Photonic Services and Their Applications

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Abstract. The poster addresses Photonic Services as a general approach to end-to-end connection over optical networks and possible types of applications that can benefit from them. Features and known challenges are highlighted. Also expected fields of application are listed and precise time transfer together with atomic clock comparison is discussed in detail with specific results.

Keywords: optical fibre communications, real-time transmission, all-optical, precise time transmission.

1 Photonic Services

In general, a Photonic Service can be defined as an end-to-end connection between two or more places in the network and can be described by its Photonic-path and allocated bandwidth. Photonic-path is a physical route that light travels from one end point to one or more other end point(s). Allocated bandwidth is part of system spectrum that is reserved for Photonic Service user all along the Photonic-path. It is important to carry signals over network with minimal impact, so the processing at the end point will depend just on the application. In present networks, delay is almost independent of capacity. It is a fundamental characteristic (constraint) of the data topology also in over-provisioned networks, where queuing and buffering are null or minimal. The requirements for delay minimization impact all communication layers, starting from fibre topology. All network application benefits from low latency, ranging from interactive (e.g. video conferences, of interaction between a user and a "cloud") to traditional data transfers. These are typically based of window confirmation network protocols (e.g. TCP) where performance of such protocols is inversely dependent on RTT (round trip time) value.

More demanding applications, especially in research community, even pose limits on latency jitter. This all is provided by well controlled all-optical network. Therefore an Optical-to-Electrical-to-Optical (OEO) conversion should be avoided to increase transparency of an optical network to Photonic Services, except for special cases.

2 Applications

Advent of many telecommunication services was driven by end-users and it is not different in case of Photonic Services. Photonic Services are called upon by

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demanding applications that are not feasible (or are with significant complications) over traditional Internet Service Providers (ISP's) network. We identified crucial parameters that characterize specific applications and pose requirements on network. The jitter in network latency represents the changes in time between any two consecutive pieces of information that arrive to destination. The jitter in network latency is also caused by lags that are introduced by (de)serialization and buffering during OEO conversion in present networks where necessary QoS parameters are solved via so called over-provision of bandwidth. The penalty for not meeting the jitter limits or service failure is mild in most applications but there are also applications, where failure interrupts whole experiment or even endangers human life. Examples of demanding applications and relevant references follow.

Interactive Human Collaboration, High Definition Video and Cave-to-Cave

The simplest case of interactive collaboration is human speech. ITU-T recommendation G.114 defines transmission latency limit up to 150ms for high-quality communication. Nevertheless speech quality is complex matter and when the echo and loss are not present the latency can be higher; users don't perceive discomfort up to 300ms. However 200ms is an empiric valued cited in many documents. The most demanding examples of this application are probably remote fine arts lessons like piano or violin lesson, where teacher should be able guide her students according to visual and aural experience delivered over the network. The fine art lesson has been tested in Brazil across Atlantic Ocean (Brazil and Spain) with success and presented at Customer Empowered Fibre Workshop 2010 in Prague [11]. Moreover, we must distinguish negligible latency (e.g. sound propagation in air) from latency to which user can adapt, for example from about 5ms for chamber orchestra to 40ms for symphonic orchestra. Nevertheless 100ms is value which can user adapted to easily. Some experiments are described for example here [12]. The overall quality is strongly dependent on the codec used and generally two techniques are applied to improve a packet loss robustness and sensitivity to a variation in the delay of received packets. The packet loss concealment technique masks the effects of packet loss and the simplest forms are based on repeating the last received frame, the most sophisticated algorithms apply HMM (Hide Markov Models). An adaptive mode of play-out delay buffer dynamically adjusts to the amount of jitter present and the value is always calculated as duration of one frame multiplied by integer number.

Cave-to-cave and HD video have recently enabled doctors and students of medicine to see the real-time high resolution video of operation by their own eyes and enjoy the precise work of top surgeons in the world. These high bandwidth demanding application usually require a dedicated Lambda to provide users with full experience. Actually a practical demonstration of HD video transfer has been accomplished in the Czech Republic over dedicated 10Gb/s link on the distance of 150km. The data stream reached transfer rates of approximately 2.5 Gb/s and the signal delay was less than 1 ms, enabling the real-time broadcast [1].

Remote Instrument and Vehicles Control

New unique instruments and facilities are often built at the most suitable places in the world that may not be well accessible. To name just a few, the unique observatory in India, that was built over 4500 meters high above the sea level in the barren desert of Ladakh [2], or highly specialized robot-assisted surgery system da Vinci located just in the most famous hospitals in the world [3]. The remote control of such instruments can save time and expenses to relocate experts to work directly on the site. The hospital in Strasburg conducted a Tele-surgery already in 2001. The robotic Tele-surgery connected a surgeon from New York to a patient in Strasburg [4]. It is worth of mentioning that there were also experts on site ready to take the manual control of robot in case of network failure. The latency for a robotic surgery is considered negligible, when it is about 100ms, but the limit of adaptability can be up to 400ms. More detailed study can be found here [13]. Recently, professionals of CESNET and Masaryk Hospital in Ústí nad Labem have demonstrated their experience with transmission of robotic operations to their colleagues in Japan [5]. In general, this type of applications has mild requirements on bandwidth and network latency. Once the Tele-surgery proceed to regular use, it will be unacceptable to interrupt the connection, because the operation can discontinue and interruption can directly endanger patients' life. These prerequisites will hardly be met in standard over-provisioned networks and probably may require a dedicated optical channel.

Many projects all around the globe are investigating intelligent transportation systems that would assist or replace vehicle driver to increase transportation safety and efficiency. Numerous tasks in future vehicle communication have been identified. Some of them should warn a vehicle driver or operator and address environmental warnings like hazardous location, traffic signal violation or slow vehicle motion. Emergency warnings like pre-crash sensing have stringent latency requirements of around 50ms with unacceptable penalty of vehicle crash. Although exchange of information among vehicles and infrastructure will be wireless, the availability of data from a surrounding infrastructure will be essential [9].

Comparison of Atomic Clocks and Ultra-Stable Frequency Transfer

Time standards are usually represented by caesium clocks and other accurate clocks should be synchronized to them. The most accurate comparison of distant clocks was made by bidirectional radio transmission using dedicated satellite channels – it is an expensive method with that requires complex instruments. Advances in optical networking opened a new comparison option by utilization of optical channels. The accuracy in order of tenths of nanoseconds or better can be achieved. Example of such experiment is described in [6].Transfer of accurate time and stable frequency between two distant places is required by experts from fields of time and frequency metrology, astrophysics, particle accelerators and fundamental physics [7]. The straightforward and beneficial approach is to utilize NRENs that already connect many research institutes and universities [8]. Successful transfer of ultra-stable frequency has been demonstrated over an optical network with live traffic [10]. This application requires dedicated equipment in network nodes, but it is possible to run it next to standard long haul equipment. Optical clocks, that provide ultra-stable frequency, are developing into frequency standards. In this case, the frequency is not transferred as a modulated optical signal – instead, the frequency generated by optical clock is subject of transmission. Any usual O-E-O conversion would violate this service, since frequency transfer requires special continuous wave narrow single mode lasers.

3 Precise Time Transfer

One of typical applications, that proved the concept of Photonic service as a multi-domain end-to-end service, is highly accurate time transfer. Results of more than a year error-free operation of atomic clock comparison over distance of 550 km are presented at poster. More information can be found in [14][15].

4 Conclusions

Photonic services have a great potential to enhance many contemporary or future applications including real-time applications. Although described application may seem to be very specialized and useful for small community of scientists, it has great impact. Atomic clocks are representing local approximation of UTC time scales and are running in every country. The accurate comparison of these time scales is essential for maintain the universal time scale UTC.

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