提出了边缘数据中心的确定性网络解决方案：TSN + SDN

Challenges and Solutions for End-to-End Time-Sensitive Optical Networking

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Abstract *Time sensitive applications rely on deterministic low latency, highly reactive, and trustable networks, as opposed to today's best effort internet. We review existing solutions and propose in this paper Deterministic Dynamic Network as a solution for end-to-end time-sensitive optical networking.*

Introduction

A number of upcoming high value services, like efficient collaboration of industrial machines for industry 4.0, of humans and robots for industry 5.0, sometimes with haptic remote control; like traffic regulation of self-driving cars, share the same need for real-time responsivity, calling for a new breed of communication networks with deterministic low latency and quality of service (QoS) guarantees.

This network should not only enable connectivity across the edge machines (i.e. robots, cars, or any connected objects) to allow good cooperation between them, but also ensure connectivity with the machines (servers) processing the generated data. We assume a scenario where the servers involved in time-sensitive applications are located in small, distributed data centers (DCs), forming the so-called Edge Cloud [1], and are close to the edge machines (e.g. <100km) so that the travelling time from/to the DCs does not impair latency excessively. It can be easily predicted that the dominant traffic pattern found only in DCs today will move out of it and contaminate the whole network where we expect services to turn up or down with the dynamics of intra-DC.

The growing interest toward ultra-responsive applications suggests that the era of pure telecommunication networking is about to come to its end. But telco stakeholders may not yet be realizing this wind of change. Most of the solutions proposed for future networks still rely either on technologies using inflexible, quasi-static optical pipelines – unable to support volatile time-dependent packet traffic – or on electronic technologies using transmission with no guarantee of delivery – non-compatible with the strict needs of time sensitive applications.

In this paper we list the challenges to truly enable time sensitive applications. We review the key existing solutions and highlight their limitations. And finally, we propose Deterministic Dynamic Network (DDN) as a solution for end-to-end time-sensitive optical networking.

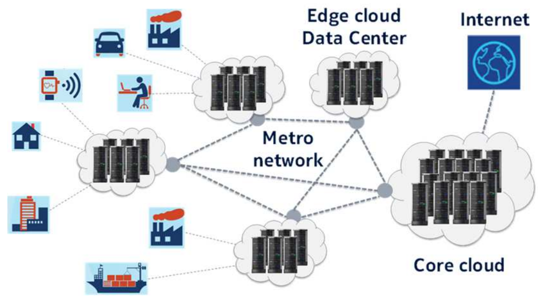

Fig. 1: Edge Cloud architecture.

Challenges of time sensitive networking

Deterministic low latency

In the Edge Cloud, should the servers be asked to do more complex tasks than the ones run today (e.g., web indexing, data statistics), we expect further pressure on network design to reduce network latency since a significant ratio of the total time budget (e.g. 90%) will likely be consumed by data processing.

With ever growing computation-hungry applications [2], we predict that a new form of massive cooperation between machines, more efficient than today's will be required. Time-constrained efficient cooperation between a large number of machines comes with a stringent requirement on arrival-time control [3]. As in an efficient meeting where no participant should be late, but none should be early either, all servers need to do their job in parallel, but collaborate with strictly the same clock. Similarly, to the networks for synchronizing robot work in factory floors [4], which had to move away from the stochastic behavior of todays' packet switched technologies because the specifications on time control were too tight. The new time-sensitive cloud must be jitter-free.

Network slicing (multitenancy) and reliability

Today, application and service providers do not entirely trust the packet switched network because it was built according to the best effort transmission paradigm – transmission with no QoS guarantee. Therefore, they cannot think beyond the given limits because of the network

limitations themselves, which preclude the creation of new types of services.
Most likely today's traffic will not be fully replaced, therefore classical applications (e.g. web, video streaming, VoIP) and new time-sensitive applications will need to coexist, despite very different requirements. While building two separate clouds can be tempting to tackle this issue, a new generic infrastructure processing both types of applications has the advantages of offering the possibility to flexibly and on-demand use any computing resource for any type of traffic and any tenant. It paves the way to true and dynamic slicing, allowing for new revenues with punctual network resources leasing.

High dynamics
We anticipate that the communication pattern in time sensitive networks will be dominated by temporary flows between a large number of cooperating machines, essentially the servers. The traffic will be a mix of constant bit rate and flows of time-dependent rate; long-lasting and short- lasting flows. The traffic will be volatile at packet and flow level, in addition of being exchanged between any two endpoints. The Edge Cloud network needs to be flexible enough to support such traffic dynamics [5].

Solutions for time sensitive networking
To build time sensitive networks, most on-going research efforts consist of hardening well-established technologies. However, those legacy technologies have first been designed for totally different network use-cases (e.g., non-time-sensitive voice and data, Industry 3.0). We review the key existing technologies here.

Optical Transport Network (OTN)
OTN [14] is a virtual circuit switching technology at a sub- wavelength granularity. Although OTN has the necessary level of reconfigurability (close to the second timescale) to fulfill most expectations of today's metro and core network, it has some limitations for the new kind of time sensitive applications. Contrary to today, the traffic in the metro segment of the Edge Cloud network is expected to become any-to-any and rapidly varying in data rate and burstiness. OTN has neither the flexibility to scale up – the number of circuits that OTN can address depends quadratically on the number of network nodes, nor the required time of reconfiguration – its signaling at a few 100ms time scale slows down its ability to handle volatile traffic.

Ethernet and Time-Sensitive Network Ethernet
The efficient packet-based processing (through statistical multiplexing) of Ethernet comes with adequate flexibility to handle the any-to-any volatile packet traffic. Nonetheless, Ethernet was natively designed to manage best effort traffic and does not guarantee any determinism in latency nor bandwidth.

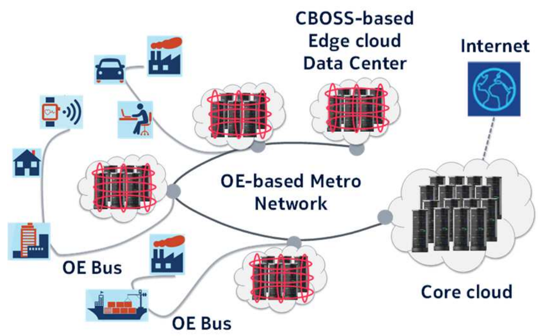

Fig. 2: OE and CBOSS based Edge Cloud architecture.

To make Ethernet more compliant with Time Sensitive Network (TSN), IEEE 802.1 standard [18] has been proposed as an extension to native Ethernet. Three sub-standards deserve to be mentioned: 1) 802.1Qbu to reduce latency and jitter through packet preemption. 2) 802.1Qbv for deterministic QoS guarantee through scheduling. 3) 802.1Qca for path control and reservation in an Ethernet switched network. Those proposed mechanisms (802.1Qxx) rely on queuing differentiation to correctly track the traffic and apply the corresponding QoS policy. TSN is very promising for 5G fronthauling. However, for medium and large networks or for intra-DC, where reservation is more needed to contain jitter, TSN is challenged by the size limits of the (expensive) shared memories needed to host all the queues. This issue is stressed in a time sensitive environment, where QoS may need to be guaranteed at an application level.

Flexible Ethernet (FlexE)
Note a synchronous version of Ethernet: FlexE [6], that interleaves flows into frames of fixed duration (slots) to offer deterministic latency through slot scheduling. The main drawback of FlexE w.r.t time sensitive traffic is the large slot granularity, the slow reconfiguration of the schedule and the absence of opportunistic slot use, i.e. even Best Effort traffic needs reservation, which requires heavier signaling and making FlexE less flexible and dynamic.

Industrial Ethernet (IE)
IE [7] is an adaptation of Ethernet to synchronous networks, expanded with resource reservation feature. Each node is granted traffic emission periods. In its current form, IE is limited to small network sizes (either in terms of number of nodes or network physical length), to low data rates and a quasi-static scheduling. IE is therefore unable

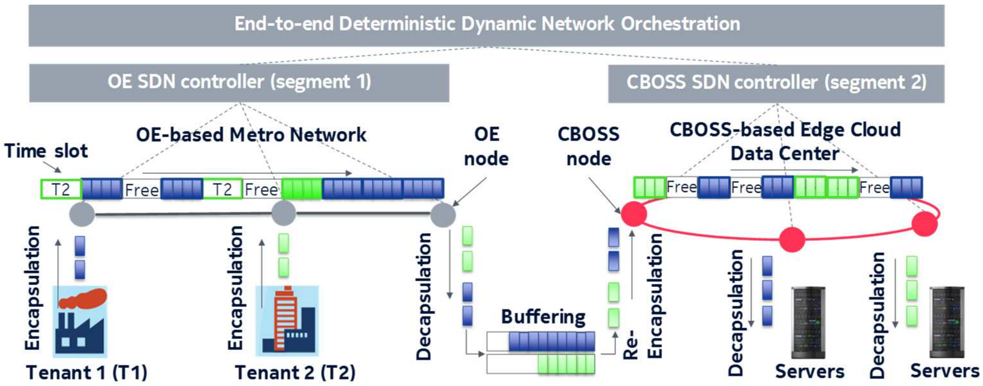

Fig. 3: Deterministic Dynamic Network (DDN).

to scale up and handle Industry 4.0 traffic, where many cooperating machines dynamically generating a large amount of data is expected.

Deterministic Dynamic Network (DDN) a new solution for time sensitive networking

We envision a unified time slotted network fabric (DDN) for end-to-end time sensitive network (Fig. 2), consisting of multiple segments that cooperate to synchronize resource reservations along a traffic flow path. We propose to create an end-to-end virtual optical circuit switched network at a traffic flow granularity to provide deterministic low latency and bandwidth on demand.

To meet this goal, we rely on two-already reported technologies: Cloud Burst Optical Slot Switching (CBOSS) [8] for intra-DC and Optical Ethernet (OE) [9] for intra DC, which we propose to combine, each in a different segment. We drive them with a Software Defined Network (SDN) control plane and an end-to-end orchestrator.

In OE and CBOSS, QoS guarantee is achieved through time slots reservation. When time slots are reserved to carry a traffic flow, the access to the channel in time and capacity is guaranteed. Time sensitive flows can therefore be easily isolated (sliced) and carried across the network with zero interaction with best effort traffic and between themselves.

In order to take advantage of statistical multiplexing, and reduce slot reservation complexity, best effort traffic accesses the channel in an opportunistic way – the first non-reserved slot is used. Overall, the network architecture achieves deterministic latency and bandwidth only for flows which deserve it.

In the proposed DDN architecture resource allocation is centrally managed by an SDN controller. This controller compute and distributes to the network nodes in its perimeter a schedule of slot reservations. The schedule is computed to respect latency and bandwidth requirements of each time sensitive traffic flow. The dynamic and fast reconfigurable (tens of milliseconds) of the schedule is the key advantage to adapt the network to fast traffic variations.

On Fig. 3 is shown an example of slots reservation and synchronization in inter-segments for tenant 1 and 2. Even if tenant traffic goes through buffering at segments interconnection, the queuing time is controlled – by giving it priority, and minimized – by synchronizing slots reservation between segment 1 and 2 so the traffic is reinserted as fast as possible in segment 2.

Conclusion

In this paper we discuss the limitations of the key existing solutions to support time sensitive applications. We propose Deterministic Dynamic Network as an end-to-end architecture for deterministic low latency, highly reactive, and trustable optical networking.

Acknowledgements

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