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Optical Transport Networks for 5G: An enabler for vertical industries

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Abstract: *This paper presents the role of optical transport networks in 5G, as an enabler of Enhanced Mobile Broadband, Ultra-Low Latency Reliable and Massive Machine to Machine services in vertical industries. Energy efficiency gains are quantified.*

Keywords: *Optical Transport; 5G; vertical industries*

I. INTRODUCTION

5G networks have been identified as key in addressing some fundamental challenges associated with societal and economic objectives, creating new opportunities for governments, businesses and individuals. Converged network infrastructures comprising wireless, optical and compute elements will play a fundamental role in bringing new digital technologies to society, organizations and countries transforming their every day's life. This approach is expected to influence a large variety of sectors offering connected goods, collaborative and automated processes within and across sectors, optimized processes with regards to energy or other resource consumption, optimized transportation and logistics etc. Some of the sectors, also known as vertical to the ICT industry, that will be clearly influenced and benefited by this approach among others include the Transportation, Energy, Media, and Factories of the Future.

However, this transformation will require new service capabilities that network operators need to support including: i) *connectivity for a growing* number of very diverse devices, ii) *ubiquitous access* with varying degrees of mobility from low to high in heterogeneous environments and, iii) *mission critical services* currently handled by closed specific purpose networks[1]. These demanding and diverse requirements cannot be supported by current 4G solutions and best effort internet connections or a smooth migration from existing network architectures and technology deployments to next generation solutions. On the other hand, 5G networks with their increased capacity, security, elasticity and adaptability can be a key asset to support this transformation delivering a set of services to various vertical industries using offering:

- *Ultra-Low Latency Reliable Services* (ULLRS) providing suitable network and compute resources for Critical Communications networks (i.e. Signaling services for train control, fronthaul services for telecom, etc)
- *Massive Machine to Machine* (mMTC) Internet of Things (IoT) serving a large number of monitoring devices
- *Enhanced Mobile Broadband* (eMBB) services requiring high network bandwidth and low latency (i.e. video surveillance, and infotainment applications, immersive media in cities etc

To support these services, the adoption of a multi-technology transport solution integrating optical and wireless network domains is expected to bring significant benefits in terms of efficiency and sustainability. These benefits are expected to further increase when concepts such as *network slicing* and *softwarisation* will be introduced. Towards this direction, the present paper provides a brief overview of the role of optical transport networks in support of vertical services. Emphasis is given in analyzing scenarios addressing the following features: a) URLLS for FH services and, b) mMTC covering the case of smart energy metering and c) eMBB services over fast moving trains.

II. OPTICAL TRANSPORT NETWORKS FOR 5G SERVICES

The overall 5G vision, involves a converged heterogeneous network environment integrating a wide variety of network and compute resources to provide ubiquitous access to a wide range of applications and services with increased resilience, continuity, and much higher resource efficiency, while ensuring increased degrees of security and privacy. In this context, Cloud-Radio Access Networks (C-RANs) have been recently proposed as a key concept to address the inefficiencies of traditional RAN systems and support services requiring very low latency, high reliability, density and mobility. In C-RAN, Remote Units (RUs), are connected to the Central Unit (CU) where the Baseband Unit (BBU) pool is located through high bandwidth transport links, transmitting I/Q streams, known as fronthaul (FH) [1]. Through its pooling and coordination gains, C-RAN addresses the increased capital and operational costs, as well as the limited scalability and flexibility of traditional RAN. However, C-RAN requires tremendous transport bandwidth and impose strict latency and synchronization constraints [1]. To address the need for a flexible transport network offering the required capacity levels we have proposed the Time-Shared Optical Network (TSON) solution [1]. However, the transport capacity problem is further exaggerated under survivable C-RAN deployments. In what follows, the role of optical networks in the provisioning of vertical services is highlighted.

A. Optical Transport for ULLRS

5G networks are expected to offer security features and mechanisms covering all segments of the 5G System including
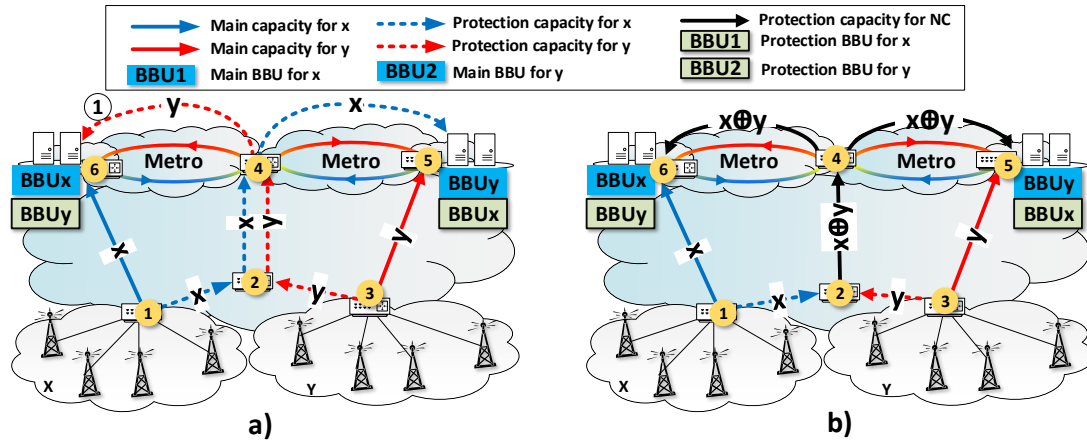
Figure 1. Protection of a C-RAN network from failures of compute and/or network elements. a) In the traditional approach, working and protection capacity for regions x, y are establishes over common links causing bottleneck b) Protection of C-RAN adoting NC. FH flows from regions x, y are multiplexed ($x \oplus y$) at ingress edge node and replicated at the reducing bandwidth requirmens by half.

the 5G Core and 5G New Radio. To achieve this, a holistic view needs to be employed considering not only individual security mechanisms (i.e. encryption of the traffic flows) but also network resilience, communication security and privacy.

To address issues related to network security and resilience, mechanisms adopting Network Coding (NC) theory [4] and multi-path routing can be utilized. These techniques can be implemented at the optical edge nodes to reduce not only the volume of the transmitted information but also protect the network link and/or compute element failures. A typical example of systems offering protection to any kind of failures (either at the optical transport or the compute domain where BBUs are hosted) is shown in Figure 2a). In case of failure of the main paths interconnecting the Remote Units (RUs) with the BBUs (i.e. paths 1-6, 3-5), FH flows are routed to their destination through a set of secondary (protection) paths (1-2-4-5, 3-2-4-6). A similar approach is taken for the C-RAN protection against BBU failures [1]. It is clear that multiple FH flows need to be transferred over a set of links introducing even higher transport bandwidth requirements. NC can be used to offer resilient FH services by multiplexing FH flows and therefore reducing the volume of the transmitted I/Q streams. This approach offers 1+1 protection capabilities without having to transfer separately the working and protection copies of the two FH streams across the optical transport network, reducing the overall protection bandwidth requirement by half (see link 2-4 in Figure 2 b).

Although NC has been extensively used to protect networks against link failures, its application in resilient FH networks has not been proposed before. This can be attributed mainly to the overhead that the application of the modulo-two sum and the replication operations of NC introduce in practical systems that may degrade the performance of C-RANs. At the same time, the operation of the decoding process at the edge imposes significant buffering requirements due to the high data rate of FH streams. To address these limitations, optical edge nodes can be combined with FPGAs to execute the coding and decoding processes at line rate. At the same time, to minimize buffering requirements, a purposely developed synchronization scheme suitable for C-RAN needs to be implemented. A comparison of the optical network power consumption for the Bristol City network for the provisioning of resilient C-RAN services is shown in Figure 2a). It is observed that when NC is adopted, the protection capacity of the optical network is reduced by approximately 33% leading to an overall reduction of the power consumption.

B. Optical Transport for mMTC

Machine to Machine (M2M) and IoT have resulted in tremendous growth of globally generated data which according to the International Data Corporation is expected to exceed 163 zettabytes/year by 2025 [5]. Once analysed, this massive amount of data, generated by billions of connected devices ranging from smart devices and autonomous vehicles to remote sensors, can assist infrastructure providers, a variety of vertical industries, policy makers and the public to derive new insights and improve society's quality of life. 5G systems with their ability to offer high-speed/low-latency internet
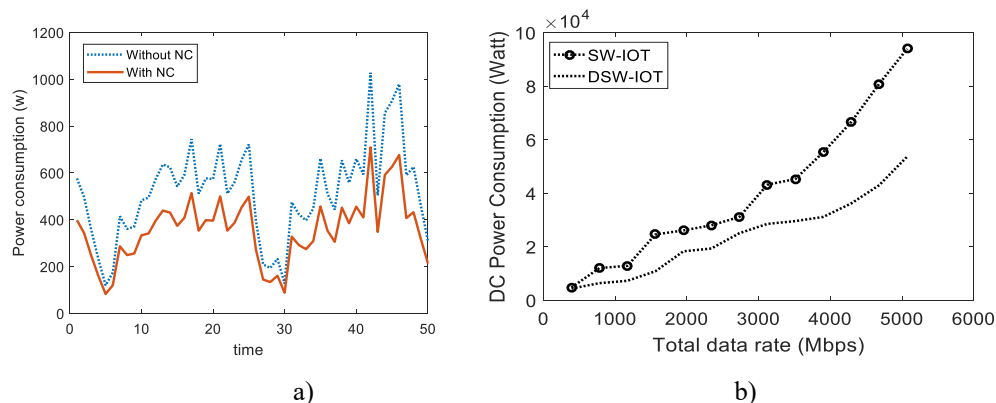

Figure 2. a) Bristol City Optical Network Power Consumption for the proviosning Resillient C-RAN services. B) DC power consumption for the traditional softwarized IOT (SW-IOT) and the disaggregated SW-IOT (DSW-IOT) as a function of the total wireless access traffic.

connectivity as well as easy access to storage and processing resources, can enable massive IoT to a broad spectrum of vertical industries [6]. In this context optical networking plays a key role in supporting the demanding transport network requirements in terms of capacity, delay and flexibility. A typical example of a 5G network exploiting a flexible optical transport solution to provide IoT services for vertical industries is the use case of railway systems. More specifically, a rail use case have been developed in the context of the IN2RAIL HORIZON 20202 EU project [7]. In this rail use case, data collected from various devices installed on-board and at the track side of the rolling stock (1) are transmitted over a multi-technology network (2) operating in accordance to the C-RAN paradigm (3) to a cloud-based data management platform (DMP) (4) that is responsible to perform data collection, storage and processing.

In this environment it is very important to identify optimal assignment of each task to the appropriate processing platform as this decision is expected to give significant efficiency gains. In the case of IoT over 5G, this decision is linked to the placement of BBU's and DMP's construction elements (i.e., message broker, control server and database manager) to suitable processing units. Optical networks can be used to provide connectivity between these elements and allocate processing functions, associated with a specific FH and IoT-Backhaul (BH) services, to different servers depending on the nature and volume of their processing requirements. To quantify the benefits of the proposed approach we have performed experiments analysing the processing requirements of, *i*) a typical BBU for an LTE system using an open source suite for benchmarking wireless systems and, ii) an IoT platform using an actual DMP system support the experimental smart metering campaign of the In2Rail project [7]. In the numerical evaluations we consider a) the standard approach where softwarised BBUs and IOT DMP are placed within the DCs (referred to as SW-IOT) and, b) the approach where the optical network is used to interconnect disaggregated compute elements, known as DSW-IOT.

Figure 2 b), compares the performance of the proposed optimization DSW-IoT scheme in terms of power consumption with the conventional SW-IoT as a function of the served IoT traffic. As expected, the power consumption at the DCs increases with the IoT load. However, the DSW-IoT offers much better performance due to its increased ability to mix and match compute and network resources, leading to improved utilization of the servers and to higher energy efficiency.

C. Optical Transport for eMBB

Optical transport networks can support a wide range of applications with highly variable performance attributes offering services ranging from delay sensitive video to infotainment services, and from best effort applications to ultra-reliable. An important consideration in the design of these platforms is the very high mobility of train transportation systems beyond 2020 that in many cases may exceed 500 km/h. In current LTE systems, connectivity and coordination between eNodeBs (LTE AP) is achieved through the X2 interface whereas connectivity between eNodeBs and the packet/service gateways through the S1 interface. Under fast mobility, for inter-eNodeB distance less than 1.2km the handovers for a train running at 300km/h should be performed every 7s leading to overutilization of network resources. A solution to this problem is to group several cells together thus forming a super cell with much longer size. To achieve this, the concept of C-RAN can be adopted. In contrast to traditional LTE systems where X2 and S1 interfaces are used to interconnect remotely located eNodeBs, in C-RAN the same protocols are used to interconnect virtualized BBUs (vBBUs) and MMEs processes that are usually executed within the same physical server. Through this approach, propagation delay and signalling overheads that are introduced by the traditional approach are alleviated thus allowing the creation of super-sized macro cells. As mentioned above, C-RAN's main disadvantages include increased transport bandwidth requirements to carry the sampled radio signals, and strict latency and synchronization constraints. Increased capacityoptical networks can be used to interconnect trackside antennas with the EPC and facilitate C-RAN operation.

III. CONCLUSIONS

This paper focuses on 5G network infrastructures and identifies the key role that optical transport networks can play in these in support of their transport network requirements. More specifically, the role of optical transport networks in 5G as an enabler for vertical industries is discussed concentrating on Enhanced Mobile Broadband, Ultra-Low Latency Reliable and Massive Machine to Machine services. Relevant resource and energy efficiency improvements are quantified.

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