D-Band Backhaul and Fronthaul Solutions for 5G Radio Access Network

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***Abstract* — The paper presents an architecture and specifications for an innovative wireless backhaul solution exploiting D-Band (130-175 GHz) for 5G and beyond networks. The solution includes: dual carrier FDD radio system capable of carrying up to 25 Gbps; radio with a double full integrated cross polar interference canceller (XPIC); each carrier has two independent segmented antenna arrays for transmit and receive. The architecture supports the flexible duplexer operation mode, full duplex mode and adaptive beam-steering capabilities for beam alignment under adverse conditions. The solution proposed is planned to be tested under real life conditions in field.**

***Keywords* — 5G, backhaul, link budget link budget, mm-wave, D-Band, radio link, beam-steering, flexible duplexer, Full duplexer.**

I. INTRODUCTION

5G requires a considerable evolution of backhaul networks to accommodate the ever-growing data traffic and new network functionalities. Despite the growing importance of fiber, wireless backhaul is of primary importance, connecting today about 60 % of all base stations to networks. An evolution of wireless backhaul solutions is necessary so that they continue playing their central role in the development of the 5G and beyond networks

Figure 1 presents a possible evolution of the radio transport networks, where higher frequency bands will be used for providing short but very high capacity backhaul links into urban environment. Such approach demands backhauling (BH) solutions with capacity up to 20-25 Gb/s and connection distances up to one km [1]-[3].

Radio BH solutions for carrying these levels of capacity must have a wide bandwidth available and accommodate channels in the order of a few GHz. The only possibility to have the available band and few GHz channels is in frequency bands around 100 GHz and beyond. Three Fixed Service (FS) frequency bands around 100 GHz are possible candidates for usage: the E-Band (71-86 GHz), the W-Band (92-115 GHz) and the D-Band (130-175 GHz).

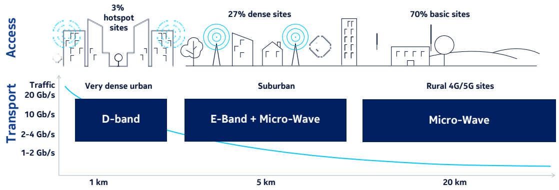

Fig. 1. Access and Backhaul Network evolution.

The E-Band is commercialized already. The W-Band is unused today. But W-Band is very similar to E-Band, and it is considered for future as the E-Band spare band.

D-Band looks very promising. In addition to being very wide and practically unused to date, it allows adopting very interesting innovative approaches, such as implementation of flexible Frequency Division Duplexing (fFDD) and usage of active phased array antennas.

In this work we propose a possible realization of a D-band backhaul solution, which we are planning to demonstrate within the frame of H2020 project DRAGON. The main architectural specifications of the system are:

- Capacity up to 20-25 Gbps for ranges of 100-150 meters
- Big active phased array antennas (up to 1024 elements) with automatic beam alignment
- Dual carriers with different transmit (TX)/receive (RX) antennas
- Dual MODEM able to Adaptive Modulation AM and cross polar canceller (XPIC)
- Mode of operation: Frequency Division Duplexing (FDD), Flexible FDD (fFDD) and Full Duplexer (FD)

II. D-BAND FREQUENCY ARRANGEMENT

The D-Band, providing in total almost 32 GHz, can be used by fixed links (see Figure 2). Some portions of the D-Band cannot be used because they are reserved for other services. The ECC Recommendation (18)01 defines three possible modes of operation: the conventional FDD, the TDD and flexible FDD (fFDD) [4].

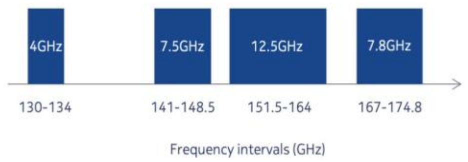

Fig. 2. D-Band available portions.

The ECC Report 282 does not recommend the usage of channels wider than 2 GHz [5]. This limitation ensures a fair usage of the spectrum by different operators. Studies performed by NOKIA demonstrate that the actual number of available 2 GHz independent channels in D-Band are 3 for TDD, 4 for FDD and 6 for fFDD. Thus, although the available bandwidth is wide, the effective number of 2 GHz channels is limited.

III. Radio Solution for D-Band

To support the fFDD mode of operation, we propose to use one antenna for TX and one antenna for RX in each carrier. Isolation between antennas should be in the order of 65-70 dB to provide proper operation

Figure 3 presents the relationship between the capacity of a single radio emission for corresponding modulation schemes and channel sizes. This reference is derived from the ETSI and it refers to the net capacity transported only [6].

Net Capacity [Mbps] single direction				
	2000 MHz	1000 MHz	500 MHz	250 MHz
QPSK	2280 Mbps	1140 Mbps	570 Mbps	285 Mbps
16 QAM	4560 Mbps	2280 Mbps	1140 Mbps	570 Mbps
32 QAM	6960 Mbps	3480 Mbps	1740 Mbps	870 Mbps
64 QAM	8000 Mbps	4000 Mbps	2000 Mbps	1000 Mbps
128 QAM	9800 Mbps	4900 Mbps	2450 Mbps	1225 Mbps
256 QAM	11200 Mbps	5600 Mbps	2800 Mbps	1400 Mbps

Fig. 3. Single emission capacity for different radio profiles.

Only something close to 12 Gbps can be transported with a 2 GHz channel, even with 256 QAM. Modulation schemes beyond 256 QAM are a challenge due to difficulties of system implementation in D-band. To reach the targeted capacities above 20 Gbps in a 2 GHz channel, we would need 65536 QAM, which is not realistic.

This transport capacity challenge can be addressed with a dual carrier transceiver that is capable of transmitting and receiving two radio carriers in different frequency channels or in the same frequency channel exploiting the different radio polarizations H and V (so called XPIC). Figure 4 shows a basic block diagram of such transceiver.

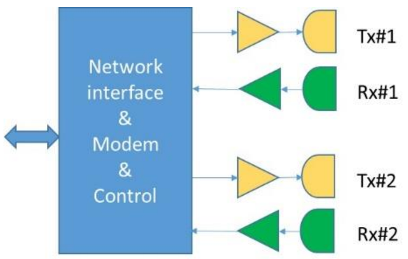

Fig. 4. Transceiver block diagram.

Possible frequency configurations that can be realized in the proposed architecture are shown in Figure 5. The architecture allows realization of Line of Sight (LoS)-MIMO as well. LoS-MIMO would be enabled by exploiting the distance between the two carrier's antennas.

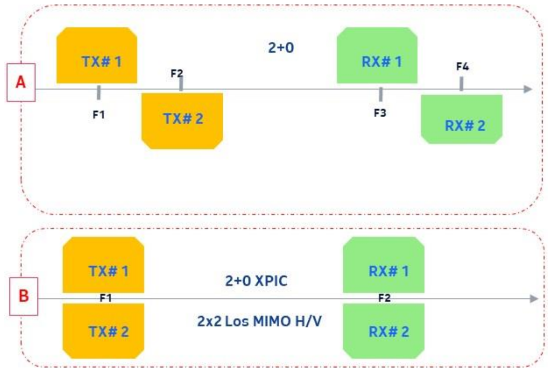

Fig. 5. Possible frequency configurations.

Configuration A is a common 2+0 H/V configuration while B is the 2+0 XPIC allowing usage of the same frequency channel for two carriers with different polarizations and can be considered also as 2x2 LoS MIMO H/V.

The proposed architecture is considering a beam steering (BS) functionality for all antenna arrays for keeping the link properly pointed in the presence of adverse effects such as wind and sun automatically [7]. Beam Steering can be used in dynamically reconfigured networks as well.

IV. Link Budget

To evaluate the link performance in terms of covered distance, we must calculate the Link Attenuation (LA) for a radio signal at given propagation conditions. This attenuation is a function of link length, frequency band and atmospheric gas attenuation. LA can be derived, for the clear sky condition, using the well-known Friis transmission equation and adding the atmospheric gas attenuation. According to ITU-R Rec. P.676, the atmospheric gas attenuation in D-Band is less than 2 dB/km below 164 GHz and rises to above 4 dB/km only at the top edge of the band [8].

An additional attenuation to be considered is that due to rain, which depends on the rain rate. The current model for determining the attenuation based on rainfall statistics is not valid at frequencies above 86 GHz and, therefore, it cannot be used in our case [9]. Moreover, recent studies indicate that the attenuation due to rain at these frequencies depends not only on the rain rate, but also on the size of the raindrop [10].

Because the rain model doesn't exist for D-band, we use in this work an approach considering the radio attenuation under clear sky conditions only to derive a stable condition for our test in field during clear sky. We expect that testing of our system in field will allow studying the rainfall statistics as well.

The main parameters to define properly a radio system are a level for the maximum transmitter power (MTP) and a level for the minimum receiver signal, called threshold. The receiver threshold (RT) identifies the radio working condition at Bit Error Ratio (BER) better than 10-6. The System Gain (SG) is the difference between the MTP and the RT. The Gross system gain (GSG) is defined as the sum of the SG with the two antenna gains.

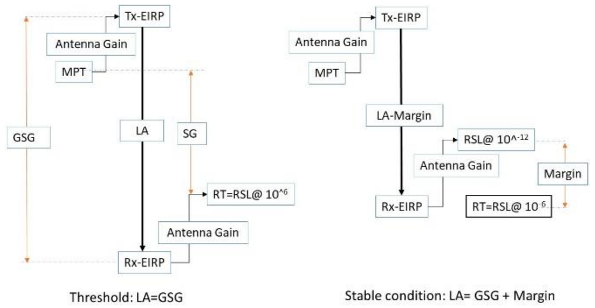

Fig. 6. Link budget with GSG and Margin concept.

Figure 6 (left) shows the physical meaning of GSG. If the link has an attenuation equal to LA, and GSG=LA, then the radio is working at its threshold because the received level is equal to RT.

Normal working condition requires BER>10-12, that can be achieved with a RSL above the RT by at least 6-8 dB [11]. The radio GSG shall be at least equal to the attenuation of the targeted link length adding a due margin for reaching the BER>10-12. This is illustrated in Figure 6 (right).

The value of GSG must be that supported by the targeted radio profile (in our case the 256 QAM/2 GHz). Specifically, for a 100 meters link in D-band, LA is 117 dB. Accounting a 7 dB margin for going to normal working condition, a required value of GSG of 124 dB is obtained. With such GSG for the 256 QAM and 2 GHz channel, it is expected transmitting 25 Gb/s over 100 meters with no error in clear sky condition.

Obviously, the same radio equipment, when it is set for a different modem profile, will provide a different value of GSG. Figure 7 shows expected GSG values for different radio profiles supported by the system assuming having a GSG = 124 dB for 256 QAM/2 GHz. For example, the GSG for QPSK will be 150 dB.

Equipment Gross System Gain [dB]				
	2000 MHz	1000 MHz	500 MHz	250 MHz
QPSK	150 dB	153 dB	156 dB	159 dB
16 QAM	140 dB	143 dB	146 dB	149 dB
32 QAM	137 dB	140 dB	143 dB	146 dB
64 QAM	134 dB	137 dB	140 dB	143 dB
128 QAM	128 dB	131 dB	134 dB	137 dB
256 QAM	124 dB	127 dB	130 dB	133 dB

Fig. 7. Equipment System Gain for different Modulation schemes @ 2 GHz.

Figure 8 shows the relationship between the hop-length and the requested GSG for working under stable conditions. All radio profiles with 2 GHz channel are mapped in the picture as well. For example, when the profile QPSK/2 GHz is used, the maximum hop-length is 1.3 km.

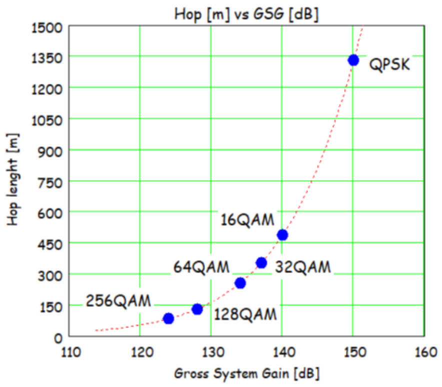

Fig. 8. Hop length vs GSG.

V. Selected Architecture

The transceiver is designed to provide the requested capacity and to enable a beam alignment functionality. The architecture for the phased array antenna is selected as the result of multiple compromises. The main objective is to obtain the GSG required with the possibility of beam alignment in a range ± 5°.

Having a phase shifter for each antenna element allows to obtain an optimal performance. However, technical challenges with Radio Frequency (RF) interconnection routing, heat management and system integration motivated us to study an architecture with a reduced number of active components. An approach based on segmented antenna arrays is used in which several antenna elements are fed by a single phase-shifter and power amplifier chain in the transmitter and several antenna elements are connected to a single LNA and phase-shifter chain in the receiver.

The table in Figure 9 shows the number of antennas driving RF chains (number of LPA) required in each configuration. The TX power level (PTx) for each power amplifier, the Noise Figure (NF) for each low noise amplifier, the antenna gain, the expected implementation losses, and the modem performances are used as reported into [12]-[14]. The more antenna driving RF chains, the higher the power consumption. Heat dissipation and power consumption are critical aspects in the proposed system. Therefore, our design strategy should be to find a configuration which minimizes power while achieving the desired GSG.

Based on the results shown in the table of Figure 9, it seems that the configuration with 4 antenna elements driven by each RF chain can be a good candidate solution, as it is the configuration with the minimum overall number of RF chains that meets the GSG requirement. On the one hand, it divides by 4 the DC power consumption with respect to an approach connecting an active chain to each antenna, easing the thermal management of such a large array. On the other hand, each 4-antenna cluster can be addressed in a symmetrical way (2x2), allowing more practical realizations of power dividers and more flexibility to scale the system in the x and y directions. In addition, it leaves more physical room for each active chain, which helps in achieving higher gain and output power, implementing balanced structures, and so on.

System simulator					
input data					
Reference data - external					
Output					
Transmitter					
QPSK Average linear Pout	0	0	0	0	dBm
Connection loss	1	1	1	1	dB
Antenna elements per LPA	1	2	4	8	
Divider + Losses	0	3.5	7	10.5	dB
Number of LPA	1024	512	256	128	
Antenna gain	35	35	35	35	dBi
# of antenna elements	1024	1024	1024	1024	
Receiver					
Antenna gain	35	35	35	35	dBi
# of antenna elements	1024	1024	1024	1024	
Interconnection loss	1	1	1	1	dB
Loss due Combiner	0	0.5	1	1.5	
Number of LNA	1024	512	256	128	
Antenna elements per LNA	1	2	4	8	
Noise Figure	13.4	13.4	13.4	13.4	dB
QPSK Target SNR for BER<=10^-6	8.4	8.4	8.4	8.4	dB
Transceiver- Results					
Average EIRP	64.0	60.5	57.0	53.5	dBm
QPSK Receiver Threshold @10^-6	-59.2	-58.7	-58.2	-57.7	dBm
QPSK - Gross System Gain	158.1	154.1	150.1	146.1	dB

Fig. 9. GSG calculation for different architectures.

Figure 10 shows the block diagram of the transmitter part of the transceiver for a single carrier. A direct conversion approach is chosen. The local oscillator is obtained through a x12 multiplication chain starting from a pure signal around 12 GHz. After the direct conversion, the signal is sent to 64 chips, each containing 4 RF chains of power amplifier and phase shifter. This number of chains per chip balances the occupied area, DC power consumption and pad count per chip, while allowing symmetrical implementations as well. Each RF chain feeds a cluster made up of 4 antenna elements. Overall, the phased array antenna is therefore composed of 1024 antenna elements, of 256 amplifiers with their phase shifters. The RX part is the mirror image of the TX part.

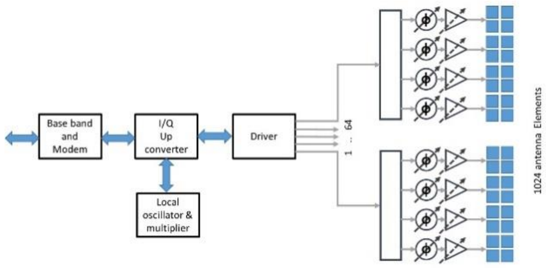

Fig. 10. Block diagram of one radio channel of the transmitter.

The effect of segmentation on performance of the antenna array must be studied as well. The main drawback of this arrangement is the generation of grating lobes due to the not perfect phase alignment of the antenna elements. However, the goal of beam steering in the system is to assist for the initial link alignment, to check that the antenna is properly aligned, and to compensate vibrations and displacements of the antenna support structures due to wind and temperature variation. These displacements are in the range of few degrees from the main alignment. Figure 11 presents levels of grating lobes in the segmented antenna array for different directions of a main lobe. For alignment beam in a range ±5°, lobes are 21 dB lower than the main one. Thus, the architecture selected provides sufficient performance inside beam steering range. A detailed analysis of the automatic beam steering alignment algorithm can be found in [15].

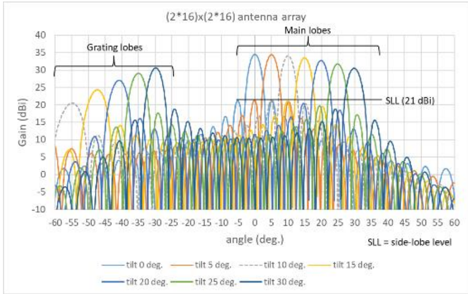

Fig. 11. Beam diagram of segmented antenna array (2x2 elements in each segment).

VI. Conclusions

The paper presents the architecture of an innovative wireless backhaul solution exploiting D-Band for 5G and beyond networks. The radio architecture is supporting fFFD, FDD, FD, TDD and the double carrier with the embedded XPIC. Separate segmented antenna arrays are used for TX and RX. The architecture can carry up to 25 Gbps and is able to align a beam in the range ±5° for compensation of beam misalignments due to vibrations and displacements of the supports.

Acknowledgment

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