Toward 100 Gbps Wireless Networks Enabled by Millimeter Wave Traveling Wave Tubes

Claudio Paoloni[1], Rosa Letizia[1], Viktor Krozer[2], Marc Marilier[3], Sebastian Boppel[4], Antonio Ramirez[5], Borja Vidal[6], Ernesto Limiti[7], Ralph Zimmerman[8]

1 Engineering Department, Lancaster University, Lancaster, United Kingdom, LA1 4YW
email: c.paoloni@lancaster.ac.uk
2 Goethe University of Frankfurt, Frankfurt 60323, Germany,
3 OMMIC S.A.S., Limeil Brevannes 94453, France
4 Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany
5 Fibernova Systems, Valencia 46022, Spain
6 Universitat Politècnica de València, Valencia 46022, Spain,
7 University of Rome, Tor Vergata, Rome, Italy
8 HF Systems Engineering GmbH, Kassel 34123, Germany

Abstract: *New generation networks for 5G need a breakthrough to support the unstoppable increase of internet traffic. Millimeter waves offer multi-GHz bandwidth for multigigabit per second data rate. For the full exploitation of the millimeter wave spectrum, due to the high atmosphere attenuation, high transmission power is needed, not available by solid state devices. Traveling wave tubes are the only enabling devices to create ultracapacity layers to distribute data with data rate at fiber level over wide areas. This paper presents the aims of a new European Commission Horizon 2020 project, ULTRAWAVE, to create for the first time a data layer with area capacity toward 100 Gbps/km^2, combining D-band and G-band internet distribution enabled by millimeter wave traveling wave tubes.*

Keywords: traveling wave tube, 5G, wireless network, high capacity

Introduction

The main challenge in the implementation of the 5G is in the capillary connection from fiber to base stations, users, and fixed access hubs. The terminals (smartphone, Wi-Fi, laptop) will continue to work in sub-6 GHz bandwidth, but these devices will require very high throughput, estimated higher than 5 Mb/s. To satisfy this requirement, the only solution is to use MIMO or high density small cells. Fiber is the ideal medium to bring data capacity, or backhaul, to base stations, but it is difficult and expensive to deploy, especially if a high capillary architecture is needed [1, 2].

The coverage by fiber is in general increasing, but it will be never sufficient to satisfy high density small cell architectures, with cell radius down to 20 meters. Also fiber infrastructure is not sufficiently flexible for future 5G demands.

The wireless backhaul is considered the most cost effective solution. However, only above 90 GHz it is possible to find wide multi-gigahertz bandwidth to support multi-gigabit data rate [3].

The availability of millimeter wave front-end in the market is limited to point to point (PtP) links in E-band (71 – 86 GHz) or at lower frequency. In principle, these links could serve for backhaul, but two front ends are needed for each small cell, with relevant issues of foot print and flexibility of cell allocations.

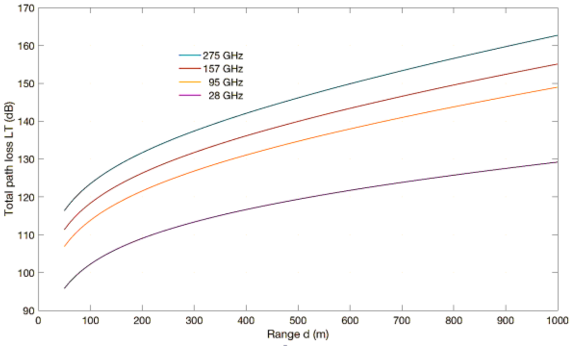

Figure 1. Attenuation as a function of distance and frequency in ITU K rain zone for availability 99.99%.

Differently, the point to multipoint (PmP) distribution, based on transmission hubs that distribute data by a wide beam in a wide area, is more cost effective, easier to deploy and has a small footprint due to the need of a single antenna for many links.

It is well known that the millimeter wave spectrum suffers from high attenuation due to the path loss, humidity and rain, that make it almost impossible to achieve long range by using low gain antennas, as required in PmP. Fig. 1 reports atmosphere attenuation, including rain attenuation in zone K, where 99.99% availability is related to 42mm/h rain for 0.01% of the time, as function of distance and frequency [1]. For 1 km distance, at 275 GHz the signal

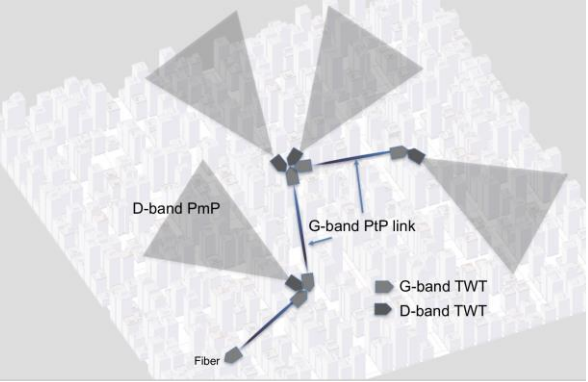

Figure 2. ULTRAWAVE layer schematic.

suffers 40 dB more attenuation than at 28 GHz. This demonstrates the need of high transmission power.

The European H2020 Project, TWEETHER [4], is in the final phase of realization of the first PmP wireless system at W-band (92 – 95 GHz) powered by a folded waveguide Traveling Wave Tube (TWT). The use of a 40 W TWT [5] permits to cover with a single low gain antenna (16 to 20 dBi) sectors with 1 km radius and 90 degrees aperture angle. The TWEETHER PmP is designed to provide up to 10 Gbps/km^2 area capacity, sufficient to provide data to 2000 high end terminals requiring 5 Mbps. Although representing a breakthrough, the demand for data rate is already exceeding this value, especially in urban areas. Most of the wireless traffic is made by high resolution images and videos. It is predicted that in 2020 the threshold of half zettabyte will be reached with area capacity projected to 100 Gbps/km^2.

The new European Commission Horizon 2020 ULTRAWAVE, "Ultracapacity wireless layer beyond 100 GHz based on millimeter wave traveling wave tubes", aims to enable a future network architecture with point to multipoint at D-band (141 – 148.5 GHz) with fronthaul at G-band (275 – 305 GHz) in point to point to provide for the first time up to 100 Gbps/km^2 for new high capacity networks. The ultracapacity layer will be enabled by two novel TWTs, at D-band and at G-band respectively. ULTRAWAVE is an international project involving academia and industry from United Kingdom, France, Germany, Italy and Spain.

In the following, the first specifications of the systems will be given and the architecture discussed.

TWTs for the ULTRAWAVE Layer

The two main design parameters are the transmission range and the Signal/Noise Ratio (SNR). A long transmission range is important to use the minimum number of front ends per unit area. The SNR defines the maximum modulation scheme for a given link and the related data rate.

Since the transmission power is the enabling parameter, the system specifications were derived starting from the output power that TWTs can generate at those frequencies.

The W-band TWT of the TWEETHER project was considered as reference [5]. Applying the power/frequency scaling law, the estimation for the D-band TWT output is 15 W, while for the G-band TWT is up to 2-3 W. An electron beam voltage in the range 11 -15 kV and a beam current below 60 mA is assumed.

Slow wave structures (SWS) above 100 GHz are mostly derived from corrugated waveguide topology, such as the double corrugated waveguide [6] or the folded waveguide. The limit of millimeter wave SWS is the low interaction impedance that determines the need of a high number of periods with low efficiency. However, the demonstrated TWT output power is about two orders of magnitude higher that any solid-state power amplifier.

Given the TWT power levels, the propagation distances were computed by a modified Friis Formula.

The PmP D-band (141 – 148.5 GHz) system, can support a low gain antenna with about 20 dBi, to provide radial sector area from 45 degrees. Assuming a 35 dBi antenna at the terminal, a radius of 600 m, corresponding to a covered area of 0.22 km^2 is obtained. By 16 QAM modulation, capacity of 40 Gbps/km^2 can be provided.

Due to the strong atmosphere attenuation, the G-band PtP link needs high gain antenna in the range of 35 dBi. The range is 600 m. These system specifications are fully satisfactory for the coverage considered and cost effective in the urban scenario where high capacity is requested.

Conclusion

A novel wireless communications scenario enabled by Traveling Wave Tubes has been presented. The millimeter wave spectrum offers quasi-fiber capacity. The formidable obstacle due to the atmosphere attenuation that so far prevented the millimeter wave spectrum exploitation will be overcome by the use of novel millimeter wave TWTs.

Acknowledgements

The ULTRAWAVE project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement no 762119.

References

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

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

[3] Paoloni, C, Magne, F, Andre, F, Begaud, X, Krozer, V, Marilier, M, Ramirez, A, Vilar, R & Zimmerman, R , TWEETHER Future Generation W-band backhaul and access network infrastructure and technology. in *European Conference on Networks and Communications (EuCNC 2017).*

[4] TWEETHER website [Online]. Available: http://www.tweether.eu

[5] Andre, F, Kohler, S, Krozer, V, Quang, TL, Letizia, R, Paoloni, C, Sabaawi, A, Ulisse, G & Zimmerman, R, Fabrication of W-band TWT for 5G small cells backhaul. in International Vacuum Electronics Conference 2017, US

[6] C. Paoloni and M. Mineo, "Double Corrugated Waveguide for G-Band Traveling Wave Tubes,", IEEE Trans. on Electron Devices, vol.61, no.12, pp.4259,4263, Dec. 2014