Sub-THz wireless system with electronic and optoelectronic transmitters

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ABSTRACT

The rising traffic demand in mobile networks is pushing the capacity need, especially in the access network. Wireless access integrated with the operator optical fiber network offers mobility and easiness of deployment. The challenge is the provision of wireless broadband capacity paired with the increasing traffic demands.

The paper describes a point-to-multipoint fronthaul distribution wireless network at D-band (141 – 148.5 GHz) fed with point-to-point backhaul transport links at G-band (275 – 305 GHz), providing tens of Gb/s data rate. The system is under development in the frame of the European Commission Horizon 2020 ULTRAWAVE "Ultra capacity wireless layer beyond 100 GHz based on millimeter wave". The D-band transmission hubs are connected to the optical core network through Gb/s class G-band links, based on a microwave photonic transmitter employing uni-traveling-carrier photodiodes (UTC-PD). A field test in real environment is planned to demonstrate the ULTRAWAVE system breakthrough.

Keywords: Wireless, millimeter waves, D-band, photonic transmitter, G-band, point-to-multipoint, point-to-point, uni-traveling-carrier photodiode.

1. INTRODUCTION

In 2020, over 60% of the world population regularly uses Internet[1]. It is estimate that 91% of them use internet via a mobile phone. The aggregated traffic from all these users adds considerable pressure to the mobile infrastructure, not only to the radio access but also to the backhaul and fronthaul. Fiber links are routinely used by carriers to feed remote antenna units (RAU). However, the trend towards stronger cell densification in next generation mobile standards (5G, 6G)[2] will challenge the feasibility of this option in terms of CAPEX (Capital Expenditure). It is widely agreed that the only alternative to reduce the cost of the network is the use of wireless technology integrated with the operator optical fiber network. Wireless backhaul and fronthaul are easier and faster to deploy than wired technologies. Since the frequency bands so far used in microwave and low millimeter regions (28 GHz) are not sufficient to ensure the requested capacity at level of tens of Gigabit per second per kilometer square (Gb/s/km^2), the upper limits of the millimeter-wave bands (140 - 310 GHz) are being considered[3].

The millimeter waves, or sub-THz region of the spectrum (90 – 310 GHz), offers numerous multi-GHz wide frequency bands suitable for Gb/s data rate. It is well known that one of the reasons why the sub-THz spectrum is not yet exploited commercially is the high attenuation, especially in rainy conditions and the high free path loss, that need Watt level transmission power, so far not available at those frequencies or very large footprint antennas to compensate the low transmission power.
The paper describes the development of a point-to-multipoint (PmP) fronthaul distribution wireless network at the D-band (141 – 148.5 GHz) fed with point-to-point (PtP) backhaul transport links at G-band (275 – 305 GHz). The system is developed n the frame of the European Commission Horizon 2020 ULTRAWAVE "Ultra capacity wireless layer beyond 100 GHz based on millimeter wave".

The wireless system consists of a mesh networks of D-band transmission hubs to illuminate areas sectors, providing tens of Gb/s data rate, where D-band terminals are arbitrarily allocated to receive an arbitrary number of channels for backhaul of small cells in dense traffic city areas. The D-band transmission hubs are connected to the optical core network through Gb/s class G-band links, based on a microwave photonic transmitter employing UTC-PDs.

To overcome the high atmospheric attenuation, new components are being developed. The main elements of the wireless systems are, in addition to the photonic transmitter, the mmMIC (millimeter wave monolithic integrated circuit) chipset built with different processes depending of the function (GaAs for Low Noise Amplifier, Up and Down converters, multipliers, InP DHBT for power amplifiers), novel traveling wave tubes (TWTs) to provide transmission power for long range (600m both at D-band with 64QAM and at G-band in QPSK), antennas both low gain and high gain in horn and lens configurations.

The paper is organized as follow. Section 2 describes the ULTRAWAVE system architecture, Section 3 the D-band point to multipoint distribution system, Section 4 the photonic-assisted G-band point to point link.

2. THE ULTRAWAVE SYSTEM

The envisaged scenario is based on combining a wireless point-to-multipoint network for cost-efficient traffic provision of a potentially large number of remote antenna units, with wireless PtP links[4]. The PmP distribution offers fast and simple deployment with less equipment, increased flexibility in coverage, low latency as well as easy redeployment of terminals[5-6]. These features make wireless PmP attractive as an alternative to fiber to provide fronthaul with an efficient Total Cost of Ownership (TCO). To reach scalable traffic capacity, the wireless link needs large bandwidth that only can be attained in the millimeter-wave band. In particular, broadband connection of RAUs is provided via a D-band point-to-multipoint network with the backhaul implemented through point-to-point G-band links to connect to the optical fiber infrastructure, as shown in Figure 1.

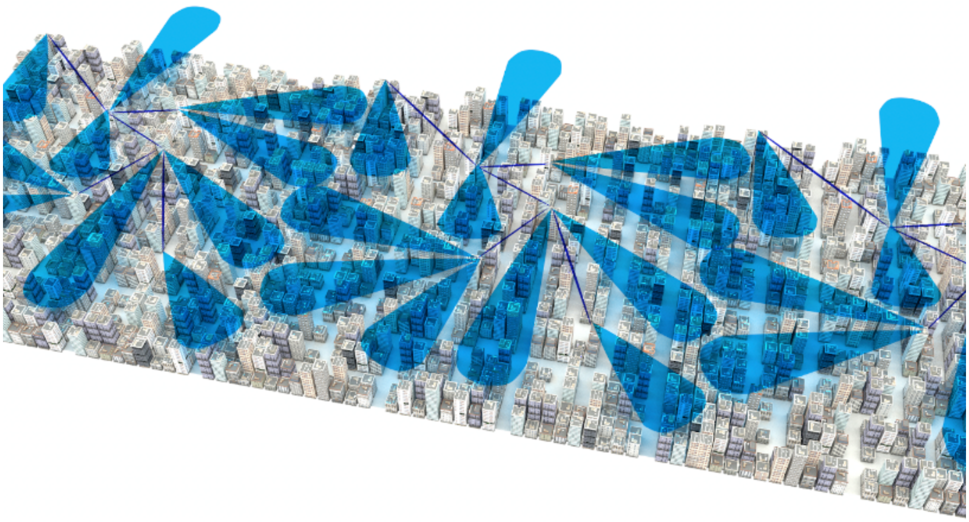
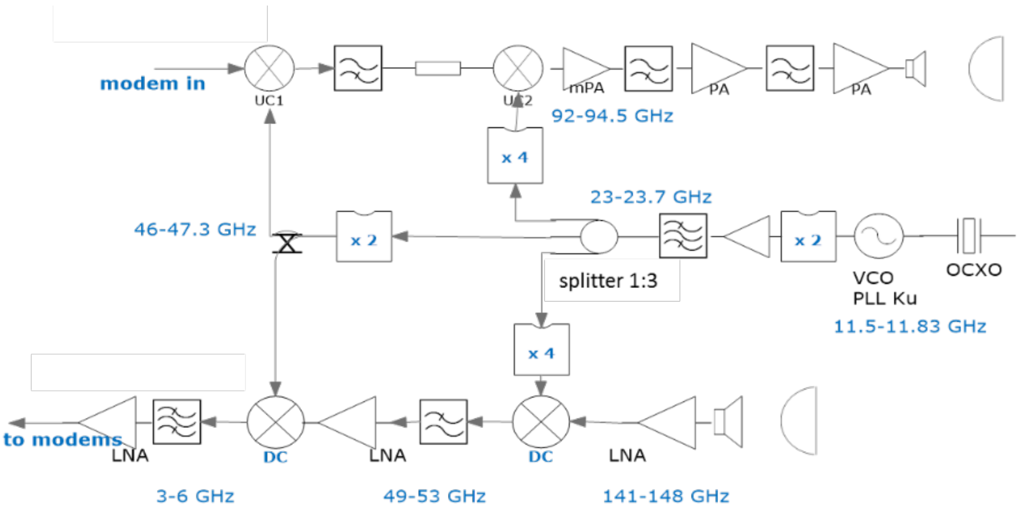


Figure 1. ULTRAWAVE concept.

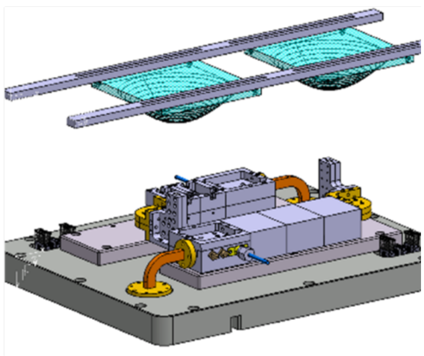
The challenge is the development of components able to provide wide bandwidth with the large effective isotropic radiated power to allow a PmP network in the upper region of the millimeter-wave band.
For a target of 30º sectors with a radius of 600 m, the saturated power at the antenna input must be around 10 W. The availability is 99.99% in ITU zone K.
To enable this vision, a full set of new millimeter wave components have been developed. Both segments of the network and the key enabling components are described in the next sections.

3. D-BAND POINT TO MULTIPOINT FRONTHAUL

The D-band window offers a bandwidth of 27 GHz. Gas attenuation in this band is moderate with losses around 1-2 dB/km. Rain attenuation is only marginally (2 dB) larger than in the E-band being mostly flat in the D-band. Given the wide bandwidth available and the moderate atmospheric losses, the D-band is attracting interest and thus it has recently been regulated by ETSI[7], who divided it in channels of 250 MHz.
The PmP approach is based on a transmission hub, which distributes high bitrate signals on a wide sectorial area illuminated by a low gain antenna to a number of terminals in the sector.



a)



b)

Figure 2. (a) Block diagram of the D-band transmission hub; (b) D-band terminal internal view

The transmission hub transceiver is shown in Fig. 2a. It. The D-band transmission chain includes an upconverter section, a Local Oscillator rejection filter, a power amplifier section made of mmMMICs (millimeter wave Monolithic Integrated Circuit), a Traveling Wave Tube (TWT) and the antenna. The key high power needed for enabling a long-range wide angle sector is provided by the TWT. The TWT is a vacuum electronic device able to reach a level of transmission power not achievable by solid-state technology. The TWT working mechanism is based on the transfer of energy from a high energy electron beam to the radiofrequency signal flowing in a slow wave structure, typically a specific metal waveguide[8]. A D-band TWT was designed[9] to provide a saturated output power of around 10 W. The TWT is in advanced fabrication phase. The main challenge is the fabrication of the slow wave structure due to the short wavelength that requires high precision CNC machining.

Several GaAs mmMICs have been developed including mixers for up-conversion and down-conversion, a Low Noise amplifier (LNA) and a x4 multiplier. The GaAs LNA to be used in the receiver chain shows a noise figure of around 5 dB with a 20 dB gain in the 141-148.5 GHz band. A medium power amplifier (MPA) and Power Amplifier (PA) have been realized by DHBT InP process. All the components are at the state of the art.

A low gain pyramidal horn antenna (4 cm length) is used to cover the 30º sector. The antenna provides a gain of 20 dBi and a main lobe width of 30° and 8º elevation angle. Side lobes and the backside lobe are respectively lower than -25 dB and -32 dB respect to the main lobe.

A D-band terminal has been designed and it is in final assembly phase (Fig. 2b). It includes the same chipset of the transmission hub, but it uses two high gain lenses antennas.

4. PHOTONIC-ASSISTED G-BAND WIRELESS TRANSPORTS

The traffic to and from the hub (D-band layer) and the fiber access point and between D-band transmission hubs is transported through point to point links at G-band (275 – 305 GHz). The G-band link implement Gb/s channel for each D-band hub sectors. This is an efficient and feasible approach, with flexibility on the number of transmission hub to link. The capacity can be estimated to reach 30 Gb/s over 600 m to 38 Gb/s over 450m assuming rain attenuation in the ITU K zone.

The transmitter and receiver of the G-band link are shown in Fig. 3. To meet the goals in terms of bandwidth and range, several technologies have been combined: photonics for the generation of the multiplex and upconversion to the G-band, mmMICs and a TWT for boosting the transmitted signal and cope with the loss associated to the free-space propagation and atmospheric attenuation.

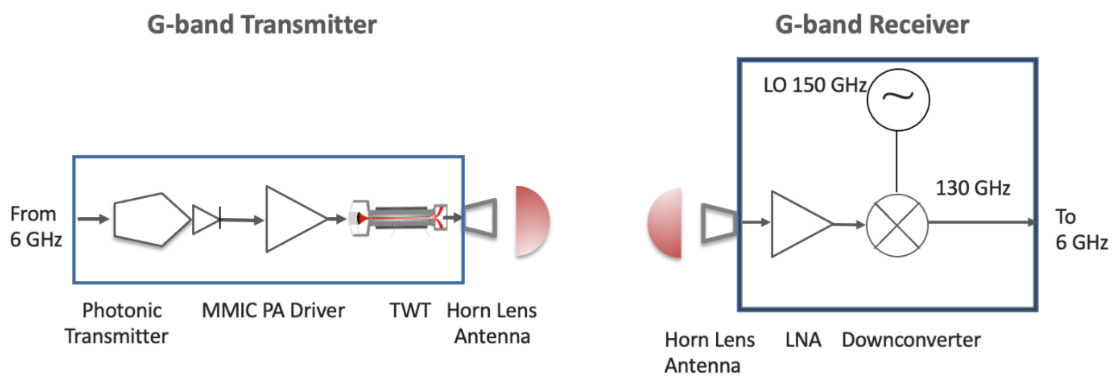


Fig. 3. Schematic of the G-band Point to Point link

The first subsystem is a photonic transmitter for the G-band. Photonics offers several unique features for wireless systems in the mm-wave and sub-THz bands[10-11]. Photonic technology provides extremely large bandwidths, and even, it can be used to directly generate multilevel signals from baseband NRZ-OOK data to make a more efficient use of the available wireless spectrum[12]. In addition, the central frequency can be chosen at any value up to 1.5 THz, i.e. covering all the available atmospheric transmission windows and it can be dynamically tuned. Photonics also allows the provision of multi-carrier transmission and multi-format easily by using a set of optical laser lines that are data modulated[13]. This parallelism offers a compact and flexible solution to divide sub-THz bandwidth in several channels to feed base stations in a modular basis. Finally, photonics allows the implementation of centralized architectures by exploiting the low attenuation of optical fiber to remotely feed emitter antennas which may be placed in a post. This is useful in backhauling scenarios where high capillarity is employed to enhance frequency reuse and to address the stringent requirements of sub-THz transmission windows.

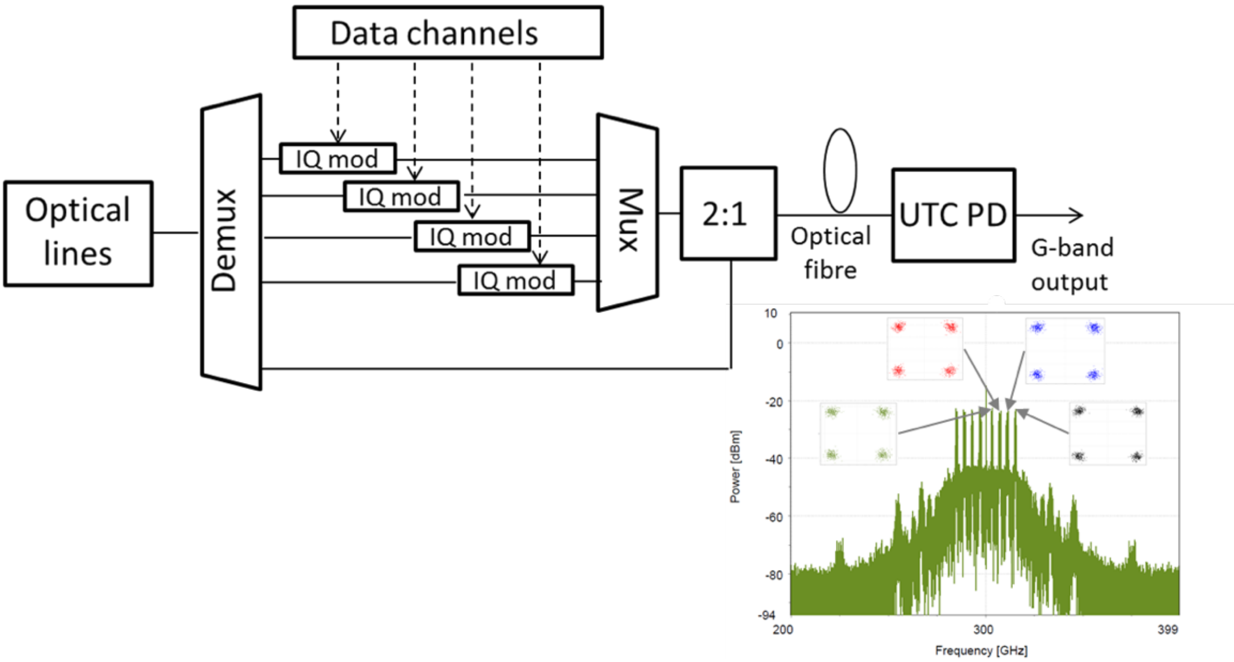


Fig. 4. Block diagram of the photonic transmitter

The photonic transmitter is shown in Fig. 4. A multiplex of several G-band wideband channels is built according to the following principle. A set of optical carriers is generated. They can be derived from a comb source[13], cascaded phase modulators[14] or exploiting optical nonlinearity[15]. In particular, two cascaded phase modulators were used to generate the set of optical carriers. The phase matching between the two stages can be introduced in the optical or electrical domain. As it can be shown in Fig. 5, electrical phase shift is more efficient in term of the power of the optical carriers. These optical lines are selected using Arbitrary Waveform Generators (AWG), demultiplexer or WSS (wavelength selective switches) and modulated. The heterodyne beat between the data modulated carrier and a non-modulated carrier at a unitravelling photodiode (UTC-PD) results in a signal in the sub-THz region. Therefore, the large bandwidth of the optical components is being used to provide a very wideband upconversion.

At present, photonic technology provides limited output power after optoelectronic conversion. To reach the aimed link range, the UTC-PD output is amplified by a MMIC amplifier based on the InP DHBT process. Then a high power TWT amplifier[16] is used, which is based on the approach used for the D-band, but with different design and fabrication technology. The signal after the power amplification is radiated by a horn lens antenna which must provide a gain of at least 39 dBi.

Finally, an all-electrical receiver is used for the down-conversion of the G-band signals. It uses the same horn antenna of the transmitter followed by an LNA based on 40 nm GaAs mHEMT technology with a target gain of 15 dB. Then, the signal is down-converted by a full Gilbert cell mixer.

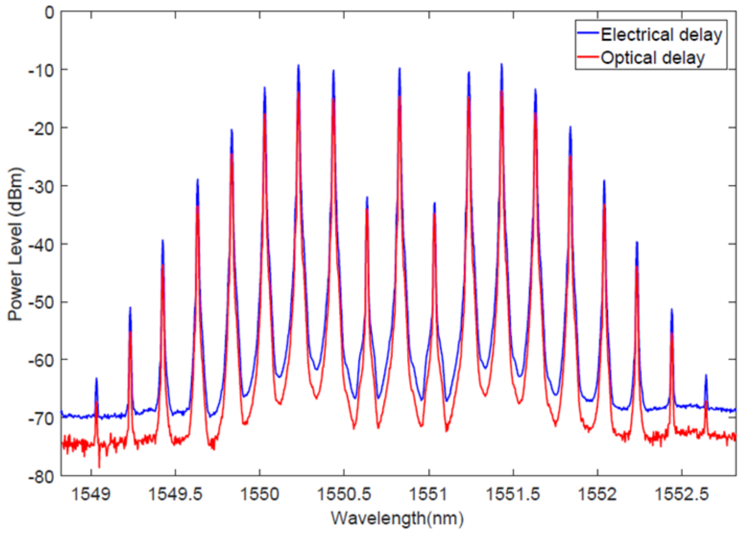


Fig. 5. Optical lines generated from a pair of PMs. In red phase matching in the optical domain; in blue when it is performed in the electrical domain.

5. CONCLUSION

A first D-band Point to multipoint wireless system with transport at G-band has been described. It allows an efficient provision of fronthaul and backhaul for future high capacity mobile networks envisaged to satisfy the 5G and 6G requirements. The combination of PmP and PtP links for fronthaul and backhaul, enabled by a combination of new TWTs, and mmMICs as well as a photonic transmitter provides an effective and cost effective solutions to connect remote antenna units in scenarios of cell high densification.

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