.1.4.2.3 Owned lines case

The metro network follows the same OPEX law as for the backhaul:

$$OPEX = A + B \cdot fronthaul\_capacity(Mbps)$$

Again, A and B coefficients are different than in the backhaul case but B still includes an implicit multiplexing gain.

A main difference here is that the fronthaul capacity strongly depends on the split point position; whenever it is positioned above RF, fronthaul traffic can be assumed proportional to cell traffic, the C constant depending of the position of the split point:

$$fronthaul\_capacity = C \cdot backhaul\_capacity$$

3.1.4.3 Last drop cost model in C-RAN

The last drop is the last segment of the transport network that reaches the base station or RU, either fronthaul or backhaul.

In leased lines, there is no need to consider a particular cost model as such cost would be subsumed within the overall connection cost charged by the third party that provides the connectivity.

In owned lines case this cost is calculated separately including civil work costs, average last drop length, and related equipment.

3.2 Analysis of UC1 on assisted, cooperated and tele-operated driving

This section presents the techno-economic and business analysis carried out for the automotive use case. Among the multiple services comprised within V2X category, the most relevant services for ONE5G project that have been identified for a qualitative focus are:

- Service #1: assisted driving aided by roadside infrastructure.
- Service #2: cooperated driving between nearby vehicles.
- Service #3: tele-operated driving.

3.2.1 UC1 deployment considerations

The above-mentioned services enclose decisive actions that require networks to fulfill strict requirements in terms of latency, reliability and availability in order to avoid disasters. For instance, some of the actions tackled by these services that can be highlighted are: collision avoidance, driving safety or driving based on cloud computing in public transportation. **Table 3-2** summarizes the main service KPIs of these services from previous deliverable [ONE17-D21].

Table 3-2: V2X Service KPIs.

Service KPIs	Service #1	Service #2	Service #3	Comments
U-plane maximum UL/DL radio latency (ms)	0.5 ms	0.1 ms	2 ms	Taken as 1/10th of the end-to-end maximum latency. Radio protocol layer in which it is measured should be specified.
U-plane maximum E2E latency (ms)	5 ms	1 ms	20 ms	Taken from [3GPP-22.886].
C-plane maximum UL/DL radio latency (ms)	10 ms	2 ms	10 ms	Max. time for C-plane state transition to "connected state". Taken from [3GPP-38.913], reduced for Service #2.
U-plane maximum DL/UL radio packet loss (%)	0.001%	0.001%	0.001% or lower	Taken as (100 - reliability)%
U-plane reliability (%)	99.999%	99.999%	99.999 % or higher, up to 250 km/h.	Probability that IP packets are correctly received within the latency time. Taken from [3GPP-22.886].

Hence, due to the sensitivity of the actions handled by V2X services, new network deployments need to be considered to efficiently develop these services satisfying the stringent requirements showedshown in **Table 3-2**. It is foreseen that Next Generation Radio Access Networks (NG-RAN) will efficiently provide URLLC services by tailoring the network to the service requirements by means of Network Slicing. Nevertheless, at this stage, it seems it is unlikely to satisfy ultra-low communications without including new network elements that help to reduce E2E latency mainly due to air interface. Thus, for the studies carried out throughout this section a special network node named "Multi-Access Edge Computing (MEC) Server" is considered to be implemented in between the core and radio access network with the aim of reducing unmanaged latency for V2X services.

Multi-access Edge Computing (MEC) technology allows reducing latency and incorporating intelligence and processing capacity at the edge of the mobile network. In such a way, it allows running contents and applications closer to the end user and avoiding going through the Internet towards the applications server to get the content and back to the user by hosting itself those interesting applications. Thus, the main functionality of MEC nodes within this automotive framework will be to host V2X applications and centralize a number of sectors under Network Function Virtualization (NFV) paradigm since they will be IT servers with full virtualization capabilities and easily scalable with the growth of traffic.

The location of the MEC server will be dependent on the considered architecture. In this work, two different approaches have been considered as it is illustrated in **Figure 3-6**.

- A fully distributed network (D-RAN) where MEC nodes will be placed at somewhere in the backhaul network aggregating a number of sectors, and

- A Partially centralized network (C-RAN) considering the two split options (2 and 7) identified in subsection 3.1.2. In this case, the MEC nodes will be placed co-located with the Central Unit (CU).

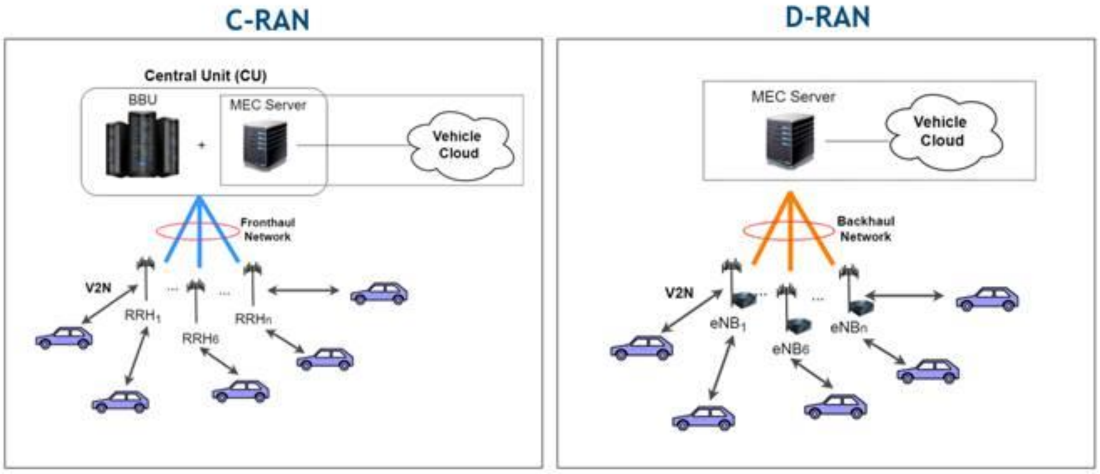


Figure 3-6: Proposed V2X architectures: C-RAN Split 2/7 V2X architecture (left); D-RAN V2X architecture (right.

V2X services are available in both Megacities and Underserved areas, as cars, bicycles and public transportation are present in both areas and likely to be moving across them. Thus, for the techno-economic analysis both scenarios will be considered and carefully studied making different assumptions to tailor the study to their needs.

In the previous deliverable [ONE17-D21], some network' and user' deployment KPIs were proposed for this use case. For simplicity, **Table 3-3** gathers the most relevant KPIs for the techno-economic analysis.

Table 3-3: V2X Network and UE deployment KPIs, as taken from [ONE17-D21].

Network and UE deployment KPI	Megacities	Underserved area
Scenario	Urban grid for connected car	Highway
Inter-site distance (ISD, m)	500	1732
Aggregated system bandwidth	Up to 200 MHz	
BS antennas	Up to 256 TX/RX	
UE antennas	Up to 8 TX/RX	
Maximum number of UEs	1000 UEs – Max 200 active UEs	
Connection density	1000 veh. / km^2	85 veh. / km^2

From**Table 3-3**, it can be seen that the main difference between megacities and undeserved areas is due to network density. Megacities are characterized by the deployment of a large number of cells separated hundreds of meters between them to cope with the high traffic density demands. Therefore, the number of aggregated cells by either MEC node or the CU will be significantly higher in these ultra-dense scenarios than in Underserved Areas.

The maximum bandwidth envisioned for these use cases is roughly 200 MHz since V2X services also comprise infotainment applications, which require high data rates such as multimedia and gaming for passengers to spend the time inside the vehicles. However, the V2X services considered in this study do not require high data rates as they are mainly for advanced driver assistance systems and traffic efficiency where the amount of traffic is moderate or even low. Therefore, it is proposed to narrow down the required bandwidth for these services to tens of Hertz in order to achieve the ultra-low latency requirements [see Table 3-2**:**], as low rate connectivity may be sufficient for them.

On the other hand, Multiple-Input Multiple-Output (MIMO) capabilities are envisioned to be exploited for V2X services to either improve user experience or network efficiency. MIMO technology brings multiple benefits for V2X not only as an enabler to increase data rate for supporting infotainment applications, as it was stated before, but also to increase the number of simultaneous connections with vehicles that are allowed for a single cell. AsAs the number of available beams growsgrows, the number of simultaneous connections allowed will increase.

In general, the minimum number of antennas at the UE side or BS side will determine the maximum number of beams, and consequently the maximum number of simultaneous connections to a single cell. According to**Table 3-3**, the maximum number of simultaneous connections allowed would be limited by the number of antennas at the vehicle. Notice that the values presented in **Table 3-3** are given to cover a wide set of V2X services and environments, so that they can be more optimistic than the real ones due to e.g. derived problems with the form of antenna factor. In addition, for underserved areas, where the objective is to provide long range communication, MIMO capabilities may not be as good as it is illustrated in **Table 3-3** or even be de-activated. Therefore, for undeserved areas the number of simultaneous connections will be surely limited by BS capabilities.

3.2.2 UC1 qualitative assessments

All the above considerations have to be taken into account and carefully studied for the quantitative outcome as they highly impact over CAPEX and/or OPEX analysis. Therefore, a careful selection of these network parameters would be key to perform properly the techno-economic analysis. Nevertheless, some conclusions can be obtained, from a qualitative point of view, according to the analysis depicted throughout this section:

- The capital needed to invest (CAPEX) in both C-RAN and D-RAN deployments will be directly dependent on the number of sectors aggregated by either the MEC node or the CU, besides the number of sectors per site. Therefore, the capital invested will be amortized to a greater extent as the number of sectors increases.
- In addition, for C-RAN deployments, the split option performed in the protocol stack, will affect CAPEX since a higher level of centralization will allow reducing the costs derived from dedicated hardware equipment (see hardware pooling gain discussion in subsection 3.1.3.1). So that, comparing the CAPEX costs of a centralized versus distributed network, these will be more similar as the split option becomes higher. So C-RAN scenarios with high-layer split will have similar costs as a fully distributed scenario since they share a lot of similarities as just the PDCP layer is centralized.
- In C-RAN deployments, the operating cost (OPEX) will increase slightly compared to a distributed topology since a new connection is required to connect the RRHs/RUs with the CU. This connection, named as fronthaul network, will be based on fibre of greater or lesser capacity depending on whether the split is lower-layer or higher-layer, respectively. On the other hand, there is an OPEX reduction related to hardware footprint reduction in the site, compared to D-RAN deployments, especially in leased rooftops. Moreover, site maintenance expenses should be reduced since the majority of hardware’s failures are the BBU, i.e. better failure detection and less outage time occurs in C-RAN deployments.

- The MIMO order and the bandwidth considered in both scenarios will affect just the operating costs (OPEX). High MIMO orders and bandwidth would increase fronthaul (C-RAN) and backhaul capacity (C-RAN, D-RAN), producing an increase of the fibre costs.
- Finally, in rural areas where robustness and availability are sought before increasing capacity since no high orders of modulation and/or MIMO are envisioned, the costs derived from these technologies will not have much weight on OPEX total. However, these areas have the disadvantage of the smaller number of aggregated sectors by the CU and sectors per site to amortize expenses.

3.3 Analysis of UC3 on Smart cities

This section focuses on the smart cities scenario of use case 3 on non-time-critical processes and logistics for dense urban and suburban areas management. The objective is to provide mMTC services for applications such as traffic management, waste collection and management, parking detection and information, air monitoring, etc. where data has small payloads and no high constraints on latency.

Before going through the qualitative analysis for the smart cities mMTC use case, an overview of the situation for 5G mMTC in standardization bodies is needed.

3.3.1 5G mMTC considerations in standardization bodies

Standalone NR 5G Rel. 15 specifications were released mid-June 2018. Rel. 15 has been designed to provide the foundations of eMBB and URLLC services (see Figure 3-7).

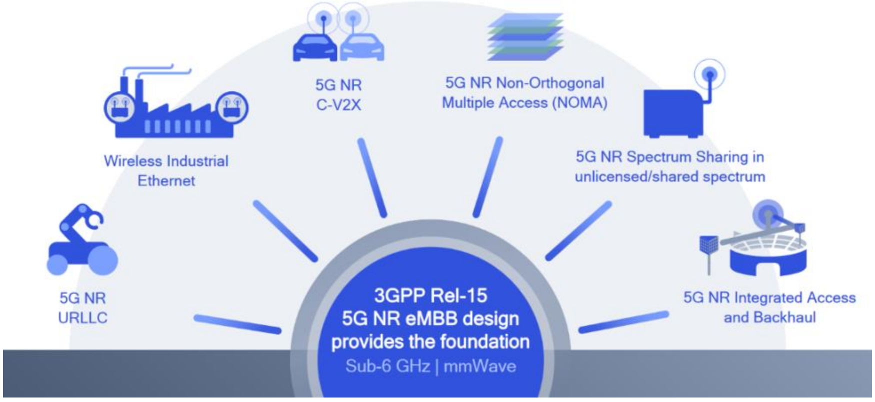


Figure 3-7: 3GPP 5G NR technology roadmap (Source: [Qua18-NR])

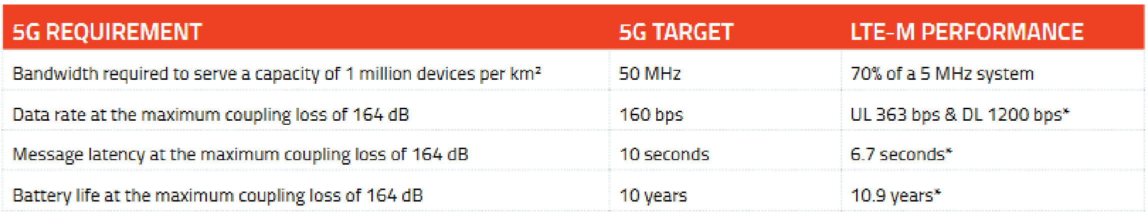
As for addressing low power, wide area (LPWA) IoT use cases, 3GPP has indicated to the International Telecommunication Union (ITU) that it will submit both NB-IoT and LTE-M technologies as candidates to meet the 5G LPWA requirements outlined in IMT-2020 – the ITU's vision for future 5G mobile broadband communications. To further support the view that NB-IoT and LTE-M support the 5G LPWA requirements, 3GPP has also agreed that LPWA use cases will continue to only be addressed by evolving LTE-M and NB-IoT as part of the 5G specification process and that no 5G New Radio (5G NR) based solutions should be studied or specified for LPWA use cases in Rel. 16. 3GPP is in the process of studying mechanisms to allow NB-IoT and LTE-M to connect to the 5G core network and to coexist with a NR carrier independently from an LTE one. This will allow the 5G systems of the future to support LTE, NR, NB-IoT and LTE-M using the same core network, confirming that NB-IoT and LTE-M are on the path to 5G [GSMA18].

Four main KPIs and requirements are targeted for 5G LPWA use cases:

- Maximum Coupling Loss (MCL): up to 164 dB (extreme coverage)
- Massive connection density: up to 1 million devices/km² in urban environment
- Long UE battery life: up to 15 years (low power consumption)
- Less than 10s latency

LTE-M and NB-IoT have been designed to meet these requirements and will continue their evolution as shown in **Figure 3-8**, **Table 3-4** and **Table 3-5**. In [SWEA+17] a group of more than a dozen industry players evaluated LTE-M performances against the 5G IoT requirements for coverage, message latency, and battery life as specified in 3GPP TR 38.913 [3GPP-38.913] and the capacity requirements as defined by the ITU report IMT-2020 requirements [ITU17-M2410]. It was shown that LTE-M performances for extremely deep coverage (see **Table 3-4**) are reaching the 5G IoT target performances, even if the evaluation was performed for mostly LTE-M Rel. 13 specifications. In [RP-170511] and [RP-170512] the conclusions are clearly stating that LTE-M and NB-IoT releases 14 respectively, are fulfilling all the 5G mMTC requirements.

Table 3-4: LTE-M Rel. 13 performances in terms of capacity, coverage, latency and battery life compared to 5G target performances (Source: [SWEA+17])



5G REQUIREMENT	5G TARGET	LTE-M PERFORMANCE
Bandwidth required to serve a capacity of 1 million devices per km²	50 MHz	70% of a 5 MHz system
Data rate at the maximum coupling loss of 164 dB	160 bps	UL 363 bps & DL 1200 bps*
Message latency at the maximum coupling loss of 164 dB	10 seconds	6.7 seconds*
Battery life at the maximum coupling loss of 164 dB	10 years	10.9 years*

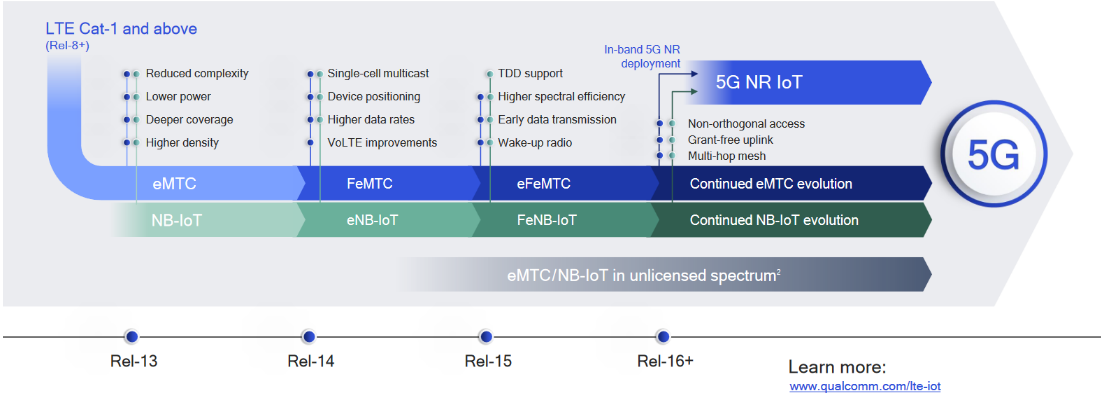


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Figure 3-8: 5G NR IoT roadmap (Source: [Qua18-NR])

Table 3-5 gives an overview of Rel. 15 LTE-M and NB-IoT evolutions. The 5G coverage requirement is now met by both LTE-M and NB-IoT. The latency has been improved in order to meet 5G latency requirements (less than 10s). Improvements have been also made for both technologies in terms of energy reduction and capacity. Both technologies will continue to evolve in Rel. 16 and beyond (Non-orthogonal multiple access (NOMA), grant-free uplink access are technical components to be standardized among others).

Table 3-5: Detailed view of Rel. 15 LTE-M and NB-IoT evolutions

Criterion	eFeMTC (Rel. 15)	FeNB-IoT (Rel. 15)
Deployments/HD-FDD	Standalone, in-LTE channel/HD-FDD, FD-FDD, TDD	Standalone, in-LTE channel, LTE guard bands/HD-FDD, TDD

Target coverage (MCL)	164 dB	164 dB
Bandwidth	Max. 5 MHz, idle mode and Coverage-enhanced mode B UL: 1.4 MHz	180 kHz
UL peak data rate	DL/UL: 4 Mbps/~7 Mbps FD-FDD	DL ~127 kbps/ UL ~143 kbps (HD-FDD)
Transmit power classes	23 dBm, 20 dBm	23 dBm, 20 dBm, 14 dBm
Latency	Improved latency compared to cat. M2 (Early Data Transmission)	Improved latency compared to cat. NB2 (Early Data Transmission)
Mobility	Enhanced mobility compared to cat. M2	The same as cat. NB2
Voice	Yes, enhanced support	No
Other optimizations	More capacity in UL, energy reduction (wake up radio signal)	Energy reduction (wake up radio signal), higher density support

It is hard to predict the specifications of the 5G NR IoT or when they would be released but while NB-IoT and LTE-M should continue their evolution, designed to address and support LPWA use cases, the 5G NR IoT may be addressing new IoT use cases, a bit more constrained in terms of latency and requiring higher throughputs. One can think to connected credit card or car access control use cases. For this kind of applications, we are not anymore delay tolerant (less than 1s latencies) and the required payloads are much higher than tens of bytes.

3.3.2 UC3 qualitative assessments

The specific situation of 5G mMTC in standardization bodies is analysed below.

It appears that the cost network analysis when moving from Rel.15 to Rel.16 for smart cities applications would mean to evaluate the evolutions of LTE-M and NB-IoT, as no 5G NR IoT will be specified in Rel. 16. Even if it was eventually the case LTE-M and NB-IoT would continue to be the ones addressing LPWA use cases. This means that the cost evolutions would be limited to software upgrades.

This makes the future quantitative evaluation of its economic impacts irrelevant. Since traditionally the mechanism of cost structures of mobile network software and its evolution costs depend on the commercial contracts between the operator of a mobile network and its software providers, the same software could not only have different costs but even the variables in its cost structure can vary from one mobile network operator to another.

However, some analysis could be performed in order to quantify the cost in terms of resources from Rel. 15 to Rel. 16. A solution would be to be capable of quantifying the need for additional resources for mMTC traffic on LTE-M and NB-IoT between Rel. 15 and Rel. 16. It would be very difficult to quantify the resource sharing between LTE-M and NB-IoT. That said, we would have to quantify, on one side, the resource sharing between eMBB traffic and LTE-M traffic and, on the other side, the resource sharing between eMBB traffic and NB-IoT traffic, considering for each analysis that 100% of the mMTC traffic is addressed by one or another of the technologies.
The resource allocation schemes for LTE-M and NB-IoT are different. For NB-IoT, one PRB is all the time 100 % dedicated to the uplink traffic. Depending on this traffic more resources can be allocated (10 PRBs would be necessary to fulfil the 5G mMTC requirements as stated in [R1-1703865]). For LTE-M, six PRBs are allocated for DL control channels. Then, if there is no

uplink traffic, there are no allocated uplink resources. And as soon as there is some uplink traffic one LTE-M narrowband is allocated. More narrowbands can be allocated in parallel in case of higher traffic, with the appropriate scheduling of MTC devices (3 narrowbands would be necessary to fulfil the 5G mMTC requirements as stated in in [R1-1703865]).

3.4 Analysis of UC4 on long range connectivity in remote areas

This section analyzes a use case dedicated to underserved areas, for the provision of minimal voice and data services over long distances in low density areas. The applications targeted are minimal services including voice over long distances plus best effort data services for smartphones, tablets, etc. The priority of this service is to provide a maximum coverage (up to 50 km in rural and 100 km or more for ultra-rural) without strict requirements on throughput.

Radio coverage is thus the main KPI to tackle when assessing this use case. On the other hand, user throughput requirement could be relaxed compared to other use cases more dedicated to Megacities scenario. Nevertheless, minimum uplink and downlink user throughputs are required to allow provision of minimal services. Link budget studies based on target throughputs will determine which link between uplink, downlink and control channels is the limiting factor in coverage.

3.4.1 UC4 deployment considerations

Wide radio coverage has also some implications on backhaul topology. In ultra-rural and even rural environments, it might be hard to reach the first network point of presence with high cell radius long range solutions. Techno-economic study will account for need of multi-hops due to long distances in the case of microwave backhaul solutions. In the case of satellite solutions – that could be envisioned for ultra-rural deployments – traffic density in wide areas covered by long range solutions will be accounted for. Transport network model will consider the work performed in mmMAGIC (reminded in subsection 3.1.4) taking into consideration both D-RAN and C-RAN options, with split points 2 and 7, with leased optical fiber and microwaves.

Economically sustainable wide coverage will be achieved by a smart mix of software (SW) features and site configurations with well-designed passive infrastructures.

Candidate SW feature for coverage extension are likely to be based on signal repetitions in an eMTC fashion. Massive MIMO features are also seen as potential candidates. Some ONE5G technical components will be assessed to check if they satisfy UC4 requirements.

3.4.2 UC4 qualitative assessments

Deep rural environments are very often associated with low population density in emerging countries with low ARPU (Average Revenue Per User) users making network rollout economically unsustainable with traditional radio solutions that are adapted to mature markets. Techno-economic study will account for those impacts on the amortization period.

From a techno-economic perspective, pure SW feature costs will be hard to tackle because they are vendor dependent and feature prices are not known yet today.

Long Range solutions in extreme rural environments will be assessed in priority in low-band frequencies (700MHz-800MHz) to benefit from their good propagation characteristics. Massive MIMO features will only be available in high-band frequency ranges due to antenna size constraints. Propagation characteristics of high-band frequencies are worse than low-band ones but beamforming capabilities enabled by Massive MIMO will increase significantly radio coverage. Thus, Massive MIMO will be assessed in One5G project from a link budget perspective coupled with qualitative tech-eco studies to check if a trade-off between high-frequency propagation and beamforming gain can be reached and whether Massive MIMO features could satisfy UC4 requirements.

Techno-economic study will provide extensive passive infrastructure scenario analysis. From a site configuration perspective, several options will be assessed to find the best trade-off between site cost and cell radius. Site configuration levers that will be studied are:

- Tower/mast height: the higher the antennas, the larger cell radius, but the higher the site cost.
- Sectors number per site: from 3 up to 18 sectors with adapted antenna numbers, antenna gains, number of RRHs… By increasing the sectors number, antennas with thinner horizontal aperture and higher antenna gain will be needed. As a rule of thumb, doubling the number of sectors will result in 3 dBi antenna gain.
- Antenna configuration with vertical diversity: from 1 up to 4 vertical antennas will be considered. Addition of antennas will allow signal diversity gain with 3dB gain in link budget at each antenna addition.
- MIMO configurations: MIMO 2x2, MIMO 4x2. MIMO configurations will be studied with various RRH and power configurations. MIMO features principles are to form beams that focus energy in a dedicated space direction and thus increase signal strength and improve radio coverage. Low frequency bands (700-800 MHz) are expected to be used to benefit from their propagation characteristics. Massive MIMO configurations are not likely to be done in low band frequencies due to antenna size constraints, nevertheless Massive MIMO configurations in high bands (2.6 GHz / 3.5-3.7 GHz) will be assessed from a techno-economic perspective in UC4.

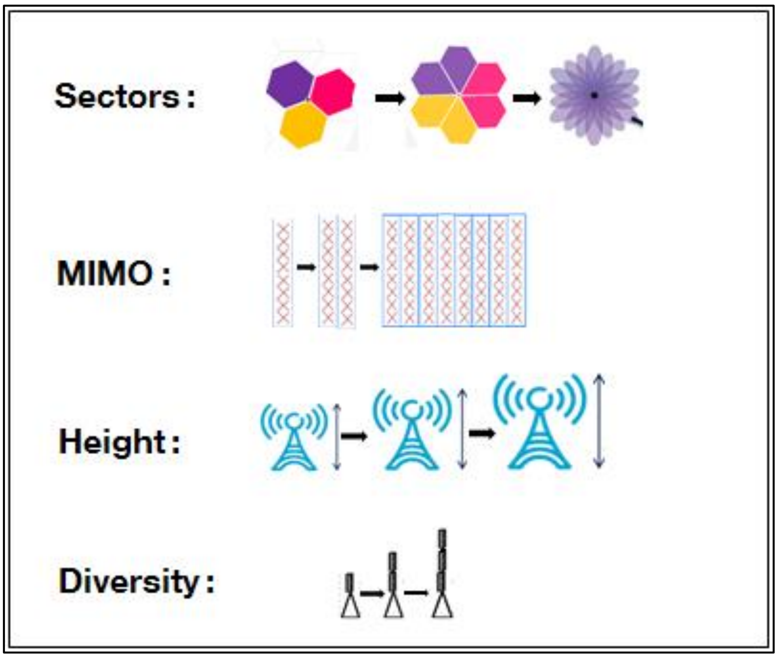

Figure 3-9: Site configuration options for UC4 techno-economic study

This coverage and capacity study permits a proper estimation of the number of gNB.

In addition to the costs linked to mast specific elevation, number and type / configuration of antennas, as well as energy supply and consumption, some qualitative considerations can be given on other cost items:

- Site acquisition, civil works and installation costs in C-RAN are an input fraction of those in D-RAN because of the lower area and less equipment required.
- Site rental costs in C-RAN are specified as an input fraction of those of D-RAN because of less space required on the site.
- Backhaul in C-RAN benefits from zero installation cost as the BBU is located at the operator's premises. It only comprises IP backbone costs.
- Fronthaul rates in C-RAN are assumed proportional to the backhaul rate with such proportionality constant dependent of the split point position.
- Operations and maintenance costs such as on-site interventions, adjustments, failures, electronic maintenance, are an input fraction of equipment CAPEX. This fraction is lower in C-RAN than in D-RAN because of the reduced number of interventions and easier access to centralized premises.
- Air conditioning and rectifiers costs in C-RAN are a fraction of those in D-RAN thanks to pooling.

3.5 Analysis of UC9 on ad-hoc airborne platforms for disasters and emergencies

The emergency services can benefit hugely from the advanced capabilities that 5G networks are promising to unleash. From the very high data rates in eMBB services to the ultra-reliability and extreme low latencies in URLLC services, 5G offers new opportunities for the development of innovative communication, surveillance and remotely operable robotic solutions in this domain. However, the wide area 5G coverage will take a considerable time to be realized, particularly in Europe, as the European operators seem to prefer a more evolutionary path from 4G to 5G. The first deployments are very likely to be only within urban hotspot areas, providing patchy 5G coverage over 4G underlay networks, even in large cities. Within this context, we propose this 'on demand', rapidly deployable 5G solution for the emergency services, which can overcome the constraints posed by patchy 5G coverage.

The solution will be drone based, with the drones rapidly deployed to the localized emergency or surveillance area. The drones can provide very high data rate 5G services like UHD video or novel applications like interactive 3D maps, for the benefit of the emergency crews. The drones can also provide high definition imagery to the ground stations for search and rescue and surveillance missions. The drones will act as remote radio heads (RRH), with the fronthaul link designed to reach the nearest compatible 5G small cell or the LTE small cell. If this connection is too far for a single FH link, the solution relies on relay drones to extend the reach of the drone support. Thus, a form of IAB (integrated access and backhaul) solution needs to be developed, with the required spectrum 'borrowed' from the ground based 5G small cell network.

This techno-economic analysis is conducted in the backdrop of the first LTE based emergency services network (ESN) being developed to be deployed in UK in 2020 [HOME18]. The operator EE is planning this network, with the use of their existing 4G spectrum and with some extensions to their current 4G network infra-structure. We have been in discussion with them to better understand this developing network and to see how new services like this proposed 5G on demand service can be incorporated into such an ESN in future.

The technical details of the proposed solution will be provided in the next section. The subsequent section will provide the techno-economic analysis, addressing 3 core questions with regard to this solution.

- What are the main cost drivers for this proposed solution?
- How to cost the additional capacity provision in Fronthaul and Backhaul links of the commercial 5G/4G network?

- How to cost the ‘on demand’ borrowing of spectrum from the main commercial 5G network?

3.5.1 UC9 deployment considerations

The drone based solution should be capable of providing extreme high data rate communications to whatever location within a defined region. This could be, for example, the city limits a certain emergency service would operate (e.g.: London Fire Brigade). The drones provide high operational flexibility in terms of covering a given location, however due to reliance on battery power, the amount of time a drone can stay airborne and support communication links will be limited. One solution to extend the battery life will be to reduce the complexity and weight of the communication equipment payload on the drone. Thus, we propose to use drones as remote radio heads (RRH), with centralized baseband processing units. The centralized RAN options (C-RAN - as discussed in this chapter) are very likely to be implemented in 5G networks, so this is also a logical step in 5G network architecture perspective.

While the drones can be flown over any potential location within a defined region to provide 5G access, the real challenge is in providing the fronthaul and backhaul connectivity to the drone. In this solution, we propose to have integrated access and backhaul (IAB) capability for the drones and with the ability to dynamically partition the available spectrum for access and backhaul (fronthaul) needs. The drones will be able to wirelessly connect with selected 5G and 4G small cells within this region, with self-aligning fronthaul capability. These cells will act as relays to provide the fronthaul links to the drone RRHs. Some of the relay links may need to be multi-hop, with additional drones also acting like relays in the established link. 5G small cells are likely to have the vertical beam-forming capability with 2D planar arrays and these could potentially be assigned to serve as relays to the drone RRHs. Selected 4G small cells will need to be equipped with these 2D planar arrays (supporting the 5G drone operable frequencies), to serve as relays for the drone RRHs. The system design should take into account the maximum number of relay hops permissible (in light of the end to end delays these cause) and correspondingly designate the relay points in the ground networks.

A schematic diagram of the proposed solution is depicted below in Figure 3-10.

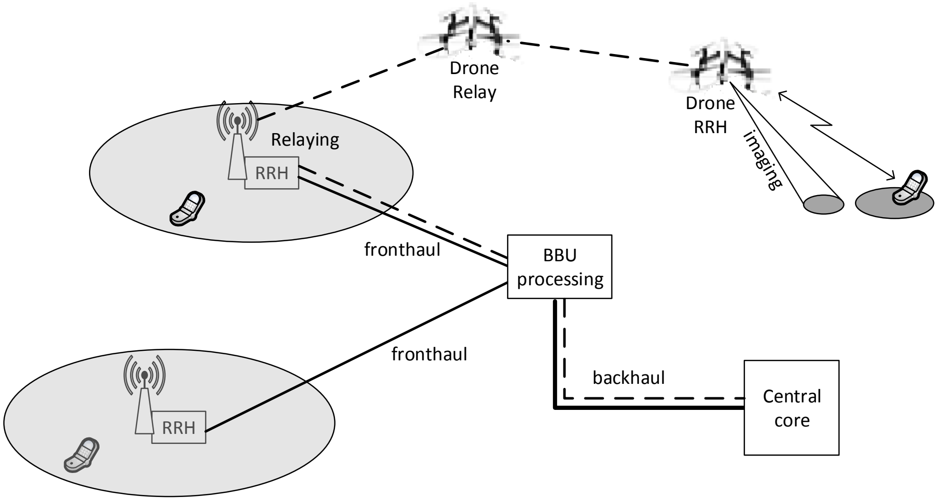

Figure 3-10: Schematic diagram for 5G on-demand solution for emergency services

As some emergency situations will need communication links over a time period exceeding the battery life of drones, an efficient drone swapping mechanism is needed in the solution. Some form of group handover from the serving drone RRH to the replacement RRH and also an efficient method to switch the relay fronthaul links will be needed. The number of drones needed to operate this communication solution should take these replacement scenarios into consideration. Also there should be enough redundancy in the drone counts, should there be multiple simultaneous emergency incidents where the drone based communications are demanded.

Another important consideration is the type of 5G services and the related devices that the proposed drone-based communication solution will provide. The provision of extreme data rates enables multiple services with enhanced quality to be deployed both in the uplink and in the downlink (from/to emergency services crew to/from the drone RRH). In the uplink, the crew on site and within the hazardous area can transmit multiple UHD and high resolution image streams back to the control station. These can be helpful for the control station to determine further steps in emergency response and can also be a vital source of on-site evidence for any future inquiries and prosecutions. In the downlink, the control station can send customized information to each of the emergency service crew. For example, in a building fire, these can be high resolution 3D maps of each floor sent to a fire fighter who is designated to operate on that floor. These kinds of maps can be sourced while the emergency crews are on their way to the affected site and delivered at the site, accelerating the emergency response. In terms of high resolution imaging carried out by the drones for search and rescue and surveillance missions, this proposed 5G solution enables multiple high resolution video streams to be transmitted back to the control centre. For example, these can be multiple infer-red video streams covering 360° from the drone vantage point, in a night time search and rescue mission.

The 5G capable devices that will be used in this application needs to retain all the key features of emergency response devices. These are – the rugged design to sustain high temperature, dust, moisture conditions, the light weight and long battery life, simple and quick functionality to enable communications, ability to be worn and attached to body gear etc. Also, a higher level of device reliability will be required than for the commercially available mobile devices.

3.5.2 UC9 qualitative assessments

In this qualitative techno-economic analysis, we will try to answer three key questions related to this proposed solution. They are listed below:

- What are the main cost drivers for this proposed solution?
- How to cost the additional capacity provision in FH and BH links?
- How to cost the ‘on demand’ use of spectrum?

3.5.2.1 What are the main cost drivers for this proposed solution?

The main costs for the proposed solution can be broadly categorized into 3 parts. The first will be the costs in upgrading the 5G and existing 4G networks to accommodate the additional capacities generated by this drone based solution. The second will be the procurement and operation costs for the specialized drones and the specialized devices needed for the emergency crew. The third cost category will be the spectrum usage related costs. We will briefly examine these three cost categories below.

The network upgrade costs mainly relate to provisioning the additional fronthaul capacities from the selected small cell gNB/eNBs and the backhaul capacities from the centralized BBU processing centre (Figure 3-10). We assume an existing leased line network for fronthaul/backhaul with no deployment costs (CAPEX) for the operator. Usually dark fibre is available in the networks to provide additional capacity and the incremental cost for this additional capacity will be our main focus. We provide a qualitative cost analysis in the following section for these incremental costs. Another related cost will be for the provision of 3D beam-forming and additional fronthaul handling capability for the selected 4G small cell eNBs. These 4G eNBs will need to be replaced with newer models with these integrated features. Only the selected 4G cells for the fronthaul provision will need to be replaced. The unit cost of a small cell eNB and the installation costs (mostly on lamp posts) will not be very high. The 5G gNB small cells (or RRHs) are assumed to be innately capable of providing this 3D beamforming functionality, so the above costs only relate to modifying the 4G small cell eNBs (or RRHs).

The specialized drones will need to carry the additional payload of the communication equipment, have longer battery life in operations, highly stable in air for connection of fronthaul links to the ground stations and also may need customized rotary blades as not to interfere with large (in element number) antenna arrays they will need to carry. Such specialized capability needs to be designed and manufactured, so the unit costs will be much higher than an off-the shelf drone. The specialized device costs will be higher than normal 5G devices mainly due to two reasons. Firstly, these need to have the specialized properties that we discussed above and secondly the production volumes of these devices will be much lower than mass market commercial devices.

The third main cost driver will be the costs of the spectrum to support this service. As this is designed as an on-demand service, assigning dedicated spectrum will severely underuse the resource and will not be economical. We will develop a scheme of licensed shared access with priority assigned to the proposed emergency on demand communication service. This will be an internal shared access scheme within the same operator running a commercial network and providing the emergency services network (including the 5G drone communications). This spectrum usage model is in line with the future emergency services networks moving into employing 4G LTE (and later 5G) – starting with first such deployments in UK in 2020. We will detail the main components of the cost model later in the dedicated subsection 3.5.2.3.

3.5.2.2 How to cost the additional capacity provision in FH and BH links?

As per the proposed deployment model in Figure 3-10, the drones will act as pure RRH units, with only the radio transmission capabilities. It would connect to the ground based small cells, which in turn will have the C-RAN functionality splits. In line with the broad assumptions in this chapter, we will consider split points 2 and 7 and see the likely increases in the fronthaul and backhaul capacities these options would entail. The quantitative cost analysis will be developed for the leased lines option, in line with the study done in the mmMAGIC EU project and reported above in subsections 3.1.3 and 3.1.4 of this chapter. This will be carried out in year 2 and will be reported in D2.3. For the qualitative analysis here, we will look at the key aspects that would influence a fronthaul and backhaul cost model.

The proposed emergency services communications would add a significant incremental capacity on the fronthaul and backhaul connections and it has to be assumed that this capacity needs to be provisioned at all points where the selected ground based 5G and 4G small cell gNB/eNB relaying capability is provisioned. Having more ground relay stations gives more flexibility in configuring the overall connectivity to the drone base station, may be with a fewer drone relays. This can push up the fronthaul and backhaul costs, while reducing the number of drone relays and related operational costs. On the other hand, having fewer ground relay stations could reduce the fronthaul and backhaul costs but would increase the number of drone relays and related operational costs. Also, there may be limits on the maximum number of relay drones based on the communication link set-up times and the link accuracies required. These aspects would lead to an interesting trade-off analysis, which we plan to conduct in the quantitative study during the second year of the project (to be reported in D2.3).

In dimensioning the incremental capacity on the ground based network from the drone supported emergency network – two possible scenarios can be considered. The emergency can occur within the coverage area of the group of 5G small cells (one of which provides the ground relay) and taking part of the spectrum away from the ground small cells would be necessary (as we discuss in the spectrum usage model in subsection 3.5.2.3). Realistically, this would not make a significant increment in fronthaul and backhaul capacity, as the 5G ground small cells would experience a capacity reduction similar to the amount of spectrum taken out. If the emergency occurs within a 4G small cell service area, the capacity increment will always happen, as only 5G spectrum will be used to provision the drone communication service. Secondly, the emergency can occur outside the 5G or 4G small cell coverage areas and a number of relay drones are used to connect this to a ground relay. In this case, the 5G spectrum is used effectively outside the coverage area of the small cells and only minimal impact on a 5G small cell can expected when a highly directional relaying beam connects the drone link to the ground relay station. Thus the drone related capacity would linearly increment the fronthaul and backhaul capacities when the emergency incident occurs outside the coverage area of the ground relay 5G small cells. As the capacity dimensioning has to be done for the highest possible strain on the fronthaul and backhaul networks, this linear increment scenario has to be considered. Thus, no multiplexing gains will be considered for the incremental capacity from the drone based ESN.

Also, it is likely (in an exceptional scenario) that the same 5G/4G small cell has to relay capacities from more than one drone supported emergency. We'd propose to use two incidents as a limit to dimension fronthaul and backhaul capacities of at least some of the small cells used as relays.

3.5.2.3 How to cost the 'on demand' use of spectrum?

Licensed spectrum is a significant cost in operator's CAPEX, but it gives the certainty of exclusive access for the operator to dimension, plan, construct and operate a cellular network based on this resource. For this drone based emergency communications service, we are looking at the emerging model in UK, where a commercial cellular operator will replace the TETRA based emergency communications network with a LTE based system in 2020 [HOME18]. Within this context, this likely 5G service that we are proposing will also need to utilize the commercial 5G spectrum. However, the emergency service communications are enacted only sporadically (in time and space) and this proposed 5G service on top of this is activated only on an 'on demand' basis. Hence, having dedicated spectrum would lead to severe under-utilization and we propose a methodology to cost the occasional use of commercial spectrum to support this service.

The proposed cost model is based on an internal Licensed Shared Access (LSA) mechanism within the operator's 5G spectrum. LSA schemes are actively studied by many regulators as a means to ease the growing demands on the scarce spectrum resource, as shown by the referred example study for UK spectrum policy forum [LH15]. The spectrum (by default) is allocated for the use in operator's commercial network. It is assumed that future 5G small cells will operate in wider bandwidths of at least 100 MHz. When the need for drone-based communications occurs, the required portion of the 5G spectrum will be transferred to the emergency services, on a priority allocation basis. The field tests on LSA [GUI16] have shown that this re-allocation process can be completed within 40 s between external entities demanding spectrum use. For an internal re-allocation model that we are considering here, this transition will be even quicker.

When a request is made for the usage for this drone based service, it should be determined if the incident has occurred in a 5G small cell coverage area (which uses the same spectrum) or outside of it. If the incident is in a 5G small cell area, the amount of spectrum needed to support the emergency services should be taken out of these impacted small cells and allocated to the drone communications. The spectrum re-allocation will impact the eMBB services the small cell is providing and this is likely to be the dominant application at least in the initial stages of 5G deployment. Spectrum is needed for radio access as well as fronthaul operations, down to a ground relay station. Additional amounts of spectrum will be needed for longer operations, when there is a need to replace the in-flight drones running out of battery power. This would entail a group handover operation to swap the active drone base station. This additional spectrum however is needed for only shorter amounts of time, until the handover process is complete.

The cost of the spectrum will be worked out on an opportunity cost basis. That is to determine the cost to the commercial network while the spectrum part is taken out to support the drone communications. The costs will vary as per the time of day, severity and duration of the incident etc., so the model estimates the costs retrospectively. The final cost bearer for the drone service would want to have some upper limits of the costs agreed beforehand – to ensure that the final costs do not surpass the estimated budget levels.

We would propose to calculate the opportunity cost based on the capacity demand that the operator’s commercial network could not support, due to part of the spectrum being taken up for the drone based service. This cost will vary from small cell to small cell and on the fact that how loaded were the affected cells during the spectrum part re-allocation. By looking at the actual capacity demand and the impact on this when the spectrum is curtailed, we can cost the real impact of spectrum re-allocation. Statistical capacity profiles per particular time of day and for variations like week day/ week end should be developed on historical data and used to compute what the commercial capacity demand would be at the time of a spectrum re-allocation. Also, non tangible factors’ like users experiencing poor QoE during these spectrum curtailment periods can also be taken into consideration in this cost model. Some statistics like the user complaints during this time period, from this location can be utilized to quantify some related opportunity cost here.

The emergency event itself can create a surge in capacity demand, as people will try to share videos, contact their loved ones etc. In our view, this demand should not be added to the opportunity cost the operator suffers due to spectrum re-allocation. It could otherwise be perceived as an attempt to profit from the emergency situation.

3.6 Potential evolution to quantitative study in D2.3

The techno-economic analysis for the four use cases described in sections 3.2, 3.3, 3.4 and 3.5 will be further extended in next deliverable (D2.3). The objective will be to provide a quantitative analysis of the various configurations envisioned in each case and that are summed up below.

3.6.1 Use Case 1: assisted, cooperated and tele-operated driving

For the automotive use case, the techno-economic analysis will compare the two scenarios considered for this use case, Megacities and Underserved Areas, under the different architectures proposed to develop V2X services, C-RAN and D-RAN (both with MEC nodes).

Firstly, a data collection process will be carried out where the cost information of all network elements present in both C-RAN and D-RAN scenarios as well as MEC node derived costs will be collected. C-RAN costs will be given as a fraction of D-RAN costs, as some costs such as power consumption costs, HW dedicated equipment costs, etc., do decrease thanks to centralization.

Secondly, CAPEX and OPEX analysis for the above-mentioned scenarios and architectures will be carried out by using mmMAGIC tool. In this analysis, different assumptions will be made to tailor the scenarios to V2X services requirements identified in **Table 3-2** and **Table 3-3** and taking as input the qualitative analysis performed throughout section 3.2.

Finally, the results obtained from the previous analysis will be studied and analyzed carefully to result in a comparative conclusion of the benefits/drawbacks of providing V2X services in Megacities and Underserved areas, under the approaches considered.

3.6.2 Use Case 3: smart cities

As stated in section 3.3, some quantitative analysis on cost deployments would be tricky with smart cities applications as it would be linked to software upgrades of LTE-M and NB-IoT technologies.

As for quantifying the need for additional resources for mMTC traffic, a whole analysis would be necessary. The objective would be actually to quantify the resource sharing between eMBB and mMTC traffic. This means traffic hypotheses (message frequency, payload size, BS deployment, propagation model, device repartition, percentage of devices at the edge of coverage etc…) and capacity analysis. A close follow up of 3GPP discussions will be carried out to try to establish such scenarios and provide such quantitative analysis in D2.3.

3.6.3 Use Case 4: long range connectivity in remote areas

For every site configuration (summed up in Figure 3-9), the techno-economic study will take into account all the network costs in order to derive a TCO per site configuration:

$$TCO\ (1\ year) = CAPEX + OPEX$$
$$TCO\ (5\ years) = CAPEX + 5 \cdot OPEX$$

CAPEX part will include costs related to site/mast, antenna installation, gNB, antennas, fronthaul/backhaul, energy equipment etc.

OPEX will include costs related to energy consumption, backhaul OPEX, site renting, maintenance for RAN, solar energy, site etc.

The cost assumptions in centralized and distributed networks, as reminded in subsection 3.1.3, such as hardware pooling gains, energy consumptions and number of sectors, will be used. The same way, for cost network quantitative evaluation, the use of mmMAGIC formulations [mmM17-D14] reminded in subsection 3.1.4 will be used.

Thanks to link budget studies, the covered area for each site configuration will be derived. TCO per area unit will give a good insight on network profitability in ultra-rural and rural environments.

3.6.4 Use Case 9: ad-hoc airborne platforms for disasters and emergencies

The quantitative study in the D2.3 will consider two main areas. The first area will be to estimate fronthaul and backhaul capacity needs for this proposed solution, and look at the incremental cost of provisioning such fronthaul and backhaul links. A leased line model will be considered (in line with the mmMAGIC D1.4 assumptions as detailed in subsection 3.1.4), and the incremental cost of this additional capacity will be estimated. The second area will be the opportunity cost estimation for the prioritized shared use of spectrum (internal LSA model) for this ‘on demand’ service from the commercial 5G usage.

Both studies will rely on estimating the capacity demand from this proposed ‘on demand’ 5G emergency communication service. We will use realistic assumptions about the application types demanded from such a service and estimate the cumulative capacities that would impact the fronthaul/ backhaul and spectrum provision. We will also study the service deployment costs and the likely trade-offs in having longer relay chains with fewer fronthaul and backhaul supported ground nodes and vice versa.

The quantitative studies will be synchronized with the other techno-economic study items through the use of similar C-RAN centralization options. By using the split points 2 and 7, this study will also be highly relevant to any of the cellular operators who may consider deploying such a drone based network in future, in an extension of the emergency services networks.

4 Conclusions and future work

The work presented here in D2.2 covers the initial results from the evaluation of two selected TeCs in the system level simulator and the qualitative techno-economic analyses of four selected use cases. Both these work areas should be treated as a work in progress leading to the second year of the project, where the final results will be reported in D2.3.

Chapter 2 provides a detailed account of the overall simulator development and the adaptations to support the two selected TeCs plus their first related results. The TeCs are considered in isolation in these initial analyses. Only eMBB traffic is considered and only the downlink is simulated.

The results for the centralized multi-cell scheduler demonstrate significant gains in both the average downlink throughputs per user and per km^2 area, with the proposed TeC. Also the fairness of the applied scheduler is demonstrated by CQI distribution results, which show notable representation of lower CQI even with very high user densities. Therfore the initial results validate the benefits of the core TeC implementation to a high degree.

The results for the component carrier manager indicate that while the downlink average throughputs are not improved, the average latencies are significantly reduced by the proposed solution. This can point to a key benefit in eMBB applications like AR (Augmented Reality) and VR (Virtual Reality) where the enhanced data rates as well as the low latencies are critical for a good user experience.

Several simulator test cases have also been evaluated for eMBB, mMTC and combined URLLC/mMTC service categories. The related results demonstrate how the average latency and throughput gets affected when the number of users are increased up to 9975 in the eMBB test cases and up to 200,000 in mMTC related test cases. The eMBB related results indicate that both the average latency and average throughput are impacted when the number of active users reaches the noted upper limit. The mMTC related results show that while the average latency is severely impacted when the number of devices increases closer to the upper limit, there is little impact on the average throughput.

The qualitative techno-economic analysis on four selected use cases is presented in Chapter 3. The general guidelines for C-RAN deployments are noted as per the 3GPP recommendations and the related Fronthaul and Backhaul cost models are developed in line with the work done in mmMAGIC project [mmM17-D14]. The Automotive and Drone based D&E communications use case studies indicate how the C-RAN options are utilized in their respective analyses. The overall costs of including the proposed MEC servers in the Automotive use case and the Fronthaul and Backhaul costs in relaying the Drone RRH traffic are directly impacted by the C-RAN options. The Smart city and Long range connectivity use cases detail the overall deployment models and options they investigate and the plans to align with the suggested C-RAN options.

In future work, four other TeCs from WP3 and WP4 will be evaluated in the simulator in the second year and also the likely performance gains from applying all these TeCs in combination will be assessed. The results will be compared against a baseline 3GPP Rel. 14 and Rel.15 system. On developing the current TeCs further, higher frequency re-use schemes like NOMA and CoMP will be considered for the centralized multi-cell scheduler. For the component carrier manager, the current dual connectivity will be extended to multi-connectivity. Different traffic types expanding eMBB to URLLC and mMTC will be considered for both TeCs in the second year, while the analysis will also cover the uplink.

The techno-economic studies will be extended to quantitative assessments, which can demonstrate the likely costs with more realistic deployment assumptions. Also the current four separate studies will have some alignment through the utilization of common C-RAN options and the usage of network slicing themes.

References

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