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This deliverable describes the work done during the first six months of DREAM in Work Package 1.

The proposed radio solution operating in D-Band with steerable antenna, capable to carry up to 100Gbit/s has been studied and improved. The requirements for DREAM radio solution (capacity, latency, hop length and availability) have been derived looking into 5G and considering a possible evolution.

Then, considering this set of network requirements, we have provided a first analysis and estimation of the solution feasibility. In particular, the most important aspects considered were:

- Whether and how the solution can satisfy the network requirements
- Whether the spectrum resources in D-Band are sufficient
- Whether the solution satisfies the requirement to make feasible a meshed network in urban environment
- Whether the solution is feasible using the DREAM technologies and approach

Considering that all checks above have been concluded with a positive result, we have proposed the identified solution as the candidate solutions for DREAM project.

A deeper analysis of all these points will be carried out in Task 1.2, considering the feedbacks as well from the others DREAM project tasks.

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Contents

List of abbreviations

ACM	Adaptive Coding and Modulation
ATPC	Automatic Transmit Power Control
ATTM	ETSI TC-Access Terminals, Transmission and Multiplexing
BB	Base Band
BBER	Background Block Error Ratio
BER	Bit Error Ratio
BW	BandWidth
BWA	Broadband Wireless Access
CCDP	Co-Channel Dual Polarized
CEPT	Conférence Européenne des administrations des Postes et des Télécommunications
CS	Channel Separation - Channel Spacing
C-RAN	Centralised RAN
D-Band	Frequency band 130-174.8 GHz
EC	European Community
ECC	Electronic Communication Committee of the CEPT
EIRP	Equivalent Isotropically Radiated Power
FD	Full Duplexer
FDD	Frequency Division Duplex
fFDD	flexible Frequency Division Duplex
FEC	Forward Error Correction
FS	Fixed Service
FWA	Fixed Wireless Access
HDFS	High Density Fixed Service
IEEE	Institute of Electrical and Electronics Engineers
ISD	Inter Site Distance
ITU-R	International Telecommunication Union - Radiocommunications standardization sector
ITU-T	International Telecommunication Union - Telecommunications standardization sector
LAN	Local Area Network
LoS-MIMO	Line-of-Sight MIMO
MIMO	Multiple Input - Multiple Output
MP	Multi Point
MP-MP	Multipoint-to-Multipoint
NF	Noise Figure
NLoS	No Line of Sight
OJEU	Official Journal of the European Union
P-MP	Point-to-Multipoint
P-P	Point-to-Point
QAM	Quadrature Amplitude Modulation
RAN	Radio Access Network
RBER	Residual BER
RF	Radio Frequency
RIC	Radio Interface Capacity
RPE	Radiation Pattern Envelope
RR	Radio Regulation
RSL	Receiver Signal Level
RTPC	Remote Transmit Power Control
RX	Receive or Receiver
SR	Symbol Rate
STM-N	Synchronous Transport Module, level N
TDD	Time Division Duplex
TX	Transmit or Transmitter
W-Band	Frequency Band 92-114.5 GHz
WGSE	Working Group Spectrum Engineering
XPD	Cross-Polar Discrimination
XPI	Cross-Polar Interference
XPIC	Cross-Polar Interference Canceller
ZDD	Zero Division Duplexer

List of symbols

°	degree
CSmin	minimum practical Channel Separation (for a given radio-frequency channel arrangement)
dB	deciBel
dBc	deciBel relative to mean carrier power
dBi	deciBel relative to an isotropic radiator
dBm	deciBel relative to 1 mW
Gbit/s	Mega-bits per second
GHz	GigaHertz
m	metre
Mbit/s	Mega-bits per second
MHz	MegaHertz
mW	milliWatt
ns	nanosecond
ppm	parts per million

1. Introduction

The first goal of the document is to derive a set of requirements for D-Band radio solutions enabling an up to 100 Gbps reconfigurable approach for meshed beyond 5G networks that fulfil the requirements of “beyond 5G” telecommunication network scenarios.

The second goal is to carry out a first analysis of the DREAM solution feasibility.

In the following, we will provide a short overview of the 5G mobile networks and we will identify the main requirements of the transport networks. Then considering the 5G requirements, we will derive, what could be the “Future network beyond 5G” requirements, in term of Capacity, hop length, Availability, Latency, Network topology and so on to be considered as the DREAM input.

Based on the “Future network requirements beyond 5G” defined and taking into account the frequency resources of the D-Band, starting from the initial DREAM solution, we will propose an improvement of such solution to be used as the candidate solution for project DREAM.

A first rough estimation about the candidate solution, either in term of feasibility and compatibility against the network requirements is provided as well, anticipating here, the deeply studies devoted to validate the solution that will be carried out in T1.2.

Considering that, we would like to exploit the DREAM results and finding in future commercial products, particular attention to the radio regulation (Frequency plan, mainly) and the Standardization aspects (Radio requirements) are taken into account.

2. Transport network for Next generation

4.x and 5G are the next evolutionary steps in telecommunication networks and they will introduce new constraints on the transport network. 5G in particular will find use in many high-end applications such as extremely fast broadband, massive machine-to-machine communications and critical machine communication. The evolution of 5G mobile networks has then to cope with serving higher traffic loads than today with different and inhomogeneous requirements.

In general, the different applications will place their own stringent demands on the transport network's capacity, reliability, energy efficiency and latency.

Another factor is the development of new Radio Access Network (RAN) architectures, adding centralized RAN and cloud RAN to the well-known distributed RAN and introducing new fronthaul interfaces. These different architectures have very different latency and capacity requirements on the fronthaul interface itself.

In this document we will concentrate on the network infrastructure evolution, particularly the transport section which connects the access part of the network (RAN) with the core.

Among the different transport technologies, wireless radio (microwave and millimiter wave) is considered a suitable solution, often with lower cost than fiber.

To highlight the role of the radio solution in a transport network, it may be worth to consider that today according to analysts over 50% of Mobile Sites worldwide are connected via Microwave or millimiter wave radio links (up to over 90% in some networks).

For this reason, a radio transport network is forced to evolve as well to avoid becoming the bottleneck and thus not limiting the capacity and performance of the whole system.

In the recent years, different techniques have been introduced in wireless transport in order to enhance the capabilities and moreover new spectrum bands have been used for Gbps speed and lower latency: V/E bands (60-80 GHz) are the last introduced, while W (90GHz) and D-Band (130-175 GHz) are currently under analysis.

In this document, the objective is to derive a set of network requirements for future wireless networks beyond 5G to be used as DREAM input.

We circumscribe the possible DREAM's application area to the range of tens Gbps over distances of few hundred meters, therefore full outdoor solutions for backhauling/Fronthauling or similar applications, including Fixed wireless access (FWA). Some example of use cases and scenarios will be listed together with their requirements for future wireless transports with some consideration for scaling up to a beyond 5G scenario.

2.1 Towards 5G

Today's 4G networks use LTE, which is primarily designed to carry mobile broadband traffic. 5G differs from 4G LTE in that it will be natively designed not for a single traffic type, but for multiple types with different requirements. 5G will not only be a 'new radio access technology family' but will expand to multiple dimensions by providing a common core for numerous radio technologies (cellular, Wi-Fi, fixed), multiple services and network operators. 5G applications are usually segmented into three categories:

1) Extreme broadband to dramatically boost throughput and provide reasonable speed everywhere
2) Massive Machine-to-Machine (M2M) communication to connect billions of sensors, meters and machines.
3) Critical machine-type communication allowing immediate, synchronous eye-hand feedback to enable remote control over robots with stringent requirements for latency and reliability.

One of the main effects on transport will be to force it to become more dynamic to handle different kinds of services, with widely varying requirements for such things as mobility, reliability, latency and energy efficiency.
For instance, mobile broadband will require huge capacity (reaching more than 10 Gbps as peak data rates) and video caching capabilities. Massive IoT will instead need high density but without mobility.
And mission-critical applications will be more about low latency and high reliability.

The Figure 2.1.1 taken form [2] tries to summarise the major challenges foreseen today for 5G networks.

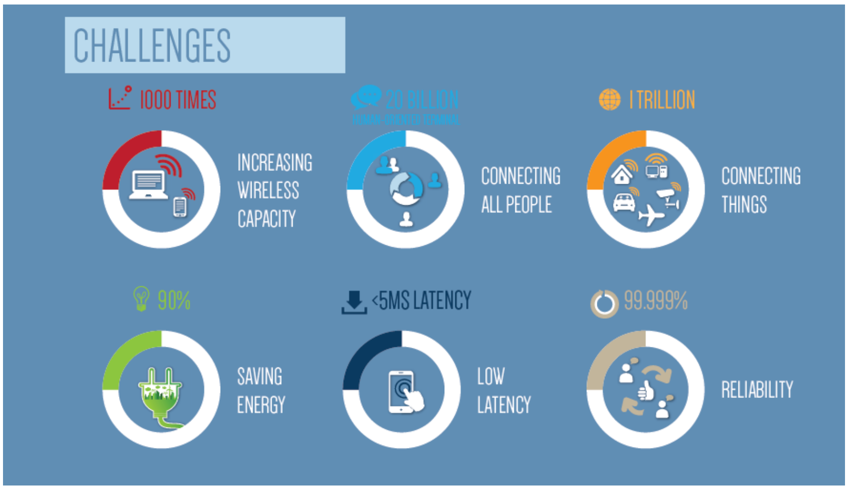


Figure 2.1.1. 5G major challenges

Such different requirements will demand different network solutions (the evolution of existing network and potentially new networks) and different deployment models (including dense small cells), an appropriate network infrastructure (which will include both fibre and wireless connectivity to the core network) and access to different spectrum bands.

One of the most important requirements is the increasing of the wireless capacity (speed) that has to be provided to devices that can be mobile or at least nomadic, and therefore through a wireless access system, a RAN network. Associated with the capacity, we will note the low latency requirement, that is associated just to some services, the most time critical.

Concerning the reliability, there could be some 5G critical services, which would require up to 99.999% and more. It should be noted here that latency and reliability are concept connected to an end-to-end service.

A good reference concerning current 5G study on scenarios and requirements for next generation access technologies can be found in [6] [7] [8].

The following Figure 2.1.2, shows the breakdown of Bandwidth (capacity) and latency requirements for all potential 5G use cases. This is useful to have a first reference of the real numbers we can expect.

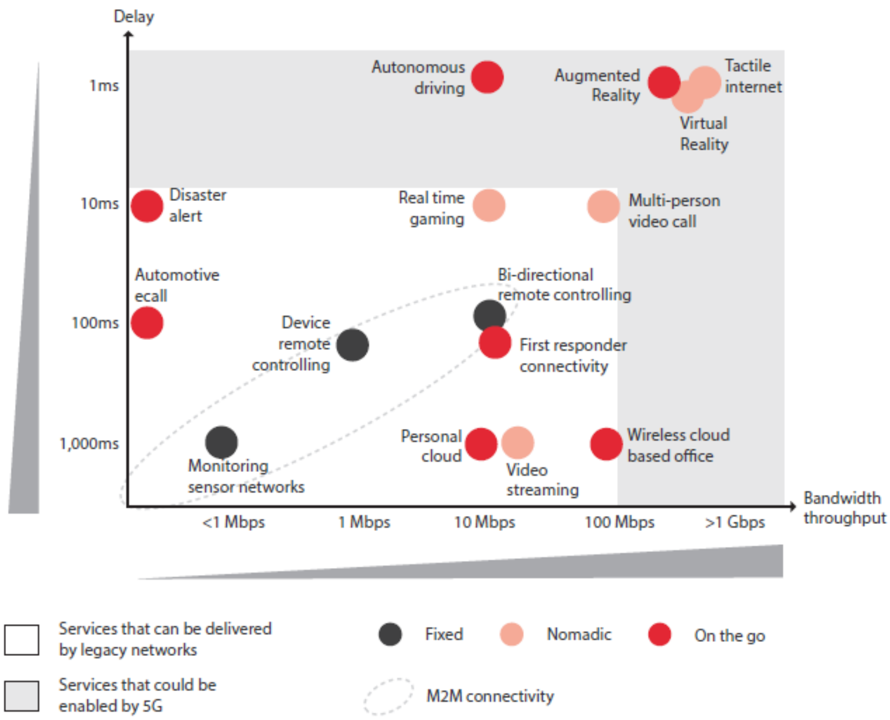


Figure 2.1.2. Potential 5G use cases: Bandwidth and latency requirements [3]

It may worth noting here that, mobile and nomadic services, then the services shall be served by the RAN, includes the most demanding in terms of Bandwidth demand (Capacity) and Delay (Latency) as well. Services requiring even more that 1Gbit/s and less than 1ms are foreseen.

The following Figure 2.1.3 shows the 5G RAN spectrum evolution where mmWave bands, allowing huge channel size compared with traditional RAN bands below 6 GHz, are considered

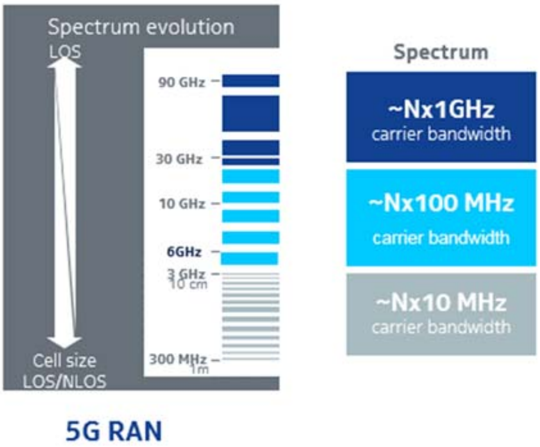


Figure 2.1.3. 5G RAN spectrum evolution

The availability of frequency spectrum is a critical component of wireless networks. The diverse set of services and applications enabled by 5G will require access to different spectrum bands with different characteristics:

- Spectrum at lower frequencies, below 6 GHz, allowing channel size of nX10MHz and good propagation conditions, to enable 5G coverage to wider areas;
- Spectrum at higher frequencies with large channel size, nx100MHz and moderate propagation conditions, to provide the necessary capacity to support a very high number of connected devices and to enable higher speeds to concurrently connected devices; and
- Spectrum at very high frequencies above 24 GHz and today considered up to 86GHz with channel size in the order of GHz, for providing ultra-high capacity at very low latency.

A detail about the 5G candidate bands could be find in the RSPG 'Work Programme for 2016 and Beyond' [4] or in the CEPT Roadmap for 5G [5].

The RAN cells at frequencies above 24 GHz, today foreseen at 26-28GHz and 60GHz, will have very small coverage. Therefore, it is likely that 5G networks in millimeter wave bands will be deployed on urban areas only and where services requiring high traffic and low latency will be requested.

Now we can pass to consider the transport network. From here on, we will concentrate our attention on the RAN evolution in higher frequency bands only and the relevant needs in transport segment of the network. This is pertinent with the DREAM scope as in our proposal addressing an approach for dense network.

The Figure 2.1.4 summarises the impact of the Radio Evolution towards 5G on the Transport Network.

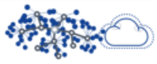
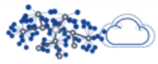
RAN	lte	lte	5G RAN - Sub 6GHz	5G RAN - cm & mm waves
Density	10-20 BTS/km²	20-50 BTS/km²	20 – 50 AP/km²	150 - 300 AP/km2
Throughput: MHz and bps	20Mhz+20Mhz+20Mhz / 256QAM ~1 Gbit/s	LAA / LWA >1 Gbit/s	n x Gbit/s	10 Gbit/s
Transport Network impact	• Fiber & Microwave • Latency: 5-10ms • Phase & Time (CA, CoMP)	• Fiber &Microwave • Short MW hops (E-Band) • Latency 2.5-5 ms • Phase & Time (CoMP, CA, eICIC)	• Fiber & Microwave : FH, XH and BH • Shorter Radio hops (E-Band, W/D Band) • Latency: few ms • More stringent Phase & Time	
Topology & Architecture				
RAN	D-RAN / C-RAN	CloudRAN w/ Ethernet FH	• Cloud RAN w/ Ethernet • FH, SDN & SON, Network Slicing	• Cloud RAN & massive SC deployment, • SDN, SON, Network Slicing

Figure 2.1.4. Impact of the Radio Evolution towards 5G on the Transport Network

We observe that, the transport network evolution to support 5G RAN has to cope with requirements in term of capacity, latency, Hops lengths, but also has to support different transport model, ranging from Backhaul, XHaul up to Fronthaul imposing stringent requirement as capacity and latency. Last but not least, even the transport network topology has to evolve from what is today, based on tree topology and few rings, to something closer to a full connected topology, the meshed network, managed from a central control.

Small cells are currently a focus of research leading to new challenges for the backhaul network because of their dense deployment. The forecasted rise in traffic demand of mobile users has to be met with new network architectures. While the trend of reducing the cell area coverage improves the spectrum spatial efficiency by allowing the carrier frequency reusing, at the same time it imposes challenges in cell edge intelligence and distributed cell control in order to avoid degrading the spectrum temporal efficiency due to the small cell high-density area.

Two main aspects may be worth to analyse here are:

- the C-RAN approach, having an impact on data traffic and latency that has to be supported inside the Transport network
- the maximum connection length that has to be supported having impact on transceiver and antenna performances.

2.1.1 C-RAN approach

An important aspect that has to be considered is the trend to centralize some network functions (including signal processing and management) in a so-called “cloud”. In this scenario, transport plays an even more crucial role: the more processing takes place in the cloud, the more data (either user or control plane) have to be carried by the transport network.

Connectivity to cell sites is still predominantly based on BH, but FH is increasingly used with the growth in C-RAN deployments. It will further evolve with the inclusion of Ethernet fronthaul, particularly well-suited for densified networks. Here are in the following some more information about the RAN evolution and the consequent impact on transport network.

In Distributed RAN, the most popular RAN configuration serving today 2G/3G/4G services, Radio and baseband functions are collocated at the cell site:

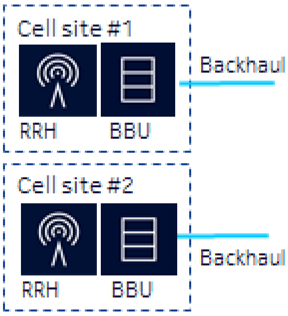


Figure 2.1.5. Distributed RAN

This approach foresees a traditional connectivity towards the core network, which is the backhaul (mainly Ethernet based).

In the Centralized RAN radio functions are located at cell site, while all baseband functions are centralized and fronthaul (FH) is based on CPRI or similar interfaces like OBSAI.

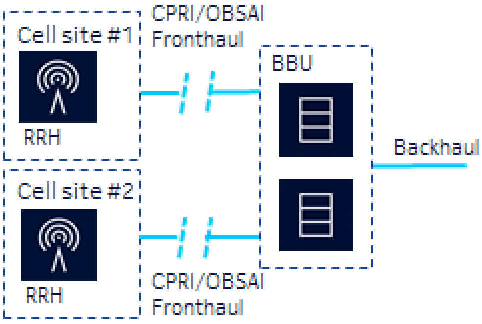


Figure 2.1.6. Centralised RAN

To be noted that, in the Centralized RAN, backhaul is still used for network interconnection. The ultimate evolution of the RAN network is called Cloud RAN, where baseband functions are split between radio site and the cloud. This approach is also leveraging on Virtualization of Network functions (VNF).

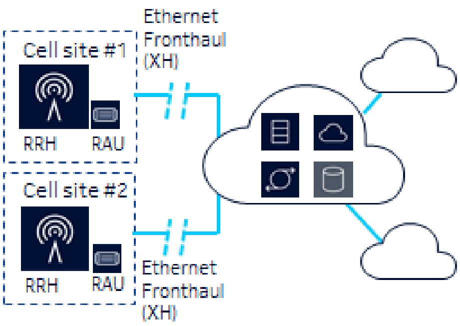


Figure 2.1.7. Cloud RAN

Ethernet fronthaul, a set of new fronthaul interfaces are being defined and referenced here after with X-Haul (XH), is used to interconnect these functions. Backhaul is still remaining to be used for network interconnection.

In the C-RAN model the FH, according to NGMN's specifications, has strict capacity and latency requirements driven by the CPRI interface itself. In Figure 2.1.8 an example for the LTE cases and 5G.

		LTE	LTE-A	5G
BW	MHz	20	40	100
Number Antenna	Antenna	2	4	16
Sampling Bit-Width	bits	30	30	30
Sampling Freq	MHz	30.72	61.44	153.6
Payload (IQ Data Rate)	Gbps	1.84	7.37	73.73
CPRI Rate	**Gbps**	2.45	9.83	98.31
		CPRI 3	CPRI 7	Not Specified

Figure 2.1.8. Example of CPRI's rate for LTE, LTE-A and 5G

It should be noted that CPRI/OBSAI interface are not scaled effectively to meet 5G bandwidth requirements and CPRI rate up to 100Gbib/s can be easily required.

In densified networks with small cells, the need for fiber-based transport creates a big challenge in C-RAN deployments. The new approach for FH interface, leveraging on Ethernet and functional splits, offers a way to address the cost and availability of transport solutions by keeping some of the BBU functionality at the cell site.

This allows reducing the capacity and latency requirements of the XH – the link connecting the cell site to the remote baseband. The XH does not require the use of the CPRI interface, enabling the use of a variety of wireline or wireless solutions.

More details about CPRI, eCPRI and functional Splits, can be found in [9] [10] where different options or level, up to 8, not yet well defined are today envisaged for XH.

With a functional split RAN, topologies are easier to deploy and the underlying business case improves. On the downside, however, functional splits may impose a cost/availability versus performance trade-off, because the split might limit the ability of the RAN to manage interference, hence reducing the scope for RAN performance optimization.

Looking now at the transport network to cope with RAN evolution, here below it is provided a simulation of three possible 5G RAN site configurations and an analysis of transport network requirements (mainly Capacity and latency).

The Figure 2.1.9 reports capacity and latency requirements a transport network has to fulfill, to serve three diffferent RAN sites when four different approaches are adopted, from traditional Backhaul up to CPRI Frount Haul.

It should be worth mentioning here that this is just a pure exercise to point out the main differences in requirements that different transport network architectures may require.

A suited radio transport network architecture should be chosen, among what is feasible, according to the rigth tradeoof between the RAN performances needs and TCO (including here the cost of the transport).