D-Band Transport Solution to 5G and Beyond 5G Cellular Networks

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***Abstract*—The mobile data traffic increase and the future connection of billions of Internet of Things (IoT) devices require operators to reshape the existing transport network architecture. Today, more than 50 % of Base-stations (BTS) are backhauled via radio. Radio technology can continue to play this vital role in future transport networks if it is able to evolve to cope with the new capacity level and latency requirements supporting the new 5G services. In this paper, a possible answer to this demand is provided, proposing a radio solution working in D-Band (130-170 GHz) and enabling a reconfigurable meshed network that can support the backhaul needs of future 5G and beyond networks.**

***Keywords*—5G, backhaul, link budget, mm-wave, D-Band, radio link.**

I. Introduction

The ever-increasing mobile data traffic is driving continuous innovation in wireless communications, and next generation (5G and beyond) mobile networks are foreseen to provide Gbit/s data rates per each user. This poses several new challenges to the network infrastructure, especially when a radio solution is concerned [1]. According to [2]–[4], for next 5G case, a radio backhaul transport network close to the access part should provide:

- capacity up to 100 Gbit/s (50 Gbit/s go + 50 Gbit/s return)
- connection availability better than 99.9 %
- latency lower than 0.1 ms
- connection lengths of up to 1 km, with 90 % of the expected hop-lengths below 300 m

Even adopting high spectrally efficient quadrature amplitude modulations (QAM) and the spatial diversity enabled by multiple-input/multiple-output (MIMO) technology, the requirement of capacity reaching hundred Gbit/s needs large bandwidths, which are available only in the high millimeter-wave and sub-terahertz regions [4], [5]. Because of the vast bandwidth readily available, the D-Band, ranging from 130 to 170 GHz, is now being considered as a potential candidate for high capacity backhaul links for 5G and beyond [6].

In our vision, the exploitation of D-band radio links with beam-steering functionality may enable the realization of a reconfigurable meshed transport network (depicted in Fig. 1), with capacity exceeding considerably what is enabled by present backhaul solutions in E-band (80 GHz). The beam-steering functionality of the radios in one node enables changing the direction of the radio signal transmission and reception, and thus changing which other node in the meshed network this node is connected to. With a meshed architecture, by using an adequate network management strategy, each node can be reached from any other node by at least two different paths. This feature relaxes the capacity and/or availability requirements of the single radio connection. Moreover, the network features a high degree of reconfigurability that can be

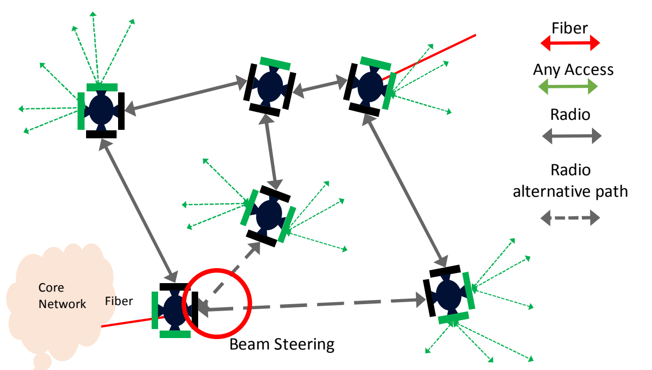

Fig. 1. Small-Cells equipped with steerable-beam wireless backhaul links in D-band.

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exploited to bypass occasionally failure links due to weather conditions, increasing substantially the network reliability.

This paper presents a study of the D-band radio link, with beam-steering functionality, intended for use in the meshed network of Fig. 1. Firstly, the spectrum availability in D-band is discussed, paying attention to current regulations and provisions in view of a rapid deployment with a commercial solution. Next, the proposed radio architecture, meeting the required performances is introduced. Finally, system level simulations are presented to prove the achievable capacity and hop-length of the link.

II. D-Band Frequency Arrangengement

The portions of the D-Band spectrum available for wireless communications are shown in Fig. 2. According to the ECC Recommendation [6], only some parts of the spectrum, out of a total block size of ~ 45 GHz (from 130 to 174.8 GHz), will be actually available, because other portions are reserved for different services. In total, there will be 31.8 GHz available.

The four spectrum blocks in Fig. 2 and the quite large gap between the first two blocks, make challenging the use of a conventional Frequency Division Duplexing (FDD) approach because of the requirement, according to [7], of at least 14-16 GHz separation between the TX and RX. For this reason, the alternative solution called flexible FDD (fFDD) is here proposed and investigated as well.

III. Radio Solutions for D-Band

Table I summarizes the results of the analysis of different radio architectures meeting the 100 Gbit/s capacity requirement. For each radio architecture, the feasibility of four different schemes, namely Time Division Duplexer (TDD), Frequency Division Duplexing (FDD), flexible FDD (fFDD) and Full Duplex (FD), is evaluated. The analysis considers that a single bi-directional link connection is feasible (marked as 'ok' in the 'Single connection feasibility' column of the table) if there are enough available spectrum resources: a suitable

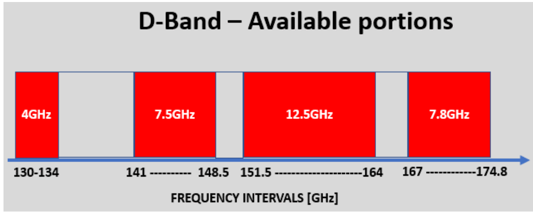

Fig. 2. Available portions of D-band for wireless communications.

channel in the case of TDD and FD or a couple of suitable channels (at given distances) in the cases of FDD and fFDD. When it is impossible to find the required spectrum resources, it is marked as 'ko'. Simplifying, a node of the network is feasible from the radio standpoint, only if at least three different link connections to this node can work without interfering each other. This implies that at least the resources for three different bi-directional links using three different portions of the spectrum (frequency diversity) shall be available for the node connections [8]. In D-band, the demanding spectral purity performance on the Local Oscillator (LO) limits the modulation order, and 256 Quadrature Amplitude Modulation (256-QAM) is therefore considered as the maximum modulation scheme. Additionally, Table I takes into account that in each of the available portions of the spectrum shown in Fig. 2, two guard-bands of 125 MHz have to be taken.

First, considering a single transceiver approach, it is easy to prove that TDD needs a channel width of 16 GHz, FDD and fFDD two channels of 8 GHz (for go and return connections) [9], while FD needs a single 8-GHz channel. Considering the portion of spectrum here available, the channel bandwidths for TDD, FDD and fFDD are not available, thus making these approaches unfeasible. Only FD remains possible, but it cannot satisfy the target of having a real meshed network with interference-free nodes, because there is not space for the three 8-GHz channels with different center frequencies (only the third block can host one 8-GHz channel).

TABLE I. Analysis for 100 Gbit/s & 256-QAM Solutions in D-Band.

		D-Band: 130–134 GHz (3.75 GHz)	141–149 GHz (7.25GHz)	152–163 GHz (12.25GHz)	167–175 GHz (7.55GHz)	Feasibility check for 100Gbps: Single connection feasibility	Feasibility check for 100Gbps: Node feasibility
100Gbps	256 QAM						
Single transceiver 1+0							
TDD	16.0 GHz					Ko	Ko
FDD	2 X 8.0 GHz					Ko	Ko
fFDD	2 X 8.0 GHz					Ko	Ko
FD	8.0 GHz					ok	Ko
2 x parallel links							
TDD	2 X 8.0 GHz					Ko	Ko
FDD	2 x 2 X 4.0 GHz					Ko	Ko
fFDD	2 x 2 X 4.0 GHz					Ko	Ko
FD	2 X 4.0 GHz					ok	ok/ko ??
XPIC - MIMO 2x2							
TDD	8.0 GHz					ok	Ko
FDD	2 X 4.0 GHz					ok	Ko
fFDD	2 X 4.0 GHz					ok	ok/ko ??
FD	4.0 GHz					ok	ok
MIMO 4x4							
TDD	4.0 GHz					ok	ok
FDD	2 X 2.0 GHz					ok	ok/ko ??
fFDD	2 X 2.0 GHz					ok	ok
FD	2.0 GHz					ok	ok

As a second step, the case of two parallel transceivers, supporting each one-half of the required capacity, has been evaluated. The results are summarized in the second group of rows in Table I. TDD and FDD/fFDD, requiring 2x8-GHz and 2x2x4-GHz channels respectively, are still unfeasible. In this case, FD still satisfies the requirements of a single connection with a chance to accommodate even a second connection.

The third step of the analysis considered the exploitation of the cross polar canceller (XPIC) to transmit one stream in H polarization and another stream in V polarization. Alternatively, two streams can be transmitted on the same polarization using a LoS-MIMO 2x2 spatial multiplexing scheme [10], [11]. With this approach, 50 % of the spectrum is reused/saved. In this case, looking at the third group of rows in Table I, all the approaches, meet the feasibility requirements of the single connection but the node feasibility is fully satisfied only with the FD approach.

The FD approach is not yet validated and it poses many challenges, especially at D-Band where it is hard to achieve the required isolation between TX and RX. Therefore, a fourth scenario has been considered. It consists of four parallel links, each transporting 1/4 of the capacity, but operating on top of the same channel by exploiting a LoS-MIMO 4x4 architecture based on spatial multiplexing. With such approach, TDD, FDD, fFFD and FD architectures are feasible to reach the 100 Gbit/s over a single connection and to make feasible a node with at least three different connections. Only FDD seems to have poor margins. With LoS-MIMO 4x4, we conclude that the transceiver (except for TDD) can be based on 2 GHz channel width, each carrying around 12.5 Gbps.

In summary, from the above analysis we conclude that, according to the network requirements, a D-band transceiver with up to 256-QAM modulation order in 2-GHz channels may be considered as the baseline for providing different levels of capacity. The most demanding scenario is the 100 Gbit/s connection that can be addressed by using four transceivers in a LoS-MIMO configuration. Moreover, considering the amount of spectrum available, a node managing at least three interference-free 100 Gbit/s links is also feasible. Finally, it is worth noticing that if the transmitter (TX) and receiver (RX) are implemented with different antennas, the fFDD and FD approaches benefit from the inherent antenna isolation.

IV. LINK BUDGET

To evaluate the radio link performance in terms of covered distance, throughput and availability, we have to consider the Maximum Attenuation (MA) of the radio signal under given propagation conditions and for a given percentage of the time.

According to ITU-R Recommendation [12] the atmospheric gas attenuation is less than about 2 dB/km below 164 GHz and rises to above 4 dB/km only at the top edge of the band, 174 GHz. The attenuation due to rain depends on the rain rate. From [13], (see Fig. 3), a rain rate of more than 60 mm/h would never be statistically exceeded in Europe for more than 0.01 % of a year.

The most important figure of merit of a transceiver is the System Gain (SG) that is the difference between the transmitter power and its corresponding receiver threshold level. Antenna system gain is the combined gain of the transmitting and the receiving antenna. Gross System Gain (GSG) is the sum of antenna system gain plus SG. The link budget is satisfied when the GSG is equal to or more than the link maximum attenuation; i.e.: GSG > MA.

Fig. 4 shows the relation between the required GSG and the maximum link coverage (hop length) considering a center frequency of 160 GHz. The plot is obtained following the methodology in [14]. The red lines correspond to the case of 99.999 % of availability (the most demanding), the blue lines to 99.99 % of availability and the magenta lines to 99.9 % of availability. The continuous lines are for the highest rain rate of 60 mm/h, while dotted lines represent the case of 30 mm/h rain rate. Substantially, no significant differences between the two rain rate cases are observed.

The simulation in Fig. 4 has been repeated for different carrier frequencies between 130 GHz and 170 GHz. The difference in GSG over the whole band remains within 2 dB.

V. PROPOSED ARCHITECTURE

To meet the aforementioned requirements, the transceiver

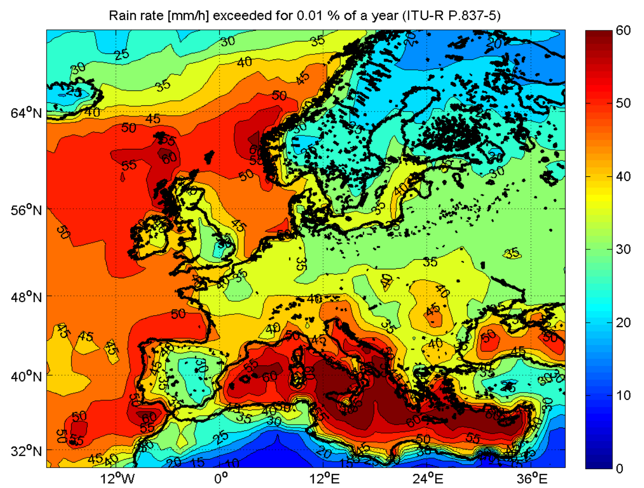

Fig. 3. Rain rate in Europe.

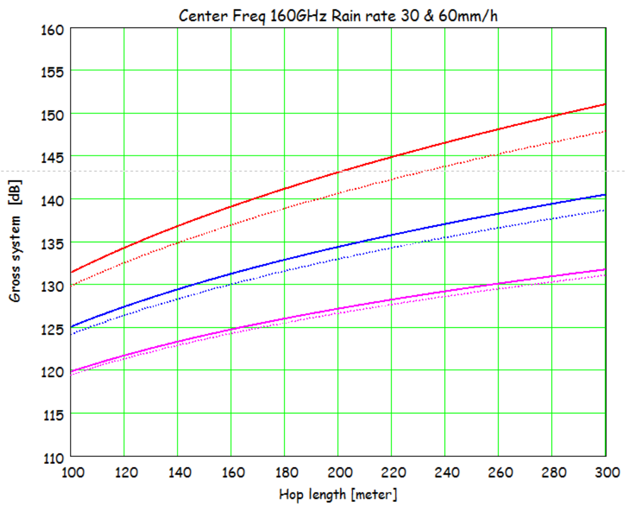

Fig. 4. Gross System Gain and hop length in different conditions.

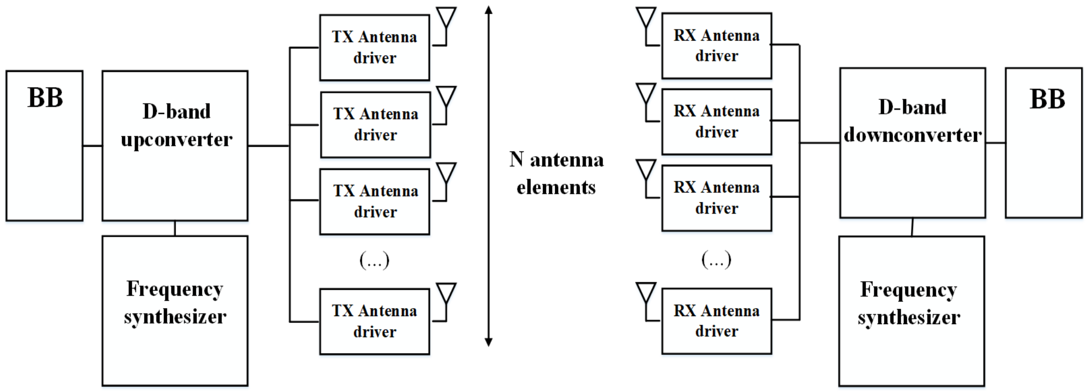

Fig. 5. Block diagram of the proposed architecture for the D-Band phased array transceiver.

architecture depicted in Fig. 5 is proposed in this work. The scope of this architecture is firstly to understand the transceiver feasibility and secondly the assessment of the transceiver GSG. The transceiver has the following features:

- Two completely different chains for TX and RX, including the antennas.
- For both TX and RX, a square (nxn) phased array antenna. Each element of the TX antenna is supposed to be fed by its own TX chain, made of a Power amplifier (PA) directly connected to the antenna element and a phase shifter preceding the PA. Similarly, each element of the RX antenna feeds its own RX chain, composed of a low-noise amplifier (LNA) and a phase shifter.
- All Tx Chains are fed by a D-Band upconverter.
- All RX Chains contributions are summed coherently at the input of a D-Band downconverter
- Up and down converters are connected to a Base-band circuitry that includes Mod/Dem functionalities.

With this block diagram in mind, a first estimation of the equipment GSG has been done considering that the main parameters, such as the TX power level (PTx), the Noise Figure (NF), the antenna gain, the estimated implementation losses and the Modem performances, are known or can be estimated [15].

The values used for the estimation are summarized in Table II. Concerning the PTx level, considering an approach based on SiGe BiCMOS technology, we can assume to reach around 0 dBm of PTx. With the same technology, a Noise Figure close to 14 dB seems achievable. Implementation losses considered are 2 dB for the TX and 3 dB for the Rx. The antenna element gain is estimated to be 4.5 dBi. The modem performances are derived by the existing solutions in E-Band that already foresee profiles up to 256QAM in 2 GHz [9].

As reported in Table II, we have estimated to be able to reach a GSG around 135 dB when considering 256 antenna elements and QPSK in a 2 GHz channel. Different values can be obtained using different antenna size for different modem profiles, modulation schemes and channel widths.

TABLE II. SYSTEM SIMULATION.

System Simulation		
Transmitter		
QPSK Average linear Pout	0	dBm
Interconnection loss	2	dB
Antenna element per LPA	1	
Antenna element gain	4.5	dBi
# of antenna elements	256	
Receiver		
Antenna element gain	4.5	dBi
# of antenna elements	256	
Interconnection loss	3	dB
Noise Figure	14	dB
Transceiver- Results		
Number of LPA	256	
Number of LNA	256	
Average EIRP	50.7	dBm
Antenna gain	28.6	dBi
QPSK Receiver Threshold @10^-6	-55.8	dBm
QPSK - Gross System Gain	135.0	dB

VI. EXPECTED RESULTS

Considering the LoS-MIMO 4x4 architecture, Table III presents the capacities and relevant hop-lengths for different modem profiles and different antenna sizes that can be obtained when scaling the GSG value obtained above. The simulation is provided for the case of 60 mm/h rain rate and 99.9 % of availability. Using a single transceiver or two transceivers in XPIC configuration, a different set of capacities, 1/4 or 1/2, can be provided.

It can be observed that plenty of different use cases can be covered with this solution, with capacity levels up to 100 Gbps and hop-lengths exceeding 1 km.

VII. CONCLUSIONS

This paper has described a pragmatic approach to define a possible transceiver architecture that can be used as base line to provide a radio connection for a meshed transport network for 5G and beyond. Firstly, the paper has considered the most demanding aspects of a future network in terms of capacity and hop length, expected to be up to 100 Gbps and up to 1 km

TABLE III. CAPACITIES AND HOP-LENGTHS FOR DIFFERENT ANTENA AND MODEM PROFILES.

AV	Capacity	Antenna Size			AV	Capacity	Antenna Size		
> 99.9%	Los-MiMO	# 256 Ant	# 512 Ant	# 1024 Ant	> 99.9%	Los-MiMO	# 256 Ant	# 512 Ant	# 1024 Ant
Modulation	250 MHz				Modulation	1000 MHz			
QPSK	2.7 Gbps	695 m	>1000m	>1000m	QPSK	10.6 Gbps	430 m	865 m	>1000m
16 QAM	5.4 Gbps	335 m	695 m	>1000m	16 QAM	21.7 Gbps	195 m	430 m	865 m
32 QAM	6.7 Gbps	255 m	550 m	>1000m	32 QAM	26.8 Gbps	145 m	335 m	695 m
64 QAM	8.1 Gbps	180 m	395 m	805 m	64 QAM	32.3 Gbps	100 m	235 m	510 m
128 QAM	9.8 Gbps	110 m	255 m	550 m	128 QAM	39.4 Gbps	60 m	145 m	335 m
256 QAM	12.5 Gbps	65 m	160 m	365 m	256 QAM	50.0 Gbps	35 m	90 m	215 m
Modulation	500 MHz				Modulation	2000 MHz			
QPSK	5.3 Gbps	550 m	>1000m	>1000m	QPSK	21.3 Gbps	335 m	695 m	>1000m
16 QAM	10.8 Gbps	255 m	550 m	>1000m	16 QAM	43.3 Gbps	145 m	335 m	695 m
32 QAM	13.4 Gbps	195 m	430 m	865 m	32 QAM	53.5 Gbps	110 m	255 m	550 m
64 QAM	16.1 Gbps	135 m	305 m	640 m	64 QAM	64.6 Gbps	75 m	180 m	395 m
128 QAM	19.7 Gbps	80 m	195 m	430 m	128 QAM	78.7 Gbps	45 m	110 m	255 m
256 QAM	25.0 Gbps	50 m	120 m	280 m	256 QAM	100.0 Gbps	25 m	65 m	160 m

respectively. To converge towards a possible commercial product, the impact of available spectrum has been considered and deeply analyzed. Next, a first high-level assessment of the Gross System Gain that can be reasonably achieved has been done. Finally, a scalable solution, in terms of capacity and channel width has been derived. The proposed solution can be used for plenty of different radio connections use cases, since it can provide a capacity level up to 100 Gbps over 160 meter and, at reduced capacity, hop-lengths exceeding 1 km.

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