

TWEETHER Future Generation W-band Backhaul and Access Network Technology

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Abstract—Point to multipoint (PmP) distribution at millimeter wave is a frontier so far not yet crossed due to the formidable technological challenge that the high atmospheric attenuation poses. The transmission power at level of tens of Watts required at millimeter wave for a reference range of 1 km is not available by any commercial or laboratory solid state devices. However, the availability of PmP with multigigabit data rate is pivotal for the new high density small cell networks for 4G and 5G and to solve the digital divide in areas where fiber is not convenient or possible to be deployed. In this paper, the advancements of the novel approach proposed by the EU Horizon 2020 TWEETHER project to create the first and fastest outdoor W-band (92 – 95 GHz) PmP wireless network are described. For the first time a new generation W-band traveling wave tube high power amplifier is introduced in the transmission hub to provide the enabling power for a wide area distribution.

Keywords—millimeter waves; TWT; access; backhaul; W-band; 5G; Point to multipoint

I. INTRODUCTION

The urgency of enabling people to be connected to internet every time and everywhere at very high data rate and the increasing demand of bandwidth-hungry services, such as High Definition TV (HDTV), videoconferencing, online games, IoT, and many others, are placing unprecedented strain on operators' networks to deliver the required capacity [1 – 5].

Faced with this exponential increase in data traffic, the cellular network operators are confronted with a precarious situation: accommodate the ever-increasing traffic growth, yet reduce the costs and consequently increase average revenue per user. In this scenario, operators have started to upgrade their 3G cell sites to 4G e-Node Base Station and to deploy large number of small cells to supply sufficient capacity density and high-

quality contiguous and ubiquitous coverage. However, deploying large numbers of small cells helps to solve the capacity problem for the radio access network, but adds novel challenges for backhaul, with substantial impact on the costs. Such a backhaul problem on 4G small cells will indeed worsen with 5G, where density and capacity will be considerably increased (small cells of 100m radius, @ 2.4 GHz). This will lead to install a higher density of Points of Presences (PoP) to feed the small cells in the attempt to increase efficiency, reliability and consumption. The challenge is therefore to provide an affordable multi-gigabit backhaul solution that can allow flexible, scalable small cell deployments. A capacity density of Gbps/km² class is required.

A second important aspect, with social implications, of internet distribution, is the digital divide due to the still low coverage by fast broadband internet access in most of the residential, sub urban or “rurban” areas, where the deployment of fiber is not convenient or feasible. This affects millions of households with poor Internet connections. Hopefully, 5G will introduce LTE @3.5GHz very suitable to offer high throughputs to houses.

However, the current limitation in bandwidth and capacity of microwave wireless networks can only be overcome by the exploitation of unused portions of the spectrum at millimeter wave frequencies (above 30 GHz).

The total capacity requested today for the 4G plus WiFi small cells backhauling scenario is around 1 Gbps/km². It is expected that 5G will add a factor from 3 to 5 to the 4G capacity, meaning that in some dense areas it would rise to 10 Gbps/km² with small cell radius < 100m. In residential areas, the capacity could reach 1.5 Gbps/km² with larger cells (250m radius). In both cases, throughputs of a backhaul link would range from 50 to 200 Mbps per cell.

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The TWEETHER project aims to respond to this challenge by a novel point to multipoint wireless system operating at W-band (92 – 95 GHz), to provide a capacity density up to 10 Gbps/km². In this paper, the architecture and the key components of system, in advanced fabrication status, will be described [8].

II. W-BAND POINT TO MULTIPOINT WIRELESS NETWORK

A. Why Point to multipoint at W-band

The millimeter waves are unanimously considered the new frontier of wireless communications due to the wide availability of spectrum for multi-gigabit data rate [1 - 4]. The Q-band (40.5 – 43.5 GHz) [5] regulated for PtP and PmP, V-band, (59 – 64 GHz) and E-band (71-74 GHz, 81-85 GHz) [6, 7] both regulated for PtP, are already used for internet distribution. Millimeter wave PtP systems are available at V-band and E-band, based on the available low power solid state transmitters and high gain and directivity antennas (up to 50 dBi). PmP systems are available only at Q-band, with limited spectrum. PtP backhaul can be feasible only by using a high number of antennas at the transmission hub, with high cost of equipment, space and renting of the masts.

On the contrary, point to multipoint (PmP) backhaul is a more effective solution (Fig. 1), due to the use of one low gain antenna at the transmission hub to feed a high number of PoPs. It is of easy installation, high flexibility and configurability and permits significant savings in TCO (Total Cost of Ownership) with up to 50 percent reduction in comparison to fibre [9, 10]. The W-band (92 – 95 GHz) is a portion of the spectrum still not exploited, that represents a very promising band for PmP deployments, due to 3 GHz available bandwidth, the traditional light licensing for PmP, and the small footprint of the equipment made possible by the short wavelength

B. Capacity

The W-band offers almost 3 GHz (92 – 95 GHz) for high capacity wireless distribution. The system capacity is computed assuming an allocation of 1GHz per operator and a re-use frequency ratio 2. A sector would use 500 MHz in order to alternate sub-bands for frequency re-use and decoupling between sectors. This means that ten 40 MHz channels or five 80 MHz channels can be used or a mix of them, with 10 MHz of frequency guard separation between channels. With these

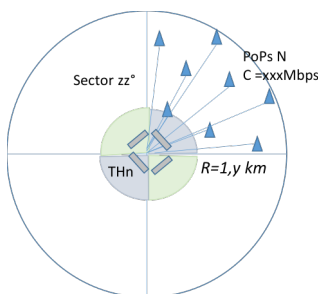


Fig.1 Transmission Hub Sectors (radius R, capacity C, sector angle zz°).

channel bandwidths, the modulation order will determine the maximum capacity over one link. In this sense, the modulation order should be limited to 64 QAM (256 QAM may be possible for very small cells at short distance) to obtain a Frame Loss Rate (FLR) under 10^{-6} .

Therefore, for an allocation of 500MHz per sector and considering 64QAM $\frac{3}{4}$ modulation scheme, the capacity delivered as a function of the modem configuration can reach 1.35 Gbps.

The total capacity of one Transmission Hub (TH) will be therefore $S \cdot 1.35$ Gbps, being S the number of sectors. Depending on the configuration of the TH, for example with 4, 6 and 8 sectors, it is possible to deliver 5.4 Gbps, 8.1 Gbps and 10.8 Gbps respectively.

C. Coverage and range

Two main obstacles have so far prevented the development of millimeter waves PmP systems: one is the atmospheric attenuation under rain conditions, the second is the technology to provide sufficient output power to overcome the attenuation.

An initial estimation of the output power needed at the transmitter for enabling a PmP at W-band was made assuming the budget link for a kilometer range and 10 terminals of 40MHz bandwidth each (e.g. considering 1GHz allocation for each operator, as explained in previous section). For this computation, a number of factors such as the absorption equations for rain intensities, including probabilities of intensities for a given ITU zone, and availabilities depending on range, antenna gains, noise figure, circuits losses, phase noise, C/N at transmission, correcting codes effect and yield of MAC layer, processing degradation depending of MSC (modem bandwidth and frequency guards, back-off, PAPR) and efficiency (FEC, MAC, IP) were considered. It has been assumed 99.95% availability.

The rain attenuation is the most critical parameter that affects the range and the availability at millimeter waves. The EMEA (Europe, the Middle East and Africa) and the US the rain zones ITU, from A to K are considered as main TWEETHER scenario. In case of ITU zone E/ F, range in the order of 1 km is obtained with 64QAM and 720Mbps with 99.99% availability. In case of heavy rain, the availability at 99.99% is

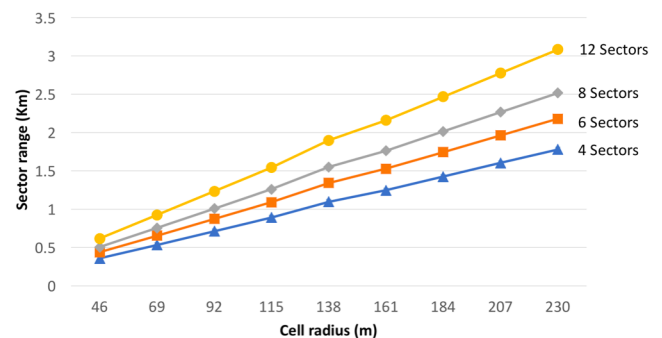


Fig. 2. Range as a function of the number of sectors and cell radius, to derive the coverage area.

obtained by ACM with a lower modulation scheme (QPSK) reducing the capacity.

The calculation provides a linear output power of 10W at the Transmission Hub to enable the requested coverage. Due to the high order of the modulation scheme, high linearity is needed, imposing 6dB back-off. Finally, an amplifier with 40W saturated power is needed. This demonstrates the challenge of enabling a PmP system at W-band as no amplifiers are presently available to provide 40 W at W-band.

Fig. 2 reports the estimation of the area covered by the system, feeding up to tens of PoPs, for different cell radius and sector angles. This figure shows that, assuming a deployment of small cells with 100 m radius, a TH with four 90° sectors covers an area of 850 m radius, equivalent to 2.5 km². This scenario is suitable for high density cells. In case of larger cells, e.g. 200 m cell radius, a TH with 12 sectors (aperture angle 30°) can cover an area of about 27 km² and about 3 km radius.

This case is suitable to provide cost effective broadband access in residential or urban areas. The decreasing of the sector angle leads to an increase in the range, underlying the versatility of the TWEETHER system given by the possibility to choose the number and the aperture angles of the sectors, depending on the coverage, with important and positive impact on the TCO.

D. TWEETHER system specifications and performance

The fabrication of equipment for PmP at W-band is a challenge. The low gain antennas for covering sectors in the range 30° - 90° requires transmission power of tens of Watt, presently not available by solid state power amplifiers [11] at these frequencies.

The H2020 TWEETHER project aims to the design, fabrication and test of the first W-band Point to multi point system. TWEETHER system specifications are reported in Table I. It is notable the high power that the TWT will provide, up to 40W saturated in W-band.

Each sector supports an end-to-end sub-network based on IEEE 802.3 aggregation, connectivity and switching standard protocols and with Gigabit Ethernet Interfaces. This sub-network comprises two elements, the Transmission Hub and the Network Terminal Equipment (NTE) (Fig. 3):

- The Transmission Hub (TH), connected to a fiber PoP, provides high aggregated capacity to feed several terminals.

The TH is composed of an Indoor Unit (IDU) dealing with the baseband and intermediate frequency communications. The IDU accommodates a stack of modems on separated channels, each dedicated to a PoP. The aggregation of these independent half-duplex TDD channels is multiplexed and sent to an Outdoor Unit (ODU), which is responsible for the up and down-conversion of the intermediate frequency channels to the 92 - 95 GHz frequencies radiated by the sector antennas integrated in this module.

- The NTE delivers basic Service Interfaces to customer's Points of Presence (small cells or residential access PoPs). It establishes a single connectivity to the TH where they are connected through a VLAN. The NTE comprises

Transmission Hub		Terminal	
Transmitter		Transmitter	
TWT Psat 40 W	46 dBm	GaAs PA Power	23 dBm
TWT P1	10 W	GaAs PA Gain	22 dB
TWT Gain	40 dB		
TOTAL Bandwidth	3%		
Driver UC + PA gain	10 dB	Upconverter Loss	-8 dB
Upconverter Loss	-8 dB	Upconverter LO rejection	10 dB
Upconverter LO rejection	10 dB	UC Output power	-5 dBm
Transition TWT-horn	-0.3 dB		
Horn Antenna aperture	90° x 8°	Lens Antenna aperture	2.6°
Horn Antenna gain	17dBi	Lens Antenna gain	36 dBi
Receiver		Receiver	
LNA NF	3.5 dB	LNA NF	3.5 dB
Gain	20 dB	Gain	20 dB
S11	-10 dB	S11	-10 dB
Transition LNA - horn	-0.6 dB	Transition LNA -feeder	-0.6 dB

Table I TWEETHER Specifications

directive antennas, a transceiver for W-band up/down conversion and the IF modem.

Once the network architecture is defined, key aspects are the capacity provided by each sector, its coverage and how many PoPs will be connected in an area and at which ranges.

III. W-BAND ENABLING TECHNOLOGY

Presently, no devices are available to provide the requested level of transmission power at W-band to enable the PmP as in Table I. The solid state electronic at W-band is progressing. State of the art high power solid state MMICs based on GaN provide power amplifiers with saturated power in the range of 30dBm [11].

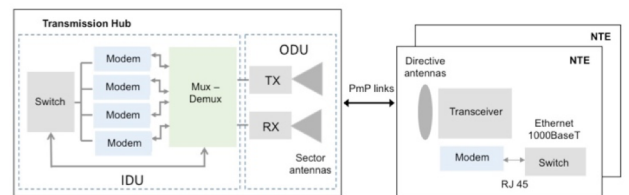


Fig.3 Sub-network layout

The challenge of TWEETHER is to develop components suitable to build a transceiver for high capacity PmP system, operationally simple, with low TCO.

The breakthrough of TWEETHER project is integrating a novel, compact, low cost and high yield Traveling Wave Tube (TWT) power amplifier with 40 W saturated output power, and

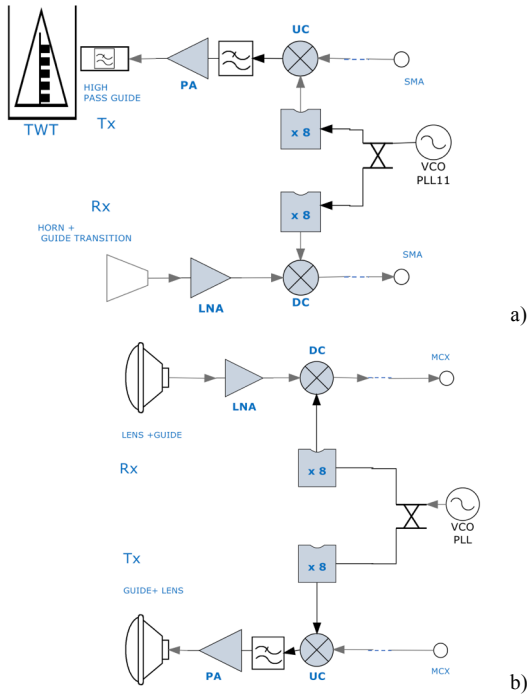


Fig.4 TWEETHER (a) Transmission Hub and (b) Network Terminal Equipment (NTE) for Outdoor Units

10 W at 1-dB compression point at the transmission hub, to power an affordable high performance transceiver, based on a novel GaAs MMIC chip-set at 92 - 95 GHz.

Regarding the radiation level, the use of a low gain antenna at the TH keeps the level below the ETSI and FCC limits.

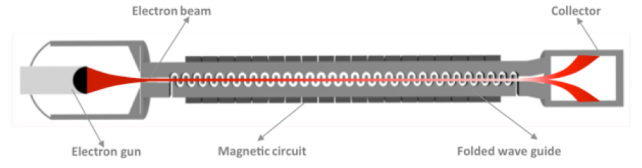
The schematics of the TWEETHER W-band system is shown in Fig.4. Transmission Hub (Fig. 4 (a)) and NTE (Fig. 4 (b)) use the same chipset.

A description the design and fabrication status for the various components is summarized in the following. The main system specifications are listed in Table I.

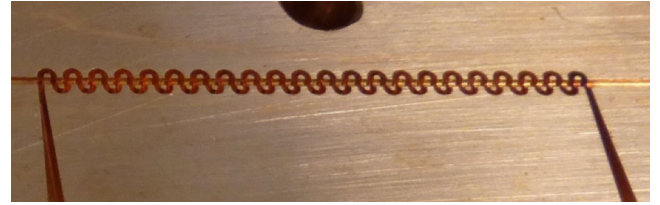
A. W-band Traveling Wave Tube

TWTs (Fig. 5a) are commonly used in specific, high end and high reliability applications where high power is needed. The maximum operating frequency of the commercial TWT is below 50 GHz due to the small dimensions that make challenging the fabrication and assembly at millimeter waves [12, 14]. At the W-band, the fabrication challenge is formidable due to the dimensions of the parts in the range of hundreds of microns. W-band TWTs are reported in literature only at laboratory level. A new approach has been adopted to make the fabrication easier and satisfy the system specifications [14].

A novel W-band TWT has been designed and is in advanced fabrication stage. The output power is higher than 40 Watt in the whole frequency range. In Fig.5a is shown the TWT cross section. The folded waveguide (FWG) is the interaction structure. The electron beam travels in the beam tunnel along the FWG and by interaction with the electric field in the FWG its energy is transferred to radiofrequency field. The electron gun and the magnetic focusing system must provide a well



a)



b)

Fig. 5 a) TWT cross section schematic with FWG and the electron beam, b) detail of the microfabricated copper FWG. To note the beam tunnel crossing the FWG.

confined electron beam. Both these parts have been fabricated and successfully tested.

The folded waveguide has been microfabricated in OFHC (Oxygen free high conductivity) copper [13]. The small section of the waveguide, 0.6 mm^2 , requires a high precision CNC milling to be realized with tolerance better than 5 microns. A sample of the realized FWG is shown in Fig. 5b.

B. Multi-chip module assembly

A purposely designed low power subassembly is under development for the TH and the NTE. It is based on a GaAs MMIC chip set with 100nm gate length, including 8X-multiplier, Power Amplifiers (PA) for the NTE (Fig.6), Low Noise Amplifier (Fig.7), Up and Down Converters and a Synthesizer. The specifications for the output power of the MMIC power amplifier are important to provide the required range to the NTE. The MMIC PA has been redesigned with the target of about 23 dBm in the frequency band, value at the state of the art in GaAs in Europe. All the chipset parts have been fabricated and measured with satisfactory results. The preliminary measurements provide a gain of 23 dB and an output power of 21.6 dBm (Fig. 6 a, b). Further improvements are in progress to increase the output power to extend the NTE range. The Low Noise amplifier provides less than 3dB of Noise Figure with 25 dB gain (Fig.7a). The LNA chip in the mount is shown in Fig.7b.

Low-phase noise LO signal generation is crucial for the required system performance. This is accomplished using a traditional low phase-noise synthesizer and a direct digital synthesizer ASIC in BiCMOS, both being currently tested.

One of the challenges is a reliable assembly of the breadboard including the W-band and IF component and the transition to the TWT. A purposely designed subassembly approach is under development to reduce the interconnection losses.

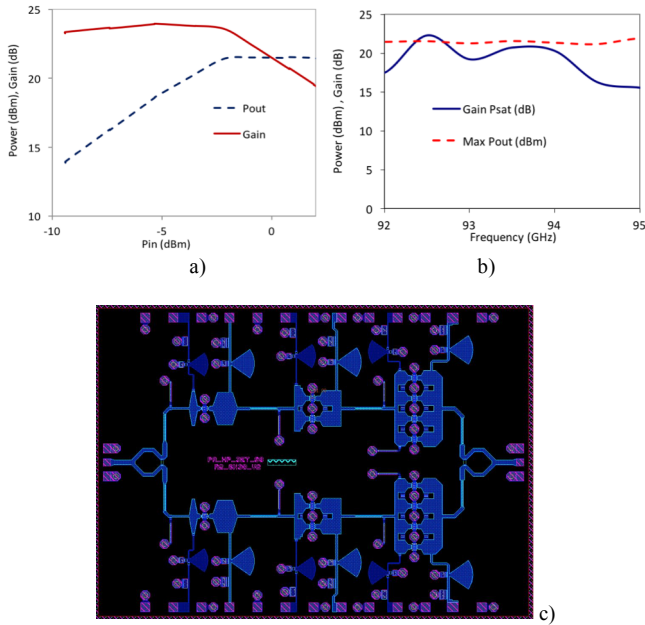


Fig. 6 W-band power amplifier. a) Pout/Pin and Gain as a function of Pin, b) Saturated power and gain, c) layout

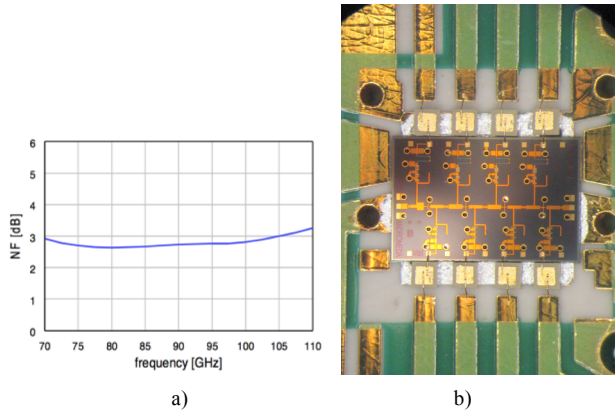


Fig.7 Low Noise amplifier. a) Noise figure and b) photo of the LNA chip

C. Antennas

In the framework of the TWEETHER project, two different antennas are required [15]. A pyramidal horn low gain antenna to cover a defined sector from the transmission hub (TH) has been adopted because of simplicity of its design and realization. The size of the aperture has been optimized to satisfy the

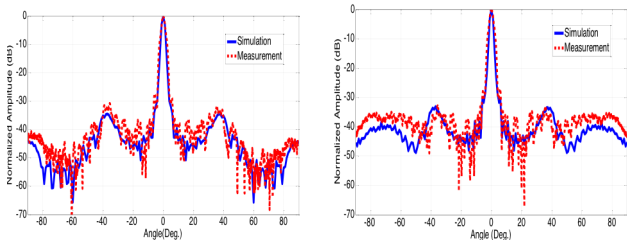


Fig. 8 Hyperbolic lens antenna diagram at 92.5 GHz, a) H-plane, b) E-plane

specification in Table I. High directive antennas are necessary for the NTE. The hyperbolic lens antenna has been chosen for its simple design and high gain. The simulation and measurements of the radiation patterns for the NTE antenna in the E and H planes at 92.5 GHz is given in Fig. 8. This result presents a high directive radiation pattern with a HPBW of 2 degrees in both planes without side lobes.

The lens profile focuses the energy up to ± 39 degrees and the gain is better than 38 dB over the required operating band.

All the antennas have been fabricated and measured.

IV. CONCLUSIONS

The H2020 TWEETHER system represents a new concept of future generation network infrastructures for backhaul and access. It is a Point-to-multipoint wireless system operating at W-band, based on a novel TWT high-power amplifier. The system has been conceived to be implemented for 4G and 5G deployments in dense urban environments with a lower TCO compared to fiber-based or point-to-point-based backhails.

The chipset and the TWT beam optics have been successfully tested. The integration of the parts is in progress.

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