Point to Multipoint Wireless Backhaul Systems for cost-effective small cell deployment

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Abstract — **Mobile data consumption has had a phenomenal rise over the last few years and is set to continue for many to come. Cell densification will play a central role in meeting this demand, allowing the same spectrum to be further reused to increase overall network capacity. In such a scenario, backhaul technologies can be expensive in terms of both CAPEX and OPEX, and none of the traditional solutions provide the necessary combination of capacity and cost-efficiency. This paper defines a Q-band point to multipoint backhaul architecture with the key nodes comprising the network that provides multi-gigabit capacity in a cost-effective manner. The small-scale field-trial of the network platform providing up to 100-Mbit/s throughput per site is also described.**

Keywords— millimetre-wave communication; wireless networks; backhaul; Q-band technology

I. Introduction

Demand for bandwidth is growing exponentially as consumers use their mobile devices increasingly with more bandwidth-intensive applications such as Internet access, photo sharing and music downloads. At the first stage, the evolution to 3G and 4G/LTE mobile technologies provides a path to more efficient use of radio spectrum and progressively higher uplink and downlink speeds to each user. However, operators' forecasts show that additional steps are needed to provide the required amount of bandwidth. As a result, the fundamental macro cell based model has to be changed so that many operators are considering deploying small cells beneath the coverage umbrella created by existing macro cells in order to keep up with consumer demand and to improve the coverage and capacity of their mobile services in a more cost-effective manner [1]. However, to leverage the benefits of small cells, there are some challenges to overcome. One of the most significant issues is how to provide scalable, flexible mobile backhaul to connect small cells back into the network, without breaking the small cell business case.

There are a number of backhaul solutions being proposed today for small cells. Most of these solutions are extensions to what is used on macro cells. These solutions range from low capacity approaches such as the sub-6 GHz non-line-of-sight (NLOS) technologies all the way up to the highly directional millimetre-wave (mm-wave) point to point (PTP) technologies in the 60 to 80 GHZ bands [2-3]. However, they present some limitations for the future small cell scenario. For example, in sub-6GHz NLOS solutions there is a distinct lack of suitable spectrum at low enough frequencies to deliver sufficient capacity and interference needs to be carefully managed. On the other hand, traditional PTP microwave radio links require large antennas at each end of the link, resulting in innately equipment-heavy and expensive total cost of ownership (TCO) network for the continuously evolving small cell deployment. Multipoint (PMP) line-of-sight (LOS) wireless backhaul is another technology that has been publicized as a solution for small cell wireless backhaul. This technology results in lower costs than PTP LOS microwave systems because of spectrum rules (regional block license versus per link license) as well as the lower number of modules at the aggregation point [4]. Traditional PMP, such as the ones operating in the 20 GHz bands, have made some great progress in demonstrating small cells applicability due to the efficiency of using a multipoint architecture. However, spectrum limitations make it very hard to achieve the required Gbits/km^2 capacity for future backhaul (narrow channels with only a couple hundred Mbit capacity per sector). End user throughput as well as quality of experience are harder to control due to extensive use of statistical multiplexing, and scalability can be challenging, making this option unsuitable for next-generation backhaul systems. Therefore, to achieve the low-cost fundamental to small cell deployments, new technologies must be considered to enable a viable business case together with the required capacity.

This paper proposes the use of the millimetre-wave frequency band, concretely the Q-band (40.5 – 43.5 GHz) where 3GHz of relatively unused bandwidth has been recently normalised by CEPT and ETSI [5], for multi-gigabit wireless backhaul. This frequency band is very promising for such an application because of its large amount of spectral bandwidth available suitable for wide channels. Actually, this band provides the bandwidth matching the current 100 Mbit/s per site and several Gbits/km^2 capacity demand. In addition, this frequency band allows efficient frequency reuse plans with very high frequency repetition rate and can be deployed either in point to point or in multipoint architectures with the perfect range for backhaul (i.e. up to 1-2.5 km from a base station), giving operators a fair bit of flexibility in their network design. Given all these benefits, this solution has been considered as the most beneficial for the implementation of next generation wireless backhaul in the framework of the EU FP7 SARABAND project. This paper defines the proposed backhaul architecture exploiting the Q-band and PMP transmission and introduces the small-scale field-trial deployed inside the project to provide up to 100-Mbit/s throughput to each terminal composing the network.

II. Q-BAND POINT TO MULTIPOINT BACKHAUL

A. SARABAND Approach

The SARABAND project proposes a wireless backhaul architecture providing multi-gigabit capacity in a cost-effective manner by exploiting point to multipoint links and the Q-band spectrum. On one hand, PMP architectures allow operators to keep the quantity of equipment low, reduce installation, alignment, rental, and maintenance costs as well as accelerating the time to market for the delivery of services and facilitating smooth network expansion. This results in a reduction of costs in terms of both CAPEX and OPEX (less equipment, reduction of site rental costs, inexpensive Q-band spectrum, etc.) and a "pay as you grow" business model. On the other hand, the Q-band provides large amount of spectral bandwidth and offers larger channel allocation. Actually, this solution uses large blocks of contiguous spectrum at the Q-band and wide TDD channels to deliver high capacity wireless data services, following the frequency block assignment plan proposed in the CEPT Recommendation ECC/REC/(01)04. The allocation plan consists of 3000 adjacent 1-MHz slots starting at 40.5 GHz. Any number of these slots may be aggregated to form a block assignment. Following these guidelines, SARABAND system equipment uses a 1-GHz wide transmitter that can be loaded with 20 channels (nominally 40 MHz wide) in a manner that a base station can be configured to use as little as 40 MHz or all 3 GHz (by using 3 transmitters fully loaded) to deliver up to 2.5 Gbit/s half-duplex per 1-GHz radio transmission (i.e. 20 channels, each delivering up to 125 Mbit/s). To this end, this backhaul network benefits from Wireless Wave Division Multiplexing (WWDM), which allows multiple independent channels to be aggregated onto a single air interface, in much the same way as optical multiplexing combines different wavelengths in a single fibre to multiply capacity. By using this technology service providers can deliver tailored bandwidth across a geographically dispersed array of end points, as shown in Fig. 1. Therefore, millimetre PMP solutions in 42GHz, when ultimately offering gigabits per square kilometre, could position as a very good alternative to meet the challenges of the small cell backhaul.

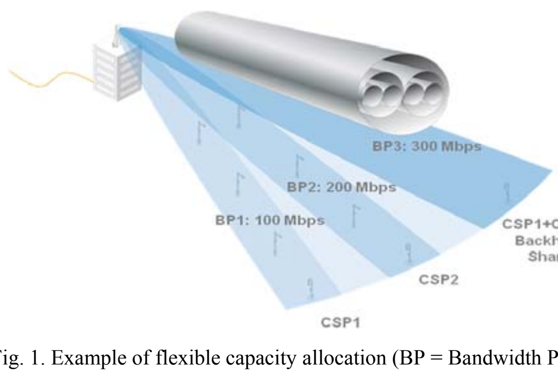

Fig. 1. Example of flexible capacity allocation (BP = Bandwidth Pool / CSP = Communication Service Provider)

B. Network Architecture

The proposed architecture is a hierarchical, PMP Ethernet-based network composed of nodes linked by radio transmissions, and remotely managed by a backhaul network management system (NMS). The layer 1 and 2 of this network is based on the 802.11n and then 802.11ac standard and aggregation on 802.3ad. Routing is a serious and expensive issue, especially at multi-gigabit throughputs, so that the architecture is based on VLANs that use mainly switching techniques rather than routing ones to carry packets to their destination. Therefore, the traffic service is provided by VLAN connectivity (layer 2) between the backhaul interfaces to customers' point of presence (PoP), i.e. traffic corresponding to each terminal is routed through a dedicated VLAN and another VLAN is dedicated to configuration and supervision of all the active network elements and transmitted over radio on the SARABAND network. Fig. 2 shows the proposed architecture for the network backhaul. As shown in the figure, the network is composed of different types of nodes. The Transmission Hub (TH) switches the packet traffic between radio links to provide connectivity inside the backhaul network. In particular, it connects several terminals or relay nodes and carries the terminal assigned VLANs. The TH comprises a transmitter (Tx) and a receiver (Rx) with sector antennas. The Tx and the Rx are connected to a multiplexer and de-multiplexer named CAI (C-band Air Interface) and this in turn to a stack of 802.11n standard based modems (from 4 to 20), which are plugged on an Ethernet switch which performs the aggregation (802.3ad). Other network element is the Network Terminal Equipment (NTE), which establishes a single connectivity to the TH through a VLAN and interconnects and delivers basic services interfaces (electrical 1000BaseT interface) to the customer's point of presence. The NTE comprises a transceiver with directive antennas, which is connected to a modem 802.11n through a combiner splitter. Finally, to extend the range of the backhaul coverage and overcome the LOS limitations, Relay Nodes (RN) can be used. In particular, RN performs functions on the down link as well as on the return path. In the downlink mode RN serves as a repeater, while in the uplink the RN collects the network requests from subscribers and switches them back to the TH.

These network nodes are composed of different elements such as radio frequency modules, multiplexers, antennas, etc. In particular, the SARABAND project is focused on the development of new technology in the Q-band to be integrated in such network nodes with the objective of providing the required performance for future backhaul networks in terms of throughput, range, coverage, and cost. In particular, low-profile high-gain antennas with gains higher than 20-30 dB_i have been developed to enhance throughput and extend the link range. Besides low-profile high-gain antennas, smart antennas are a key element for next generation multi-gigabit backhaul networks. Low-cost electronic steerable antennas based on the Circular Switched Parasitic Array (CSPA) principle have been implemented to enhance coverage, reduce interference and save energy. Concerning the front-end radio modules developed in SARABAND, they use advanced GaAs-based MMIC (Monolithic Microwave Integrated Circuit) elements and benefit from System in Package (SIP) technology integration to reduce the PCB footprint.

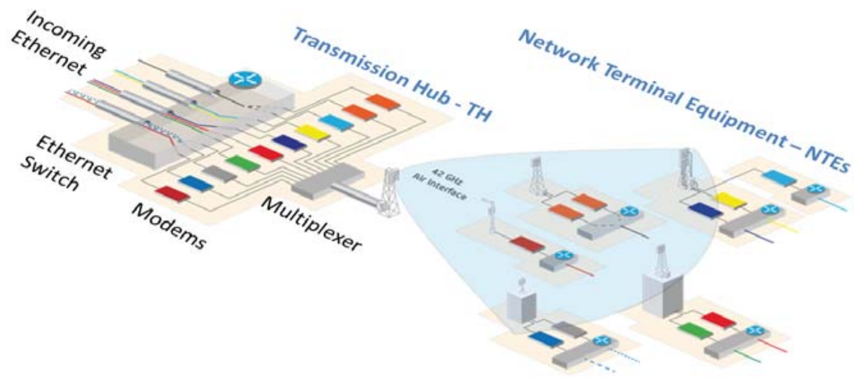

Fig. 2. Q-band Backhaul Architecture

Actually, one of the more challenging issue faced by SARABAND has been to successfully miniaturize the front-end radio modules. Thanks to the use of SIP integration and GaAs-based MMIC chip-sets developed by Bluwan compact and low-cost NTE terminals have been obtained.

III. SMALL-SCALE FIELD-TRIAL DELIVERING GIGABIT ETHERNET COMMUNICATIONS

The antennas and radio frequency modules developed in SARABAND have been integrated in a wireless network platform deployed at the UPVLC campus, where specific smart-antenna and radio functionalities have been tested in the system platform and evaluated in the small-scale field trial. This demonstrator, based on the backhaul architecture explained in the previous section, provides Gigabit Ethernet communications from a central site to 5 terminals (T_i) through the millimetre-wave network. Fig. 3 shows the SARABAND network platform for the demonstrator, whose objective is to provide a throughput of up to 120Mbit/s in an adaptive (upload/download) half-duplex mode to each terminal. As can be seen, from a Central Station (CS), a router feeds the TH through an optic fiber, which carries the terminal assigned VLANs (one VLAN deserves one terminal). Then, the TH feeds 2 Relays Nodes through radio transmissions:

- One Relay Node (RN-1) with a multi-beam antenna towards 3 terminals.
- One Relay Node (RN-2) sharing the traffic between 2 terminals.

The detailed description of each network nodes comprising the wireless network platform is given as follows. The Central Station (CS) connects the backhaul architecture through a gateway to the Internet and hosts the NMS with its database and the configuration and supervision software of the network, which configure equipment, register and display the status of the equipment, and route data flows upon VLANs to terminals and to equipment management interfaces. The NMS is interconnected to the backhaul area through IPSec tunnels terminated on the TH. The TH includes an indoor unit (IDU) with a rack of 802.11n modems, a multiplexer and an Ethernet switch, and an outdoor unit (ODU) with Q-band transmitter, receiver and a low-profile high-gain antenna. To this end, an antenna based on an innovative lens design with a sub-wavelength (sub-λ) structure, which allows the lens efficiency to be improved and provides high gain (>35dBi), has been implemented [6]. With this antenna, the system can reach distances over 2km and can provide Gigabit capacity. As shown in Fig. 3, the TH function is to deliver and collect 5*802.11n TDMA channels of 40MHz to 2 Relay Nodes. The Relay Node RN-1 is composed of the NTE with radio & antenna (ODU NTE), and the outdoor unit with a multi-beam lens antenna (ODU TH), 4-channel multiplexer (CAI-4) and the modem stacks. The proposed multi-beam lens antenna uses a passive distributor component that splits a collimated beam into the required number of beams in the desired directions, obtaining up to 5 beams with 20-dB gain to cover an angular coverage of ±30°. The function of the RN-1 is to relay and collect 3*802.11n 40MHz TDMA channels to 3 terminals (T1, T2 & T3). The Relay Node RN-2 includes a full outdoor NTE (NTE-UL with Q-band antenna 28dBi, 6°), which retrieves the millimeter-wave signal, down convert it to intermediate frequency and demodulate it to provide the allocated capacity through a standard Gigabit Ethernet port. After that, a different NTE (NTE-DL 16dBi, 90º) is employed to provide coverage in the 42 GHz band to terminal 4 (T4) and 5 (T5). Originally, the NTE-DL antenna was going to be implemented with the CSPA antenna developed in the project, which gives moderate gain (< 16dB_i) and either large (270°) or limited field of view (180°) in the horizontal plane and is a low-cost solution for electronic beam steering. The function of the RN-2 is to relay and collect 1*802.11n TDMA channels of 40MHz to 2 terminals (T4 or T5), which share the capacity of this channel (multipoint mode). Finally, the NTEs interconnect and deliver basic services interfaces to the customer's point of presence. In particular, in the network platform the NTE incorporates sub-λ lens antennas (similar to the lens antenna in the TH) to enhance the gain (> 30 dB_i) and in turn the coverage and a Q-band transceiver with better performances in terms of bandwidth (1 GHz), noise factor (4 dB), integration (42 mm x 25 mm) and gain (25-30 dB) [6].

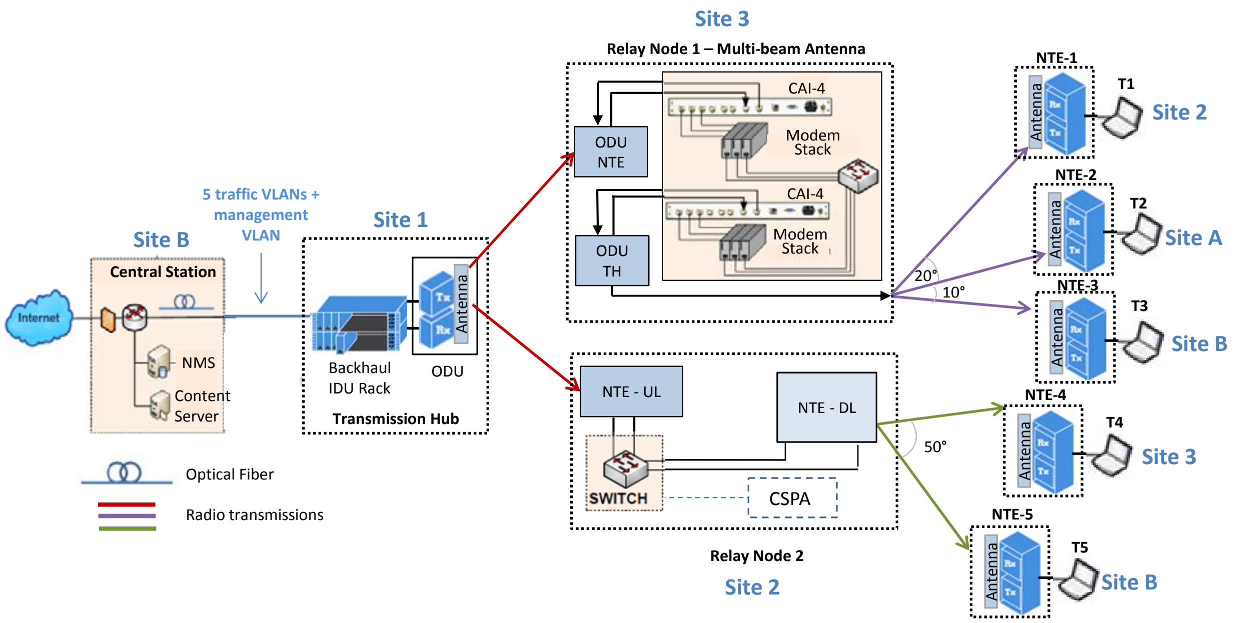

Fig. 3. SARABAND network platform (NMS: Network Management System; IDU: Indoor Unit; ODU: Outdoor Unit; TH: Transmission Hub; NTE: Network Terminal Equipment; CSPA: Circular Switched Parasitic Array Antenna; T: Terminal, Tx: Transmitter; Rx: Receiver)

Table 1. Field performances of the SARABAND demonstrator

Site Reference	Link	Beamwidth (E/H)	Gain (dB_i)	Distance (m)	Modulation	Throughput	PER
TH (Site 1)	TH-RN1	3º/3º	35	1100	16 QAM ¾	3*72Mbit/s	10^{-7} - 10^{-8}
	TH-RN2	3º/3º	35	600	16 QAM ½	2*48Mbit/s	10^{-7} - 10^{-8}
RN-1 (Site 3)	RN1-T1	6º/6º	20	500	16 QAM ¾	72Mbit/s	0
	RN1-T2	6º/6º	20	490	16 QAM ¾	72Mbit/s	0
	RN1-T3	6º/6º	20	350	16 QAM ¾	72Mbit/s	0
RN-2 (Site 2)	RN2-T4	6º/90º	16	500	16 QAM ¾	72Mbit/s	10^{-7} - 10^{-8}
	RN2-T5	6º/90º	16	160	16 QAM ¾	72Mbit/s	0
NTE-1 to NTE-5	-	5º/5º	30	-		72Mbit/s	0

Table 1 summarizes the present performance of the demonstrator. At this stage the maximum modulation order is 16 QAM ¾, but we are currently working to increase the modulation order in each link up to 64 QAM to achieve more than 100 Mbit/s per terminal. With this throughput and exploiting all the potential of the system (i.e. using the 20 modems at the TH instead of utilizing only 5 as in the demonstrator) the system will provide the required multi-gigabit capacity for small cell deployment. Additionally, we are also working to extend and enhance the performances of the systems by using an additional frequency band at the millimetre-wave spectrum, in particular, the W-band (92-95 GHz).

IV. CONCLUSION

The multi-gigabit and cost-effective Q-band PMP backhaul architecture as proposed in the SARABAND project has been presented in this article. The small-scale field trial of the network platform with a detailed description of each network nodes has been also described and preliminary results of the measurement campaign have been presented. At this stage, the throughput at each terminal is 72 Mbit/s, but we are working to increase the modulation order in each link to achieve more than 100 Mbit/s per site.

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