Contention management for Cloud RAN over an optical ring

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N-GREEN project has for goal to design a low cost optical ring technology with good performances (throughput, latency...) without using expensive end to end connections. We study the compatibility of such a technology with the development of the Cloud RAN, a latency critical application which is a major aspect of 5G deployment. We show that deterministically managing Cloud RAN traffic minimizes its latency without impacting the latency of others traffics.

Keywords : Optical ring, Latency, C-RAN, SDN

1   Introduction

Network providers have to design inexpensive networks supporting an increasing the amount of data and online applications. Much of these applications have QoS criteria, like a minimal throughput or a maximal latency. The N-GREEN project aims to design a high performing optical ring while ensuring a minimal cost for providers. The current solutions with good QoS [1], establishe end to end connection (E2E) between the nodes, which is extremely expensive. The N-GREEN optical ring is designed to ensure good performances: the hardware it requires scales linearly with the number of nodes while E2E scales quadratically making it impractical for more than a few nodes.

In this article, we study a Cloud RAN (C-RAN) application in the N-GREEN optical ring described in [2]. C-RAN is one of the major area of development for 5G; it consists in centralizing the computation units or **BaseBand Units** (BBU) of the **Remote Radio Heads** (RRH) in one datacenter. The latency of the messages between the BBU and the RRH is critical [3]. In this article we propose an SDN approach to deterministically manage the periodic C-RAN traffic by choosing emission timing and reserving containers on the ring. In a previous work [4], the authors have studied a similar problem for a star shaped network. Here the load due to the CRAN traffic is small enough to make the problem easy. However, we add several new difficulties: the messages from RRHs are scattered, there are other traffics whose latency must be preserved and the need to make reservation of containers on the ring requires additional bandwidth.

In Sec. 2, we model the optical ring and the traffic flow. In Sec. 3, we experimentally evaluate the latency when using stochastic multiplexing to manage packets insertions on the ring, with or without priority for C-RAN packets. In Sec. 4, we propose a deterministic way to manage C-RAN packets without buffers, which guarantees the lowest possible latency. It turns out that it also improves the latency of best effort packets.

2   Model of C-RAN traffic over an optical ring

N-GREEN Optical ring   The unidirectional optical ring is represented by an oriented cycle. The vertices of the cycle represents the nodes of the ring, where traffic arrives. The edges (u,v) of the cycle have an integer weight $\omega(u,v)$ which represents the time to transmit a unit of information from u to v. By extension, if u and v are not adjacent, we denote by $\omega(u,v)$ the size of the directed path from u to v. We denote by

RS (ringsize) the length of the cycle, that is $\omega(u,u)$. Each arc (u,v) can be seen as a sequence of $\omega(u,v)$ **containers**, of capacity C, expressed in Bytes. The containers are filled by the nodes. The node u can put a packet of data of size less than C Bytes in the first container of the arc (u,v) **only if it is free**. The dynamic of the network is simple: at each unit of time, data contained in a container go to the next. The ring follows a **broadcast and select with emission release policy**: When a container is filled by some node u, it is freed when it comes back at u after a whole round trip.

C-RAN traffic The RRH are the source of the **deterministic and periodic** C-RAN traffic. There are n RRHs attached to the ring and several RRHs can be attached to the same vertex. An RRH is linked to a node of the ring through an electronic interface of bit rate R Bps. The ring has a larger rate of $F \times R$ Bps. The integer F is called the **acceleration factor** between the electronic and the optical domains. A node aggregates the data received on the electronic interface during F unit of times to create a packet of size C which completely fills one container of the ring. Each period P, an RRH emits ET/F packets, i.e. a packet of size C each F units of time during a time ET (emission time), see Fig. 1.

The data of the RRH i arrives at node u at a time m_i called its **offset**. The offsets can be determined by the designer of the system and can be different for each RRH but must remain the same over all periods. We assume that all BBUs are contained in the same data-center attached to the node v. The data from u is routed to its BBU at node v through the ring and arrives at time $m_i + \omega(u,v)$ if it has been inserted in the ring upon arrival. Then after some computation time (which is supposed to be zero to simplify the presentation), an answer is sent back from the BBU to the RRH. The same quantity of data is emitted by each BBU or RRH during any period. The **latency** of a message is the time it waits in a node before being put in a free container on the ring. The aim of our study is to minimize the latency of the C-RAN traffic, both from the RRHs and the BBUs. In Sec. 4 we propose a deterministic mechanism with zero latency which preserves the latency of other data using the optical ring. We shortly describe the nature of this additional traffic in the next subsection.
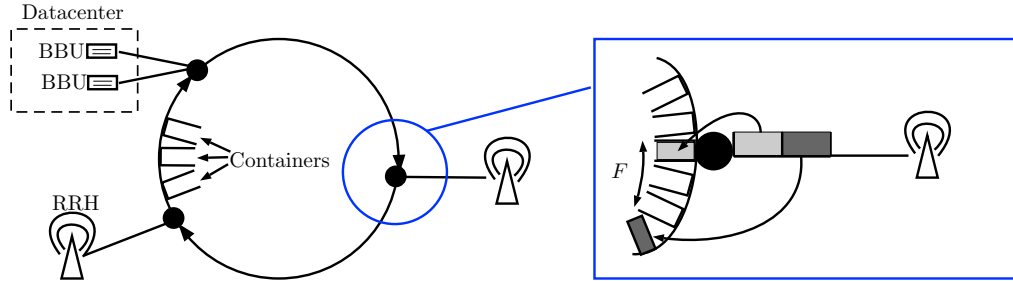

Figure 1: Opto-electronic interface.

Best effort traffic The optical ring supports other traffics, corresponding to the internet flow. We call this traffic **Best Effort** (BE), since it is less critical and one can increase the latency of BE messages to improve the latency of C-RAN messages. At each node of the ring, a contention buffer is filled by a batch arrival process of BE data. Then according to some parameters (fill rate and maximum wait time) data on the contention buffer are aggregated in a packet of size at most C. The node fills the first free container it sees with this packets. Hence, the arrival of BE messages is modeled by a temporal law that gives the distribution of times between two arrivals of a packet of BE messages in a node. This distribution is obtained by choosing optimal parameters for the contention buffer [5].

3 Evaluation of the latency on the N-GREEN optical ring

One first study the latency of the C-RAN and BE traffics when the ring follows an opportunistic insertion policy: When a node wants to send some packets, it uses the first free container available on the ring. If a node cannot send a packet, because there is no free slot or because several packets must be sent at

the same time, the remaining packet are stored in an insertion buffer. Two different methods to manage this insertion buffer are experimentally compared. The FIFO rule is compared to a method that uses two insertion buffers: one for the BE packets, and another for the C-RAN packets. When the node see a free container it empties the C-RAN insertion buffer first. Fig. 2 gives the cumulative distribution of both C-RAN and BE traffics latencies for the FIFO rule and the "C-RAN first" rule. In this experiment, the offsets of the RRH are not fixed but randomly drawn in the period. The experimental parameters are given by Fig. 3 and chosen following [2]. The results are computed over 100 instances of optical rings that are simulated during 10,000,000 units of time. The source code in C of the experiments can be found on the author's webpage [6].
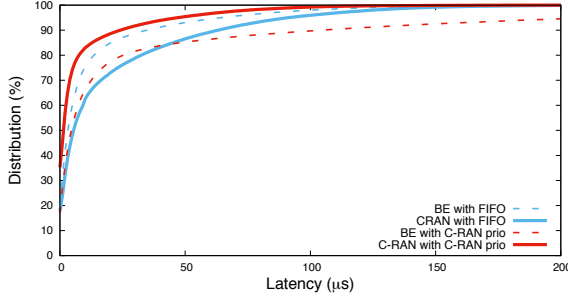

Bit rate of an electronic interface R	10 Gbps
Optical ring bit rate $F \times R$	100 Gbps
Acceleration factor F	10
Container size C	100 kb
Unit of time $C/(F \times R)$	1 μs
Length of the ring RS	100
Emission time ET	500
Period P	1,000
Number of RRH	5
Number of nodes n	5
Load induced by C-RAN traffic	50%
Load induced by BE traffic	40%

Figure 2: Distribution of latencies for FIFO and C-RAN first

Figure 3: Experimental parameters from the N-GREEN architecture

Unsurprisingly, the latency of the C-RAN traffic is better when we prioritize the C-RAN messages, while the BE traffic is penalized. Nevertheless, there is still 10% of the C-RAN traffic with a latency higher than 50μs, a problem we address in the next section.

4   Deterministic approach for zero latency

Finding good offsets for the C-RAN traffic is a hard problem even for simple topologies and without BE traffic, see [4]. On this section, we give simple solution to this problem in the N-GREEN optical ring, and we adapt it to minimize the latency of the BE traffic.

In order to ensure zero latency for the C-RAN traffic, the first container after node u, to which is attached the RRH i, must be free at time m_i. Hence the node u **reserves** the container at time $m_i - RS$. A container which is reserved cannot be filled by any node except the one which has reserved it. In the method we now describe, the C-RAN packets never wait in the node: The message sent by the RRH i arrives at its BBU at time $m_i + \omega(u,v)$ and the answer is sent from the BBU at time $m_i + \omega(u,v) + 1$.

Recall that an RRH emits a packet every F containers, during a time ET. Thus if we divide the period P into **slots** of F consecutive unit of time, an RRH needs one container by slot. If an RRH emits at time $m_i < P$, then we say it has **position** $m_i \mod F$. If an RRH is at position p, then by construction, the corresponding *BBU* is at position $p + 1 \mod F$. Since we do not allow waiting times for C-RAN traffic, each RRH uses a container at the same position during all the period.

The problem we solve now is to find an **assignment** of values of the m_is which is **valid**: no two RRHs reserve the same container in a period. Moreover we want to preserve the latency of the BE traffic. It means that the time a node waits for a free container at any point of the period must be minimized. Remark that two RRHs which are not at the same position never use the same containers. Moreover, without loss of generality, if we can fix the offsets of the RRHs to even positions so that they do not reserve the same containers, then it will fix the offsets of the BBUs to odd positions which do not reserve the same containers.

Proposition 1. *There is an assignment of the offsets $m_1, \ldots, m_k$ on the same position if $k \times ET + RS \leq P$.*

Proof. We fix $m_1 = 0$ and all the offsets will also be at position 0. Let $u_1, \ldots, u_k$ be the nodes attached to the RRHs $1, \ldots, k$. We assume that $u_1, \ldots, u_k$ are in the order of the ring. The last message emitted by the RRH 1 arrives at u_2 at time $ET - 1 + \omega(u_1, u_2)$. Therefore we can fix $m_2 = ET + \omega(u_1, u_2)$. In general we can set $m_i = (i-1) \times ET + \omega(u_1, u_i)$ and all RRHs will use different containers at position 0. The assignment

is correct, if when the RRH 1 must emit something in the second period, there is a free container. It implies that $k \times ET + \omega(u_1, u_1) \leq P$, which proves the proposition. $\qquad\square$

Remark that for each position which is used by some RRH, we lose $2RS$ because of the reservation of the RRH and of its BBU. Therefore to not waste bandwidth, it is relevant to put as many RRH as possible on the same position. Moreover unused positions in an assignment are useful to guarantee a good latency to BE traffic. The unused positions can be distributed uniformly over a slot, to minimize the time to wait before a free slot, as in Fig. 5.

However, it is possible that there are no unused position. It happens with the current parameters of the N-GREEN ring, $ET = \frac{P}{2}$, $F = 10$ and $n = 5$. Hence there is exactly one BBU or RRH at each position. If all the RRHs start to emit in the first slot, then during ET there will be no free containers anywhere on the ring, inducing a huge latency for BE traffic. To mitigate this problem, the time with free containers of each position must be uniformly distributed over the period as in Fig. 6.

We present the cumulative distribution of the latency of the BE traffic latency using the FIFO rule or the reservation algorithm proposed here in Fig. 4. Since the previous parameters were too restrictive to put several RRHs on the same position, the parameters ET and n have been changed to respectively 200 and 12, to keep the same expected load. With these parameters, the loss of bandwidth due to reservation is at most 6%.
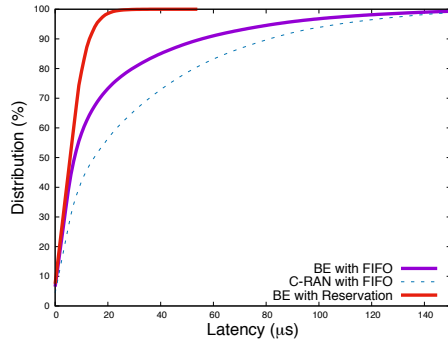

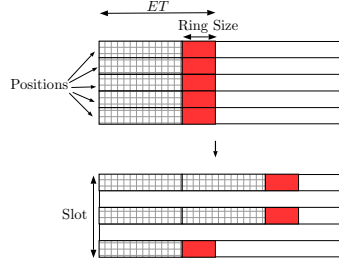Figure 4: Impact of the deterministic method on the traffics.
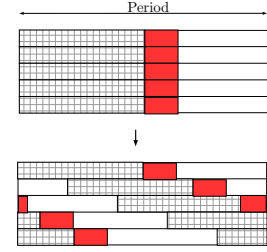
Figure 5: Repartition in the slot

Figure 6: Repartition in the period

The performance of the reservation algorithm is excellent, since the C-RAN traffic has **zero latency** and the BE traffic has a **better latency** with reservation than with the FIFO rule. It is due to the balancing of the load of the C-RAN traffic over the period, that guarantee a more regular bandwidth for the BE traffic.

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