ETSI GR mWT 015 V1.1.1 (2017-11)

Frequency Bands and Carrier Aggregation Systems; Band and Carrier Aggregation

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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) millimetre Wave Transmission (mWT).

Modal verbs terminology

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Executive summary

More and more demanding requirements will challenge the wireless transport in the near future. Therefore it appears necessary to investigate new approaches in order to meet such needs.

"Bands and Carrier Aggregation" (BCA) is one of these possible concepts, as it could be exploited to enhance radio link performance in different aspects.

Combining multiple frequency bands over the same link could in fact provide several benefits, on top of plain throughput increase, leading to an efficient use of the available spectrum. This appears to be one of the most critical point taking into account the ongoing network evolution towards 5G.

BCA could be implemented through different arrangements, depending on the application. For each of these, some new considerations in terms of network design apply, as the propagation aspects can be very different depending on the spectrum options aggregated over the radio link. The overall BCA network design, often providing multiple capacity levels with different availability, will have to fit the variety of services that need to be transported (along with their SLAs).

Another fundamental aspect, when BCA is concerned, is represented by the regulatory and licensing framework: it is indeed important that the benefits provided by such new technology are known and supported in order to boost as much as possible its usage where applicable.

1 Scope

The present document describes the "Bands and Carrier Aggregation" (BCA) concept, along with associated use cases and benefits for transport networks.

A specific clause deals with technological advancements related to BCA, such as multi-band antennas and wideband RF components.

Another aspect is related to possible barriers to the adoption of BCA in the existing standards/regulations or to proposals for incentives and discounts in the frequency licensing when BCA is implemented, due to its benefits in terms of efficient spectrum usage.

It should be noted that the BCA concept described in the present document is not referred to "Channel aggregation" system as described in ETSI EN 302 217-4 [i.3]. In fact BCA represents a much wider scope, only one of the possible BCA arrangements being a "channel aggregation" system.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI TR 103 103 (V1.1.1): "Fixed Radio Systems; Point-to-point systems; ATPC, RTPC, Adaptive Modulation (mixed-mode) and Bandwidth Adaptive functionalities; Technical background and impact on deployment, link design and coordination".

[i.2] ETSI White Paper No. 15: "mmWave Semiconductor Industry Technologies: Status and Evolution".

[i.3] ETSI EN 302 217-4: "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 4: Antennas".

[i.4] ETSI White Paper No. 09: "E-Band and V-Band - Survey on status of worldwide regulation".

[i.5] ETSI GR mWT 008: "Analysis of Spectrum, License Schemes and Network Scenarios in the D-band".

[i.6] Contribution to ECC PT SE19 meeting #76 28-30 March 2017: "SE19 (17)11 WI 37&38 BCA concept - NOKIA".

[i.7] ETSI GR mWT 016: "Applications and use cases of Software Defined Networking (SDN) as related to microwave and millimetre wave transmission".

3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

4G	Fourth Generation of Mobile Networks
5G	Fifth Generation of Mobile Networks
ACM	Adaptive Coding and Modulation
ATPC	Automatic Transmit Power Control
BCA	Bands and Carrier Aggregation
ECC	Electronic Communication Committee
PDH	Plesiochronous Digital Hierachy
P-P	Point to Point
RF	Radio Frequency
TCO	Total Cost of Ownership
TDM	Time-Division Multiplexing
W-Band	band from 90 to 114,5 GHz
Wi-Fi	Wireless Fidelity
XPIC	Cross-Polarization Interference Cancellation

4 Bands and Carrier Aggregation concept

The requirements which will challenge the wireless transport evolution depend on the services to be transported and can be very different (and even conflicting) in terms of throughput, latency, QoS, availability, etc.

The radio resource has to provide the capability to satisfy different KPIs for different services in order to meet end to end committed traffic SLAs.

Bands and Carrier Aggregation (BCA) is a concept enabling an efficient use of the spectrum through a smart aggregation, over a single physical link, of multiple frequency channels (in the same or different frequency bands).

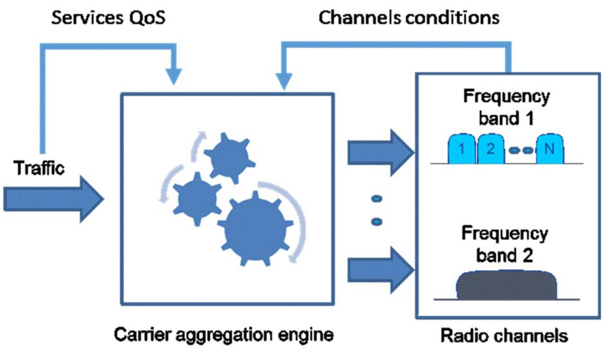


Figure 1: BCA concept

A logical scheme of the BCA includes a carrier aggregation engine and different physical radio channels. Most of the BCA benefits can be obtained thanks to the engine design which takes into account both the required traffic QoS and the conditions of the radio channels.

Radio channels (same or different frequency band) can be different in terms of:

- Channel size.
- Capacity and latency (according to the adopted radio profile).
- Availability - due to different frequency band and different results of the engineered link (solution performance linked to antenna size, system gain, etc.).
- Fixed or adaptive modulation scheme.
- License scheme - subjected to interference-free operation or not.

- License cost fees.

In practice, transmitting multiple channels from different frequency bands over a single physical link can be seen as an additional technique used to increase capacity in wireless domain, on top of traditional ones such as adaptive modulation, XPIC and packet compression.

Spectrum being a critical asset, and it is fundamental to implement methods which can efficiently use the available spectrum without wasting resources and adapt as much as possible radio portions to the input traffic needs.

For most of the different BCA use cases, it is worth noting that when assuming a target with the same level of error performance/availability, the link budget design may result differently than what is obtained in traditional cases without BCA. This will depend on how the traffic is distributed, and it is therefore strictly correlated to the proprietary carrier aggregation engine implementation. As explained in the Long-Haul application and depicted in clause 5.1, in some cases less fewer frequency channels may be needed.

Some basic indications for the link budget, mainly in term of availability, are provided in following pages, case by case.

In the next clauses of the document it will be explained why BCA is a smart method to achieve such objectives.

5 Applications and use cases for Bands and Carrier Aggregation

5.0 Introduction

BCA is mainly applicable to mobile backhaul/fronthaul applications and to wireless transport in general (including Fixed Broadband Access transport connectivity).

Main use cases applicable to BCA are listed here.

5.1 Channels aggregation in low microwave frequency bands (Long Haul application)

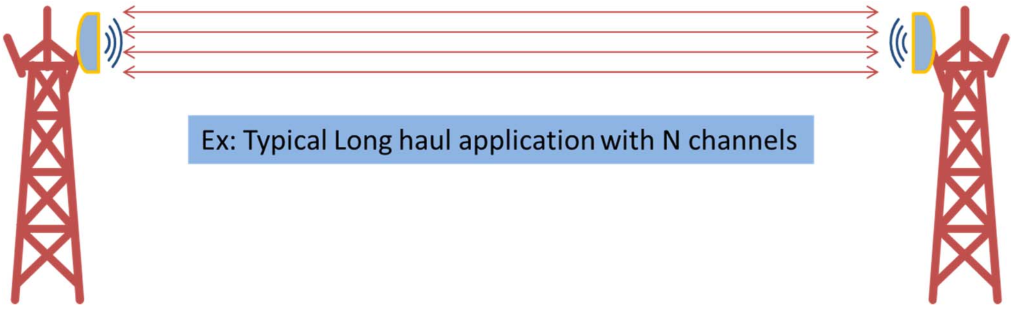


Figure 2: BCA in low microwave bands

In long haul transport, aggregation of multiple channels over a single antenna and radio link is a known technology. Those channels can be in the same frequency band or in different frequency bands, increasing the protection towards selective fading which is in fact the main impairment applicable to low frequencies. A typical case, widely used by some operators, is aggregation of 6 GHz or 7 GHz and 11 GHz, but also other combinations are possible.

Historically this kind of application has been serving SDH multi-hop transport for long distances (up to 150 km). More recently a smooth migration from TDM transport to full Ethernet and an increasing request for capacity has led to higher demand for carrier aggregation systems reaching multi-Gbit/s transmission.

This migration requirement has corresponded to a shift from traditional N+1 transmission scheme (with one dedicated spare channel) to N+0 configuration.

Microwave N+1 protection mechanisms had a rigid association between the SDH/SONET container (for example, STM1/OC3) and the related radio channel. The resulting traditional N+1 protection mechanisms had N channels used to transport NxSTM1/OC3 flows, and a spare protection channel that, when idle, could be used to carry low priority SDH/SONET traffic.

With the introduction of LTE, mobile backhaul networks are smoothly shifting from TDM-based networks to Ethernet and IP packet networks. Due to this shift, it is getting more difficult and inefficient to reliably scale microwave links with traditional microwave N+1 approaches. Packet microwave solutions based on N+0 and a smart carrier aggregation engine can provide better availability than N+1 (considering the same reference throughput).

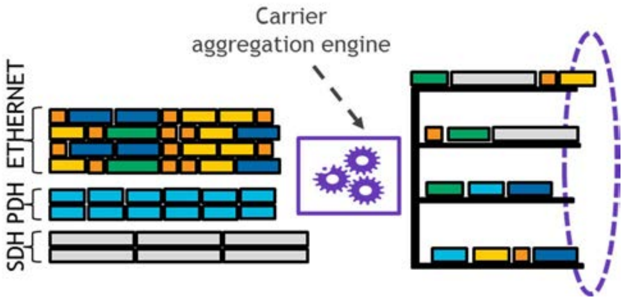


Figure 3: Distribution of traffic flows in BCA

Basically N+0 implements a BCA system in which a carrier aggregation engine distributes traffic flows over a bundle of radio channels (all active), which may have different frequency bands, polarizations and/or channel spacing. The radio channels are dynamically changing their bandwidth thanks to Adaptive Modulation, following propagation impairments.

Therefore, in case of N+0, capacity is not statically assigned to a channel but is spread over different radio channels exploiting high order modulation schemes. This allows the possibility to transmit the same level of capacity than traditional N+1 at the same or better availability, thus saving one radio channel (and its associated cost). This saving is granted by a packet microwave system, especially if some TDM traffic has to be transported to support a smooth migration to full Ethernet/IP, while for hybrid systems in such case an N+1 transmission scheme is more appropriate.

From availability point of view, in this case, where the major propagation impact derives from multipath, all channels can typically be planned with the same degree of availability (for the relevant reference modulation). Planning/licensing procedures are not different from channel to channel. Therefore, channel behavior differences are linked only to the variable capacity versus availability due to the use of adaptive modulation.

Summarizing, the main benefits of a BCA system based on N+0 are:

- The capability to bundle heterogeneous radio channels increasing granularity.
- The capability to transport different traffic types (PDH, SDH and Ethernet) in the same radio pipe.
- The possibility to avoid the need to duplicate traffic flows (e.g. TDM) on air to provide protection, thus saving also spectrum/bandwidth.
- The increased availability (considering same capacity).
- The possibility to send a single big pipe (e.g. 1 or more Gbit/s) on multiple channels.

5.2 Channels aggregation in medium microwave frequency bands

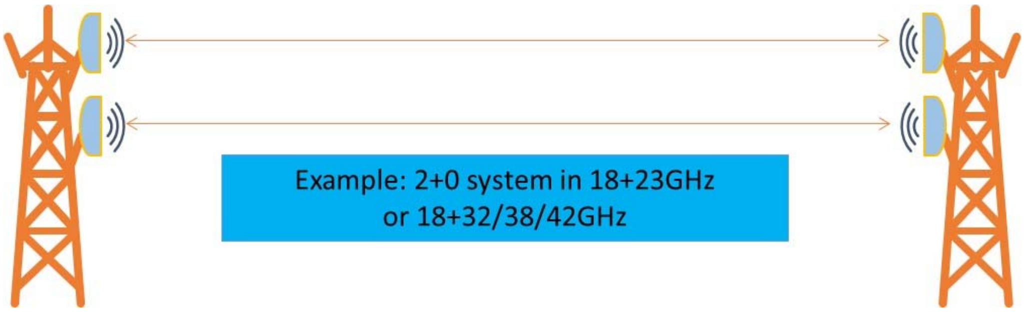


Figure 4: BCA in medium microwave bands

Channels in traditional microwave frequencies can be aggregated over the same or different bands in order to increase capacity (and over 1 Gbit/s) and to address spectrum limitations. In many cases in fact the required bandwidth cannot be found in a single band due to spectrum congestion: a given operator may not have the sufficient number of channels in a given band to reach the required capacity to cover backhaul need in a specific area.

Thanks to BCA a link can be engineered to provide the required QoS for the transported traffic, with maximum achievable distance depending on the bands which have been aggregated. For instance, an interesting aggregation is the one involving low/medium adjacent frequency bands, providing capacity increase with a link length in sub-urban environment (e.g. 10 km), combining over the same link frequencies in the range 15 - 23 GHz.

From the point of view of availability, in this case, where the major propagation impact derives from rain, the higher band channel could be planned with the same degree of availability (possibly playing with different reference modulation and or antennas) only when the bands are contiguous or close-by (e.g. 18 + 23 GHz case). When the band gap is higher (e.g. 18 + 38 GHz), this is no longer possible (unless in a very dry territories) and the higher band channels would offer a lower availability (depending on the rain zone and hop length) than the one of lower band channel. Consequently, planning/licensing procedures may be the same or be different (in term of availability target) from band to band.

5.3 Microwave and mmW channels aggregation

Figure 5 shows an example where a dual band antenna combines a dual polarization at 18 GHz with one E-Band feed (i.e. composing a 3+0 system).

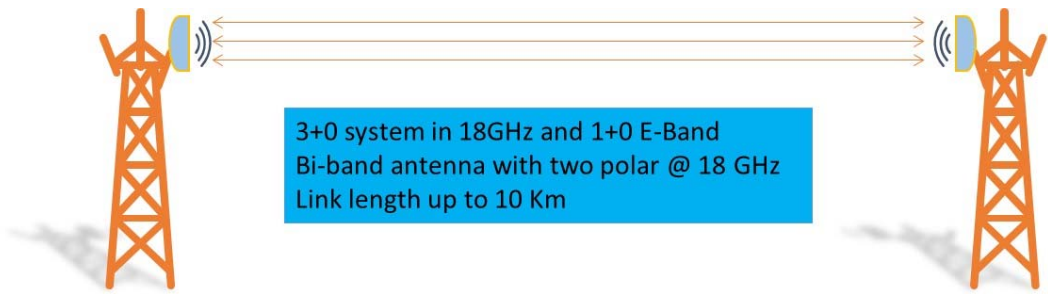


Figure 5: BCA in medium microwave bands plus E-Band

- As first example mmW seen as complement of high microwave bands to increase capacity, addressing spectrum congestion (e.g. 38 GHz + 80 GHz).
- As second example mmW seen as complement of medium microwave bands to increase capacity and extend link distance. In such case microwave band would serve most critical services at highest availability, while mmW band would serve data-hungry applications for the majority of time.

From the point of view of availability, also in this case, the major propagation impact derives from rain. The band distance is very high (e.g. 18 + 80 GHz) and the higher band channels would offer a relatively significant lower availability than that of the channel in the lower band. Nevertheless, the far larger channel size/capacity in the higher band still renders this case very attractive for Ethernet payload transport. Consequently, planning/licensing procedures are different (in term of availability target) from band to band.

The most interesting combination is between microwaves in the range 15 - 23 GHz (main bands used to cover distances up to 7 - 10 km) with the E-Band. This can be derived considering that the BCA value is coming from its capability to exploit at maximum each single frequency band which is part of the aggregation. In fact lower frequency bands (≤ 13 GHz) are able to transmit over longer distances. Therefore:

- BCA over longer distance would reduce the E-Band traffic availability and even make the E-Band link unfeasible.
- It would be more efficient to exploit these bands in terms of link length: taking into account the increasing capacity requirements in view of 5G higher frequency bands would not guarantee a good minimum traffic availability (e.g. > 99,995 %) over such link distance (7 - 10 km).
- Solutions using dual band antenna, due to its inherent dimension dictated by E-Band, will penalize too much the lower band antenna gain, resulting in a poor antenna class as well.

Here an example is provided to show a high level guidance, with the following assumptions:

- 300 Mbit/s to be transported over traditional microwave.
- 1 - 2 Gbit/s to be transported over E-Band.
- 2 ft antennas.
- Rain rate 42 mm/h.

The corresponding maximum link distance that could be achieved considering the above microwave bands and 99,995 % availability would be:

15 GHz	18 GHz	23 GHz
11,5 km	8,5 km	6 km

This is in fact compatible with the objective to guarantee around 99,9 % availability in the E-Band (1 - 2 Gbit/s) over the same link distance. In order to provide a rough estimation, the maximum distance for such capacity in the E-Band would be around 7 km. This is almost in the middle between 18 GHz and 23 GHz maximum distance and a bit stretched for the 15 GHz case, even if this is just an indication while in reality there could be different combinations of required throughput vs target link distance.

In the future also higher mmW bands (e.g. W-Band and D-band) could be complemented with a traditional microwave band in order to deliver more throughput over reasonable distances. For reference see the use case table in ISG mWT ETSI GR mWT 008 [i.5], where link distance up to 2 km is envisioned for future 5G macro cell backhaul use case.

Considering that such BCA systems can provide a wide range of traffic availability associated to different steps of capacity (due to ACM and different propagation), this well meets the need to provide, more and more in the future, different level of availability depending on the service (also linked to network slicing concept treated in ETSI GR mWT 016 [i.7] for network slicing clause).

5.4 Licensed and unlicensed channels aggregation

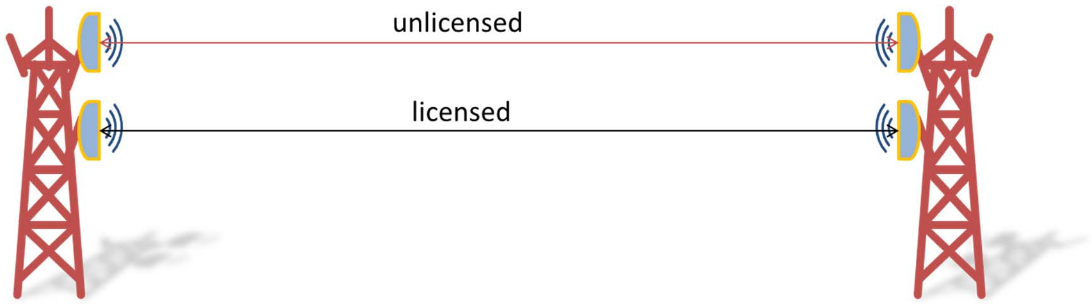


Figure 6: BCA with licensed and unlicensed bands aggregation

The approach is similar to the well-known Licensed Assisted Access (LAA) approach in the access domain, where Wi-Fi is used to complement the access band for the offloading of low-priority traffic.

As example, any microwave frequency band can be aggregated with e.g. 5,8 GHz or 60 GHz (where they are unlicensed) to increase capacity reducing TCO/cost per bit.

In this case BCA allows also for differentiation of traffic based on security criteria, by placing security sensitive traffic on the licensed part and best effort traffic on the unlicensed.

6 Bands and Carrier Aggregation benefits

Mobile backhaul/fronthaul and Fixed Broadband Access applications can benefit from the BCA concept in order to address the evolving and demanding network transport requirements.

This can mainly be achieved through a smart use of the available spectrum. The following table is a high level summary of the bandwidth reserved to fixed service in the different frequency bands, along with the indication of the reference channel spacing.

A given P-P radio link is engineered using, when available, the most appropriate frequency band which is suitable to the specific connection and application. Lower frequencies can reach longer distance and would be wasted for short links.

Therefore, low-frequency bands (usually up to 11 - 13 GHz) are commonly used for long haul applications (rural or islands connectivity), medium-frequency bands are used for sub-urban use cases and higher bands are used for urban scenarios and shorter links (with a decrease of maximum link length depending on frequency band).

Frequency Band	Duplex Spacing (MHz)	BW (MHz)	Channel Size (MHz)	Typical Applications
L6 GHz	252.04	2x 266.85	8x 29.65	
U6 GHz	340	2x 320	8x 40	
L7 GHz	161	2x 119	16x 7	
U7 GHz	154	2x 112	2x 56	Rural long-haul
L8 GHz	311.32	2x 266.85	8x 29.65	
U8 GHz	119	2x 84	6x 14	
11 GHz	490	2x 480	12x 40	
13 GHz	266	2x 224	5x 56	
15 GHz	420	2x 168	3x 56	Sub-urban medium-haul
18 GHz	1010	2x 935	17x 55	
23 GHz	1008	2x 504	9x 56	
26 GHz	1008	2x 868	16x 56	
28 GHz	1008	2x 875	16x 56	Urban short-haul
32 GHz	812	2x 742	12x 56	
38 GHz	1260	2x 1120	20x 56	
70/80GHz	1000	2x 5000	19x 250MHz	

Figure 7: Microwave frequency bands

Typically, for maintaining practical feasibility of the link, the BCA coupling would be made in the same band or by "contiguous" applications (i.e. long + medium haul, medium + short haul or short + short haul).

It will be shown in this clause how BCA can enable new scenarios, through aggregation of different frequency bands.

A summary of main BCA benefits is provided here:

- Decongesting valuable frequency bands (in general the lower ones, which are enabling longer distances).
- Enabling a higher link distance for higher-frequency bands (which cannot be reached when a traditional approach is adopted). This can be seen also as efficient use of the spectrum.

As depicted in the "BCA concept" clause 4, in order to address current and future use cases (in the view of 4G evolution and 5G) wireless transport will need to satisfy a multidimensional set of requirements.

There are some constraints which wireless transport should overcome, for example radio propagation effects. The achievable distance for a radio link is mainly determined by free space loss and rain attenuation. In particular, the effect of propagation penalizes high frequency bands, for which the path length is reduced.

Aggregating one millimetre-wave channel with one or more microwave channels achieves the objective to design a relatively long link (7 - 10 km) with high capacity providing high availability for high-priority services and lower (but still decent) availability for lower-priority Ethernet services:

- Enabling an increased channel granularity combining small channels into one logical bigger carrier, thus:
    - better matching the real capacity needs in terms of main KPIs (capacity/coverage/availability/latency)
    - improving efficiency in the spectrum usage (aggregation of unused narrow slices of spectrum)

      As an example, assume that a given operator needs to increase the transport throughput on already-deployed links which are using a single frequency band. It may be that such frequency is congested, and the operator may decide to reuse a smaller channel in another band which otherwise would not have been used. Carrier aggregation in this case is linked to smart spectrum usage and spectrum granularity.
- The Total Cost of Ownership (TCO) reduction through aggregation of licensed and unlicensed spectrum in providing the requested level of availability, protection and security.

Despite one of the main objectives of BCA is to increase the capacity over a single physical link, it is possible to think of BCA also as a way to enable different scenarios. As summary picture, figure 8 provides a view of potential BCA benefits with respect to link length and scenarios (rural, suburban and urban).

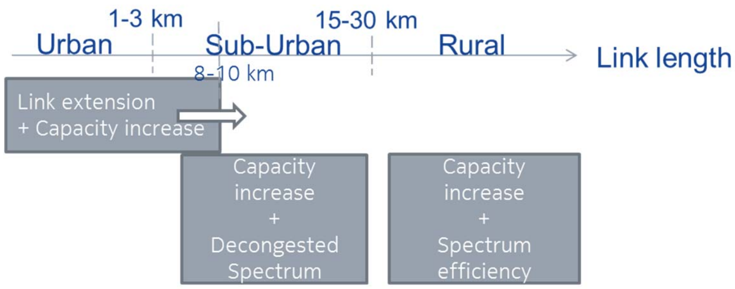


Figure 8: BCA in different deployment scenarios

For instance, the aggregation of microwave and mmW frequency bands can enable the usage of mmW bands (usually constrained by propagation effects) also in the suburban environment.

7 Technological advancements related to Bands and Carrier Aggregation

7.1 Introduction

Microwave backhaul antenna solutions intended for carrier aggregation are today mainly addressed by two separate microwave antennas. The Dual-band microwave antenna technology is the opportunity for reducing the tower leasing cost, installation time and for lightening the tower structure. This work illustrates the next antenna challenge to achieve the dual-band configuration. First results show the performances obtained for a dual-band antenna in urban configuration.

7.2 Frequency selection

Figure 7 lists the different applications and the possible frequency aggregations. Dual-band microwave antenna solutions inside the conventional frequency bands, like the aggregation between 6 GHz and 8 GHz or 11 GHz and 18 GHz respectively for the rural long-haul or sub-urban medium haul applications, are already on the market. Nevertheless, for urban short-haul applications where the frequency band selection relates to the aggregation between the E-Band millimetre wave and one of the conventional frequency bands, the microwave antenna solutions are more challenging. Radio performances are more difficult to achieve due to both the large frequency deviation and the manufacturing sensitivity of the millimetre bands.

7.3 Antenna technologies

Dual-band or broadband antennas can be designed using different kinds of technology, such as: micro strip antennas with dual access, large bandwidth corrugated horns, spiral antennas. Nevertheless, for backhaul applications, where the link budget is a key parameter, and even in urban short-haul, large gain antennas are required. Conventional backhaul applications use axial parabolic antenna technology and more recently dual-reflector antennas, such as the Cassegrain antenna, where the addition of a second reflecting surface offers additional possibilities for achieving highest performance in radiation efficiency, high lobe discriminations and for meeting the stringent class 3, or even class 4 ETSI requirements [i.3].

Parabolic antenna technology remains a very attractive candidate for the dual band backhaul solutions. At the time being, no other high performance technologies are identified.

Dual-band antenna solutions will have to maintain the same performances, such as the quality of the radiation pattern which guarantees a lower risk of interference, as so not to disrupt conventional backhaul networks already rolled out. The antenna gain should be also in the same range as with the current single-band antenna in order to keep the same distance of the microwave links.

In order to achieve this target, different key technological issues should be addressed.

Multisource feed technology is suitable for the parabolic illumination to achieve the dual band antenna configuration. However, the integration of multi-sources causes a large mask effect, as shown in figure 9, especially in E-Band where the physical dimension difference become significant compared to the wavelength. The aperture blockage impacts not only the antenna gain, but also the side lobes and thus making the compliance to ETSI EN 302 217-4 [i.3] difficult. The lower the first frequency, the more difficult the compliance to the ETSI standard will be.

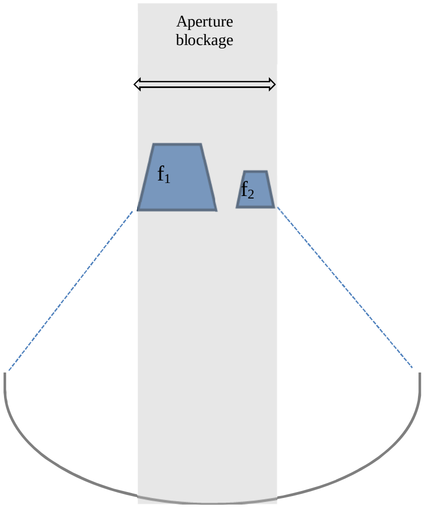


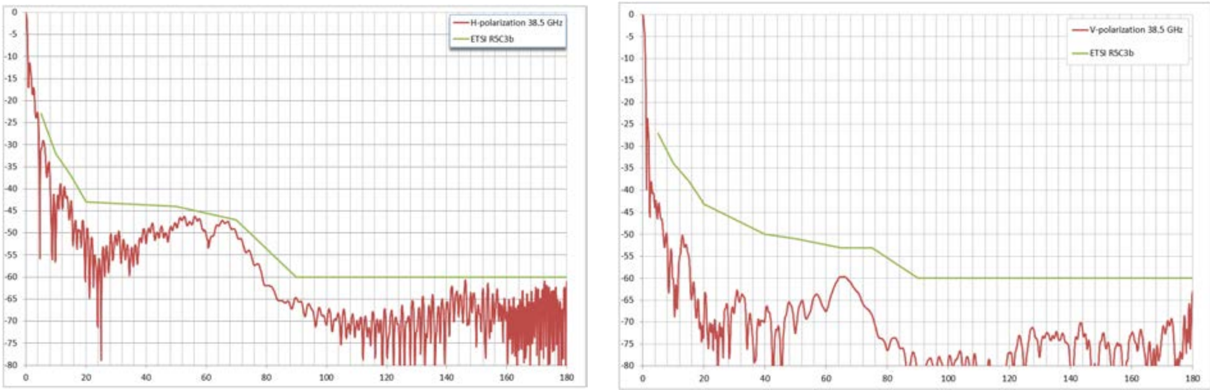
Figure 9: Feed blockage effect

- Even though the radome is only a protective part of the antenna system, it is nonetheless a key element for the antenna radiation quality and especially it impacts the side lobes of the radiation pattern. The antenna radome material should be selected to be as much as possible radio-electrically transparent. However, addressing the challenge is more difficult when the material needs to covers 1 or 2 frequency octaves in the future dual band carrier aggregation systems for the urban configuration.

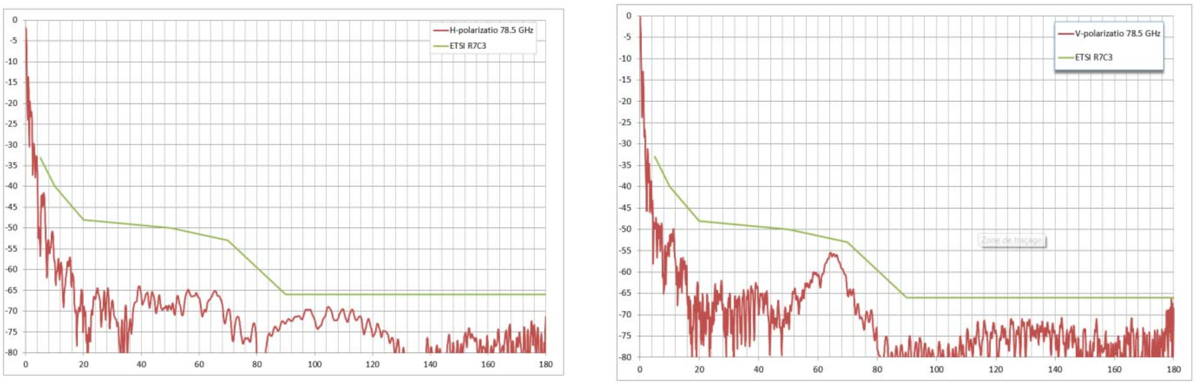
- Another technological issue could be the isolation between the bands to limit cross-talk inference. Good isolation between the E-Band and the conventional frequency band should be achieved to limit the interference on the radio aggregation systems.

7.4 First results

- Taking into account the different constraints listed above, first results of a dual-band parabolic antenna configuration are presented below. The selected urban short-haul frequency bands in this instance are the aggregation of the E-Band and 38 GHz for a 2ft antenna diameter and the assumption of a radome fully transparent whatever the frequencies. The ETSI class 3 performance can be achieved both in E-Band and in 38 GHz. As explained previously, the dual-band configuration impacts the gain performances, the actual gain in the use-case below is 2 dB lower compared with traditional single-band antennas. Concerning isolation, it is better than 25 dB between the E-Band and 38 GHz.



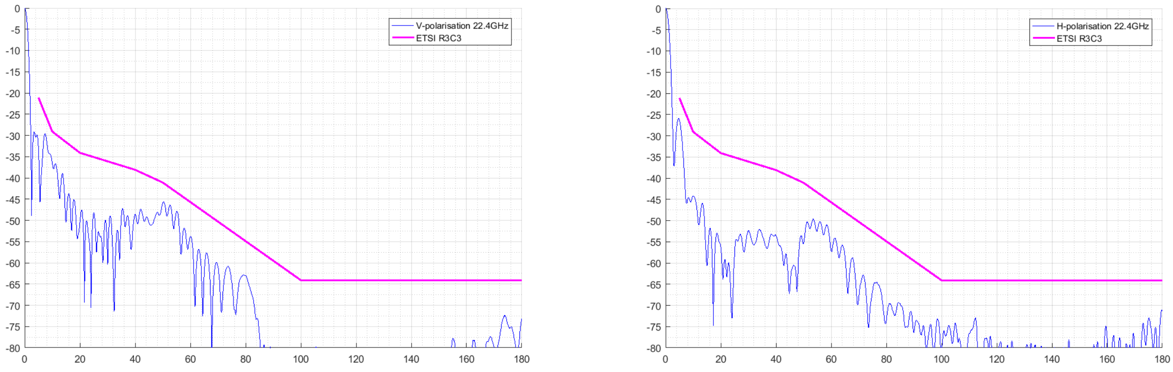
(a) 38 GHz simulation results



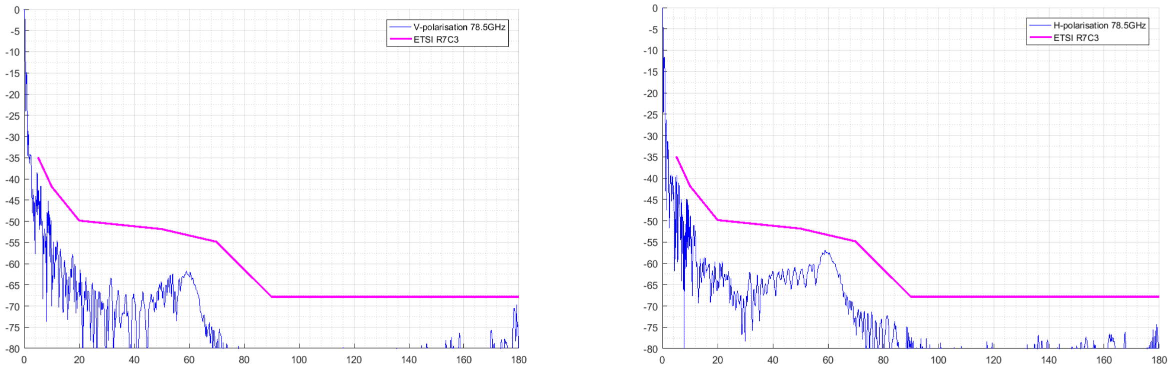
(b) E-band simulation results

Figure 10: Radiation pattern performance of a dual-band antenna:
(a) E-Band performance
(b) 38 GHz performance

- Alternative feed systems (to figure 9) at E-Band and 23 GHz for a 2 ft antenna diameter can be realized where gain is lower than single band antennas at the equivalent frequencies. For this alternative arrangement, the following radiation patterns are predicted and isolation is better than 33 dB between the E-Band and 23 GHz.



(a) 22,4 GHz simulation results



(b) E-Band simulation results

Figure 11: Radiation pattern performance of a dual band antenna:
(a) 22,4 performance
(b) E-band performance

8 Deployment and relevant network design

8.1 Link planning example: Case of E-Band and traditional microwave band

As an example of link planning, the most "disrupting" case is considered in this clause: the case where E-Band and a traditional microwave band are concerned.

In this it is assumed, which is not in principle always true, that the low-frequency band will provide the whole capacity at the highest availability required.

Example mainly derived by [i.6]:

- Hop length 7,5 Km.
- Rain rate zone 42 mm/h.
- Available @ 56 MHz channel @ 18 GHz and a 1 GHz channel @ 80 GHz.
- Bi-band antenna 38 dBi @18 GHz and 50 dBi @ 80 GHz.
- 18 GHz - XPIC - ACM till 4096QAM.

- 80 GHz - ACM till 128QAM.
- System gain: according to table 3 of ETSI White Paper No. 15 [i.2].

Requirements (example):

a) 650 Mbit/s @ 99,99 %.

b) 1 500 Mbit/s @ 99,9 %.

c) 3 500 Mbit/s @ best effort.

The planning should start with the link planning for the system operating at its lower frequency. The 18 GHz connection was designed to satisfy mainly R-a. The design method follows ETSI TR 103 103 [i.1].

Results: it is necessary to use XPIC to exploit two times the 56 MHz channel at 18 GHz to be able to reach the due capacity at the availability level requested. The reference modulation is 256QAM providing a capacity of more than 350 Mbit/s for each stream with 99,99 % of availability. Above requirement a) is therefore fulfilled. Thanks to ACM, additional capacity/availability steps are also available, see figure 12. For simplicity, disregard the additional 400 Mbit/s that the 18 GHz link provides with best effort.

When considering R-b and R-c and the 80 GHz link:

Results: The QPSK profile, at its PTx max, provides more than 1 500 Mbit/s at 99,9 % availability and thanks to ACM, an additional 3 500 Mbit/s at best effort, so fulling the requirements. The results could be seen in figure 12. Figure 12 assumes QPSK as the link reference modulation with an availability of 99,9 %.

The maximum modulation scheme sustainable at 18 GHz is here 4096QAM (> 7 dB of Fade Margin (FM) in clear conditions) and at 80 GHz is 128QAM (> 10 dB of FM in clear condition)

It is for sure not granted that such a high level of modulation scheme is usually sustainable, considering the link conditions and the consequent reduction in fade margin in clear condition. To manage this aspect, it may worth to introduce here a new concept, the Max Modulation Scheme Sustainable, (MMSS), defined as the working point able to provide the max level of capacity in best effort conditions. The margin in dB above the Relevant Threshold Level (RSL at 10^{-6}), that has to be taken in defining MMSS should be at least 4 to 5 dB above the expected RSL in normal propagation conditions. This should guarantee a quite stable condition for the maximum capacity level considering, as well, the ACM hysteresis.

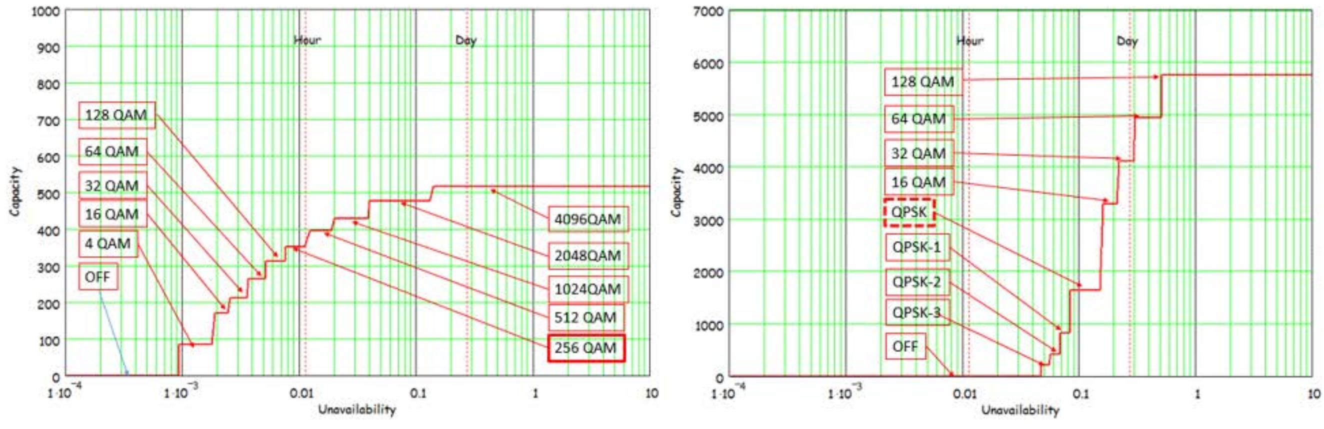


Figure 12: Capacity vs availability at 18 GHz (left) and E-Band (right)

The picture on the left shows the capacity vs unavailability for a single channel at 18 GHz with ACM until 4096QAM. The link is engineered for 256QAM as reference modulation at 99,99 % availability.

The picture on the right (E-Band), shows the capacity vs unavailability for an E-Band link with ACM till 128QAM. QPSK is assumed as reference modulation at 99,9 % availability. Obviously, it is not always guaranteed that a reference modulation can be obtained at 99,9 % availability, but only for a lower availability level. This may have an impact in regulation aspects.

For obtaining the whole link results the two pictures can be combined to obtain the following result.

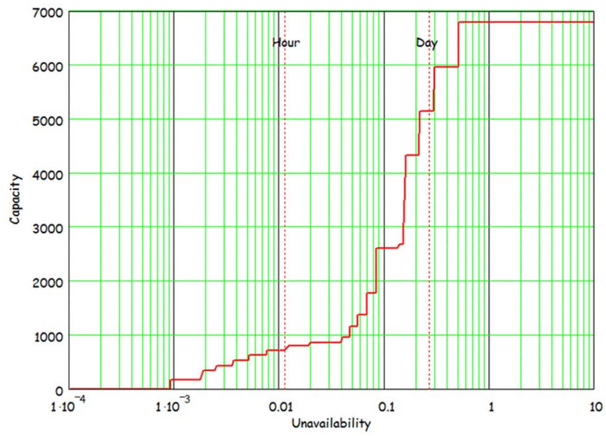


Figure 13: Capacity vs availability with BCA of 18 GHz and E band

Figure 13 can help in understanding the whole BCA link performances. It should be considered that the results obtained are valid assuming that:

a) Propagation events and their effects over the two frequency bands are always correlated and connected. These assumptions are obviously not always true in general, but in the considered situations (18 GHz/56 MHz plus 80 GHz/1 GHz) this can be assumed to be valid.

For instance, when wider channel separation (112 MHz or 224 MHz) or/and lower frequency bands are concerned, these assumptions would be likely to be wrong due to the frequency selective propagation phenomena:

a) The traffic manager engine should be common for all channels and able to distribute/re-route the traffic over multiple radio channels, exploiting "early warning" messages from radio, to be errorless. Static traffic assigned will jeopardize a lot the result.

For this specific case, the E-Band frequency coordination standpoint, the RTPC functionality is not enabled and the ATPC is being used just for adapting PTx to the actual modulation scheme. The spectrum emission mask fulfils the lower class, here QPSK. Consideration about this fact will be provided in clause 9.

9 Regulatory and licensing: Considerations and proposals

In general, the regulatory landscape has been set up looking at the different frequency bands by taking into account their features and specificity, for example in terms of propagation and channel raster.

Introducing the BCA concept will require a more holistic view in which two or more aggregated channels are seen as a single pipe with a combined performance, in terms of both QoS and spectrum efficiency, much more improved than their simple sum. This fact should be considered when establishing a fair regulatory and licensing framework for the BCA assignment, in order to support and not prevent the spreading of this new technology.

Three main points have been identified as worth considering:

1) Link availability target in planning procedures.

   Most administrations use various automated planning tools that require a set of input parameters, including the link availability. Typically, the link availability is a fixed value used nationwide for all links (e.g. 99,99 %). In case of BCA, when the band distance is relatively large (e.g. 18/38 GHz + 80 GHz bands), that availability cannot be used for the two bands, but only for the lower one; moreover, in such BCA situations, the higher-band channel should be planned only from the interference point of view, while its availability should be considered as "best effort" (i.e. to be estimated by the applicant from the available fade-margin before the license request). This may require some updating to the present planning tools and/or licensing forms.

2) Impact of an ATPC range imposed in the licensing conditions.

In all BCA cases, but especially when two different frequency bands are concerned as per the use case in the clause 4.3 (Microwave and mmW channels aggregation), the use of ATPC for the highest frequency band may become challenging and may limit the full BCA exploitation.

For instance, for the use case in clause 5.3, the E-Band should be engineered to work 100 % of the time at its maximum feasible PTx (therefore without the ATPC) in order to obtain the best results. Using the ATPC to fix the Receiver signal level (RSL) at a given value (e.g. -50 dBm) may imply the loss of plenty of capacity, because the MMSS will be limited a lot. In addition to that, it may be worth noting that high modulation schemes when larger CSs are concerned have a receiver threshold even higher than -50 dBm. Therefore, the ATPC use and its rules should be carefully analyzed/studied because it may pose limitations or even jeopardize the BCA adoption.

3) License fee.

As mentioned in clause 5 some of the main advantages of BCA are to enable a higher link distance for high frequency bands (not possible otherwise) for carrying larger capacity otherwise requiring additional channels in lower bands, decongesting such valuable bands. In other words, BCA contributes to a much more efficient use of the overall available (and sometimes scarce) spectrum.

In particular, for use case in clause 5.3, even if the physical radio link is made by two channels in two different frequency bands, it is reasonable to consider the possibility to have a lower spectrum fee (see note) in case of BCA. A proposal in this sense has been made in ETSI White Paper No. 09: E-Band and V-Band - Survey on status of worldwide regulation [i.4] where a possible E-Band license cost is suggested and a "BCA" factor is proposed as discount due to above considerations:

Where:

K = factor defining absolute figures (Country dependent) [currency]

BCA = discount factor (dmax / d) in case E-Band is used for BCA

$\mathbf{f_0}$ = Normalization factor (e.g. 38 GHz)

fc = Center Frequency of the Band [GHz]

BW = Channel Bandwidth [MHz]

Bsize = Overall size [MHz] of one sub-band (Go or Return)

In principle, this kind of license fee reduction could be applicable also to other BCA use cases which help in decongesting spectrum (for instance while using aggregating small chunks which would not be used instead, e.g. 14 MHz + 28 MHz in two bands).

NOTE: The license fees here debated are those "recurring" per year/channel; in some countries, these are different from the "planning" charge (due only once at the link activation) covering the costs of the planning itself, which are still considered justified by the need of interference evaluation also for such higher band BCA channels.

Dual-Band antenna

In case of Dual-Band antenna it may be worth to point out the following points:

- As depicted above, Dual-band antennas, even for bands not so close to each other, are today feasible. The dimension is limited by the highest band, due to fact that gain should exceed 50 dBi as practical rule.
- Antenna RPEs are obviously different between the two bands. Due to their intrinsic technical complexity, it is expected that both bands may not reach the same ETSI class.

Antenna Pointing, usually very challenging when antenna gain is close to 50 dBi, which is practically always true, and for long connection, is made feasible, in case of dual-band antenna. The antenna will be aligned using lower frequency bands, with lower gain, therefore adjusted with the higher frequency bands signal. The result, will be beneficial to the lower frequency signal as well, since the pointing will be practically perfect, without any losses.

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Annex B:
Change History

Date	Version	Information about changes
September 2016	V1.0.0	First draft document
December 2016	V1.0.1	Modifications following remarks collected during plenary meeting mWT#6: • Added pictures related to use cases Comments related to low frequency BCA use case
May 2017	V1.0.2	Added text, mainly to parts: • 7 Technological advancements related to BCA • 8 Deployment and relevant network design • 9 Regulatory and licensing proposals Clause 9: added consideration & proposal
June 2017	V1.0.3	From GS to GR Add new text for planning explanation in clause 4 mainly
July 2017	V1.0.4	Final draft after G2M 10-07-2017

History

Document history		
V1.1.1	November 2017	Publication