D-band Point to Multi-Point Deployment with G-Band Transport

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Abstract—**The first Point to MultiPoint wireless system at D-band has been designed and it is in advanced development. The European Commission H2020 ULTRAWAVE "Ultra capacity wireless layer beyond 100 GHz based on millimeter wave Traveling Wave Tubes" project aims to respond to the demand of high capacity at level of tens of Gigabit per second, in urban areas, where fiber backhaul is not economical viable and high density small cell architectures are deployed. A transmission hub powered by novel D-band TWT will feed a number of terminals arbitrary allocated in the corresponding area sector. This paper illustrates the main characteristics, advantages and networking aspects and provide a summary of the latest results of the ULTRAWAVE project.**

Keywords— Millimetre-waves; Sub-TeraHertz; Backhaul; Point to MultiPoint, TWT, Sub-TeraHertz MMICs

I. INTRODUCTION

Point to multipoint (PmP) wireless distribution in comparison to an equivalent Point to Point (PtP) system, offers flexibility in coverage and frequency allocation, less equipment, small footprint, low latency, easy redeployment of terminals. The wide frequency bands available above 100 GHz make very attractive the use of Point to Multipoint as backhaul solution in areas where very high density of small cells is deployed [1 – 8]. The difficulty of deploying a high number of fiber links is so far a substantial limit to densification. The requirement for a financially sustainable Point to multipoint links is to provide a cost per bit at least comparable, if not lower than an equivalent point to point system, to provide a range to cover a reasonable area to satisfy a significant number of users, to be have availability at 99.99% in the ITU zone of deployment and to have low footprint for a low Total Cost of Operation (TCO) [9 – 12].

While equipment at E-band (71 – 86 GHz) are affordable and widely available in the market, millimeter wave technology above 100 GHz is still expensive, with limited availability.

Links at E-band and above 100 GHz with multi Gigabit per second data rate were demonstrated. All of them are in Point-to-Point (PtP) system configuration. PtP systems have large footprints, due to large antennas with high gain, which compensates for the low transmission power available by solid-state devices at the increased the frequencies.

The D-band (141 – 174.8 GHz) is gaining interest due to the availability of 27 GHz of aggregated frequency bands. D-band is already under regulation by ETSI, divided in channels 250 MHz wide. Systems for PtP at D-band have been recently presented. The limited range and the need of a high gain antenna (higher than 45 dBi) make those systems still not suitable for a wide market. For example, such high antenna gain converts to a 3dB beamwidth smaller than one degree, which defines the pointing accuracy in all weather conditions.

To enabling Point to MultiPoint (PmP) links at D-band frequencies a reasonable low gain antenna needed for distributing the signal on a wide angle sector has to be considered, which makes installation easier but requires higher power levels. Specifically, a sector with 30 degrees aperture angle is produced by a 20 dBi antennas. It is immediate to appreciate that about 15 – 20 dB will be missed in the link budget and have to be provided by higher transmission power.

As already mentioned, solid-state power amplifiers at D-band are limited to an output power of a few tens of milliwatt. A simple calculation of the link budget shows the needs of at least 10 W saturated power at the transmitter. Presently, only traveling wave tubes [13, 14] have been demonstrated to produce this level of power over a wide frequency band. However, TWTs are still at the state of the art, the production is limited to a few exemplars worldwide. There is no estimation when they will be available in the market

The European Commission Horizon 2020 ULTRAWAVE "Ultra capacity wireless layer beyond 100 GHz based on millimeter wave Traveling Wave Tubes" project aims to produce the first Point to multipoint at D-band powered by low cost TWTs purposely designed [15, 16]. The D-band PmP system will be fed by data transported by PtP links at G-band (275 – 305 GHz) to create an ultracapacity layer of easy and flexible deployment to serve the backhaul of urban areas where tens of gigabit per second are needed. In the following will be given details on the advanced architecture and the technology progress of the project.

II. ULTRAWAVE USE CASE

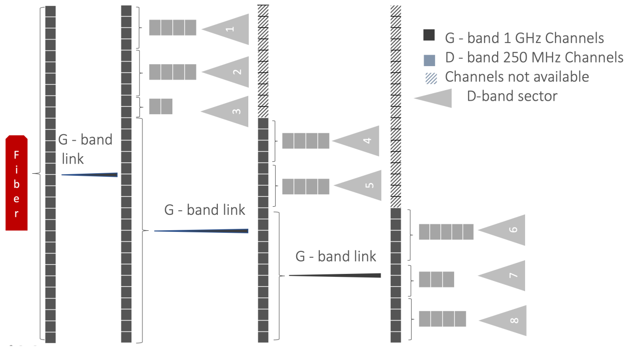
Wireless backhaul is quicker and simpler to deploy than fiber, and it is more cost-effective. Laying new fiber typically costs between €20000 and €80000 per kilometer, whereas the cost for a wireless link is an order of magnitude lower. Furthermore, in a complex urban environment, it can often be impossible to lay new fiber exactly where it is needed.

ULTRAWAVE concept and design have three key characteristics which permit to fulfil requirements exposed in the previous section [:

- Huge bandwidth which permits capacity by using robust modulations (BPSK to 16QAM and up to 64QAM). The BPSK and 16QAM more efficient regarding C/N than higher order of modulation, this feature compensates partially the propagation issue due to rain. This huge bandwidth combined with low side lobe antennas offers dense spectrum coverage.

- Multiplex of adaptive TDD channels, which permits an efficient PmP architecture and many advantageous properties as load balancing and slicing.

a)



b)

Fig.1 ULTRAWAVE concept a) deployment scenario, b) example of channel allocation

- Very low footprint of the equipment (at least three time smaller than E-band equipment for the same capacity) which reduces substantially the TCO for site acquisition and leasing.

The ULTRAWAVE network LAYER is presented as a combination of millimetre wave sub-networks PtP in G-band and PmP in D-band.

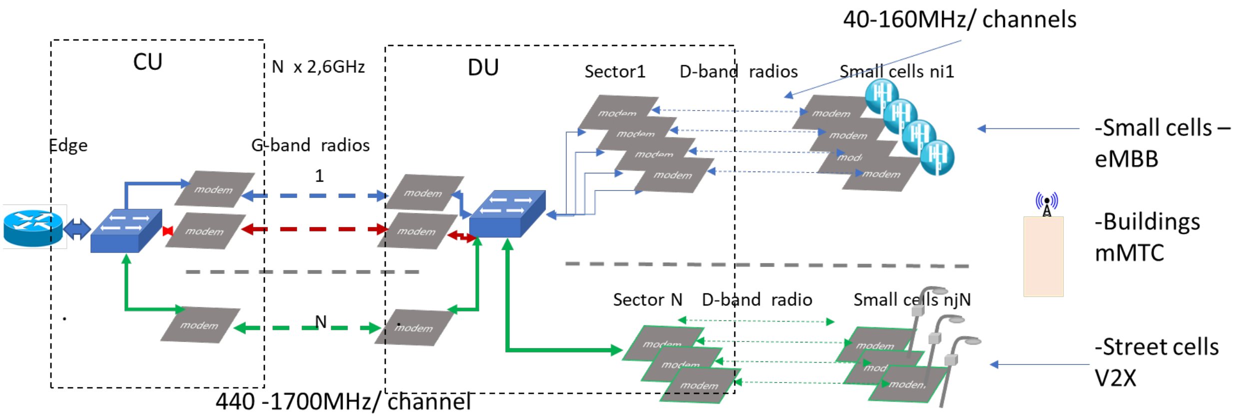


Fig. 2 ULTRAWAVE architecture at modems stacks and switching level

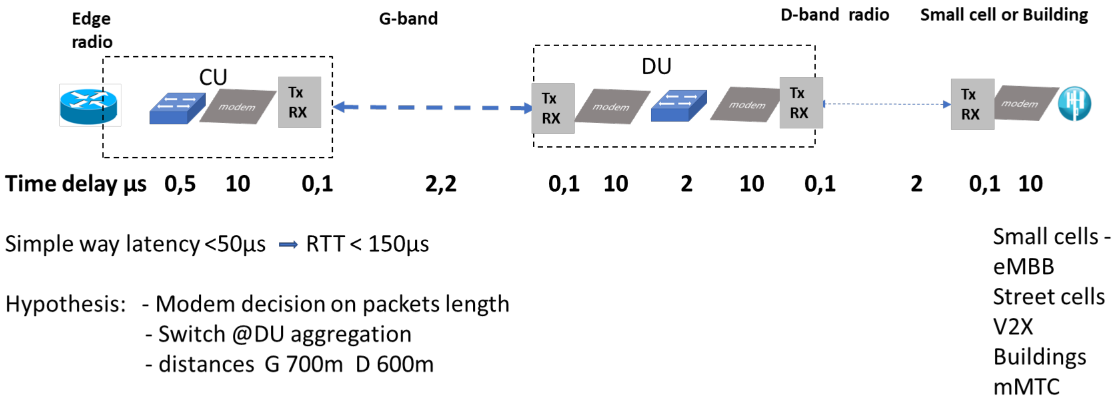


Fig. 3 Latency calculation

ULTRAWAVE aims to demonstrate a novel architecture to provide ultra-high data rate wireless in point to multipoint. The distribution is enabled by the deployment of D-band transmission hubs to produce area sector with aperture angle of about 30 degrees and 600 m range. The area can be modified according to the traffic needs by modifying the antenna gain. The D-band transmission hub are connected to the fiber point of access and in a mesh network structure by links in point to point at G-band. The modulation scheme will be 16QAM or 64 QAM at D-band and QPSK at G-band. The 30 GHz available at G-band permit high data rate.

The deployment is shown in Fig. 1a. The high flexibility of ULTRAWAVE permits many possible channel configurations. As an example, Fig.1b shows the channel allocation for the deployment in Fig.1a. There are three G-band links. One is devoted to transport data from fiber to the first cluster of transmission hub at D-band. Three clusters of D-band sectors are positioned over an ideal city layout to provide, depending on the channel allocated, 2 to 4 Gb/sec data rate. The sectors could cover different areas by varying the antenna gains.

A. Capacity

The global capacity is given by the G-Band midhaul. The capacity has been simulated for several cases of ranges and ITU areas (rain absorption); for instance, in H area capacity varies from 28Gbps at 700m to 38Gbps at 450m (30Gbps initial specification) . D-band range being of 600m ULTRAWAVE system provides around 30Gbps/km² useful bps (eg: raw bps - correcting code -MAC and IP overhead). Note that 5G target is 100Gbps/km² and that ULTRAWAVE studies considers 3 operators for competition sharing the spectrum.

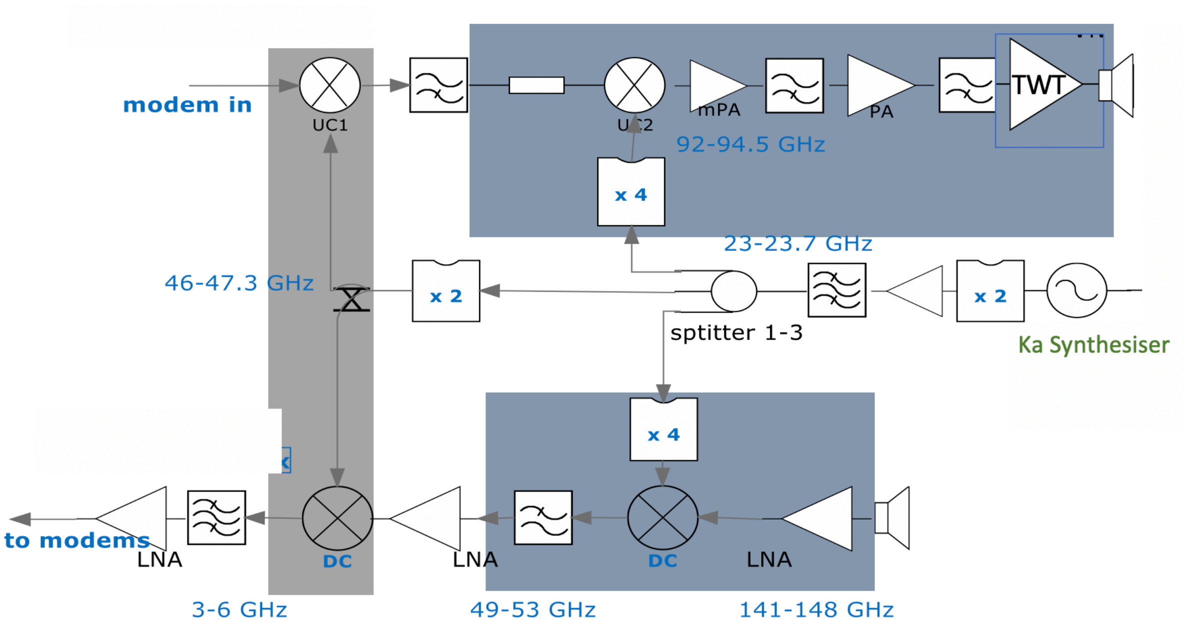


Fig. 4 Schematic of Transmission Hub

B. Networking

The data flow is a multiplex of 802.11ac modems the stack of which is housed in the hub with a switch and multiplexer and demultiplexer devices. Each modem is dedicated to a terminal. (patented system) (Fig.2).

C. Slicing

The architecture in Fig.3 shows one of the main ULTRAWAVE characteristics which is the multiplexing. On D-band, typically each channel can be dedicated to 1 class of application (a channel per slice), each modem distributes data to the same class of users (located in same sector and same Remote Radio Unit - RRU). If there is more than one class on an RRU the D-Band PmP sub-system can create VLAN per classes on modems. Indeed, the modems are PtP or PmP therefore, on a single RRU (fed by 1 modem), operator may create several VLAN according to the classes present on that RRU.

In conclusion, ULTRAWAVE design can ensure any slicing type required.

D. Latency

Latency can be computed according to the architecture presented in Fig. 2. The performances are obtained by adding the various delays over the chain, including switching-aggregation at level 2 compatible with the overall communication (Fig. 3).

ULTRAWAVE delivers a very low latency which depends only on the length of the packets transmitted and of the quality of the switches. In any case it is compatible with the requirements of latency of 5G applications in industry, health, security and especially for transports.

III. STATUS OF TECHNOLOGY DEVELOPMENT

The ULTRAWAVE system is in advanced design and fabrication status. All the components were designed. A large number of components fabricated and tested. The assembly is in progress as well as the setting of the final test in real environment at Universita Politechnica de Valencia (Spain).

The D-band PmP system consist of a transmission hub and a number of terminals. ULTRAWAVE plans to build three terminals to be deployed at different distances in the field test.

The transmission hub and the terminals share the same MMIC chipset. The main difference of the transmission hub is the TWT that powers the transmission hub and the high gain lens antenna used in the terminal instead of the low gain horn antennas of the transmission hub.

The transmission hub will have a larger size than a terminal to host the TWT. In the following the description of the system schematic and some results on performance of the different component will be given.

A. Transmission hub

The schematic of the Transmission. Hub is shown in Fig. 5 . It consists of a transmitter and receiver at D-band, two intermediate frequency levels of upconversion and downconversion are used to connect to the modem in C-band. The first IF level is with the LO (Local Oscillator) at W-band (92 GHz) to convert from D-band to Q-band. The second IF level is with the LO at low Q-band (46 – 47.3 GHz) to convert to C-band.

The D-band section includes two MMIC power amplifiers in the transmission chain. The medium power amplifier (mPA) and the Power Amplifiers (PA) are realized in DHBT InP

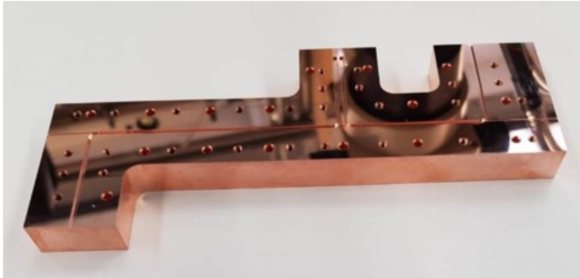


Fig.5 details of the interaction structure of the TWT.

process at FHB. The output power is about 9 dBm and 14 dBm respectively.

The Low Noise Amplifier in the receiver chain has been realized by a 40nm GaAs process. The noise figure is about 5dB. The upconverter and downconverter mixers are built by a 70 nm GaAs process. The rejection filter was fabricated by CNC milling with an insertion loss IL < 1.9 dB at D-band.

The D-band TWT has been designed. It provides 12 W saturated output power in the whole frequency band. All the parts where built. The interaction structure has been successfully measured demonstrating a wide bandwidth of

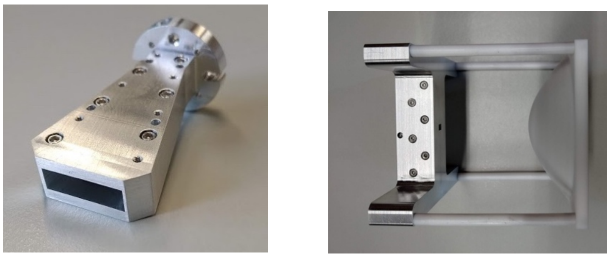


Fig. 6 ULTRAWAVE D-band Antennas a) horn, b) lens antenna

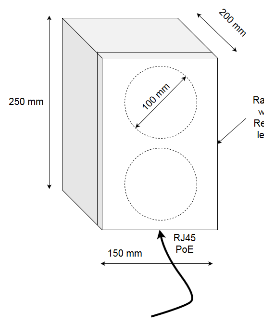


Fig. 7 ULTRAWAVE cabinet for the transmission hub.

operation. Fig. 5 shows details of the interaction structure of the TWT. Presently, the TWT is in the final assembly phase.
The Q-band to C-band section uses commercial components.

B. Terminal

The schematic of the terminal is similar to the transmission hub, but without the TWT. The chipset and the layout are exactly the same of the Transmission Hub. Each terminal is pointed directly towards the transmission hub. The transmitter is a DHBT InP Power amplifier, with about 19 dBm. A high gain antenna (39dBi) is needed to achieve the same range of the transmission hub. A second antenna with the same gain is used for the receiver.

C. Antennas

Two antennas were designed and tested at D-band. One is a low gain antenna for the transmission hub with about 20dB gain. The second is a dielectric lens antenna with about 38 dBi. Both are illustrated in Fig. 6 and have been verified experimentally.

D. Cabinet

The schematic of the cabinet for the terminal is shown in Fig.7. The size is very compact (less than 8 liters). With further optimization it is possible to reduce the dimensions for an easier deployment.

IV. Conclusions

ULTRAWAVE system offers unprecedented capability to provide high data rate at level of tens of Gb/s on wide area at D-band. It offers a very supple backhauling over a 1.2km radius area, and compliant with 5G targets as far as capacity, latency and slicing.
The system is in advanced fabrication stage.

Acknowledgment

The work has received funding from the European Union's Horizon 2020 research and innovation programs under grant agreement no 762119. This work reflects only the author view's and the Commission is not responsible of any use that may be made of the information it contains

References

[1] Ericsson Mobility Report, November 2018 on line https://www.ericsson.com/en/mobility-report

[2] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016–2021 White Paper, Cisco Mobile VNI, 2017

[3] Dhillon, S. S. et. al, "The 2017 terahertz science and technology roadmap", *J. Phys. D: Appl. Phys.* 2017, *50*, 043001.

[4] T. Nagatsuma et al. Advances in terahertz communications accelerated by photonics, Nature Photonics 10, 371-379 (2016)

[5] Z. Pi and F. Khan, "An introduction to millimeter-wave mobile broadband systems," *IEEE Comm. Magazine*, pp. 101-107, June 2011.

[6] X. Li, et al. , "Fiber-wireless- fiber link for 100-Gb/s PDM-QPSK signal transmission at W-band," IEEE Photon. Technol. Lett., Jul. 2014.

[7] T.S. Rappaport et al., " Millimeter Wave Mobile Communications for 5G Cellular: It will work!", *IEEE Access*, pp. 335-349, Mai 2013.

[8] J. Takeuchi, et. al. "10-Gbit/s Bi-directional wireless data transmission system using 120-GHz-band ortho-mode transducers," *2012 IEEE Radio and Wireless Symposium*, 2012, pp. 63–66.A.

[9] R. Taori and A. Sridharan. "Point-to-multipoint in-band mmwave backhaul for 5G networks,", *IEEE Communications Magazine*, pp. 195-201, January 2015.

[10] F. Magne, A. Ramirez, C. Paoloni, "Millimeter Wave Point to Multipoint for Affordable High Capacity Backhaul of Dense Cell Networks", *IEEE Wireless Communications and Networking Conference 2018*, WCNC 2018, Barcelona, Spain, April 2018.

[11] J. Shi, L. Lv, Q. Ni, H. Pervaiz and C. Paoloni, "Modeling and Analysis of Point-to-Multipoint Millimeter-Wave Backhaul Networks," in IEEE Transactions on Wireless Communications. doi: 10.1109/TWC.2018.2879109

[12] C. Paoloni, F. Magne, F. André, J. Willebois, Q. T. Le, X. Begeaud, G. Ulisse, V. Krozer, R. Letizia, M. Marilier, A. Ramirez, R. Zimmerman, "Transmission Hub and Terminals for Point to Multipoint W-band TWEETHER System", *European Conference on Networks and Communications,* EuCNC 2018, Ljubljana, Slovenia, June 2018.

[13] R.Basu, L. R. Billa, R. Letizia, C. Paoloni, "Design of sub-THz traveling wave tubes for high data rate long range wireless links", *2018 Semicond. Sci. Technol. 33* 124009

[14] R.Basu, L. R. Billa, R. Letizia, C. Paoloni, "Design of D-band Double Corrugated Waveguide TWT for Wireless Communications ", *Proc. IEEE 20th Int. Vac. Electron. Conf.*, Busan, South Kores, April. 2019.

[15] Paoloni, C, Boppel, S, Krozer, V, Quang, TL, Letizia, R, Limiti, E, Magne, F, Marilier, M, Ramirez, A, Vidal, B & Zimmerman, R 2019, Technology for D-band/G-band Ultra Capacity Layer. in 2019 European Conference on Networks and Communications (EuCNC). IEEE, pp. 209-213, EUCNC, Valencia, Spain, 18/06/19.

[16] ULTRAWAVE website [Online]. Available: http://ultrawave2020.eu