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Energy Efficient, Scalable Packet Transport Networks

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***Abstract*—The rapidly growing Internet traffic will put severe cost, energy and scalability issues to future packet transport networks. Strategies and example solution approaches for network and node architectures and their control are presented here.**

I. Introduction

The development of broadband Internet access for the majority of people together with the evolution of interactive and mobile broadband services as well as the increasing video content distribution over the Internet are the key driving factors for the rapidly growing traffic demands. Actual forecasts and measurements in real networks over the last years indicate an average traffic growth by a factor of 100 over the next 10 years, whereas at some hot spots like large Internet exchanges, traffic is even doubling each year [1][2]. These trends will put severe challenges to future packet transport networks which will be detailed in the following.

II. Challenges in Future Packet Networks

The amount of traffic to be handled in the metro and core transport networks directly translates into the amount of equipment which needs to be installed (CAPEX), but also into the cost for operating these networks (OPEX), out of which energy will become a critical factor for sustainability.

Most operators' networks are currently undergoing a transformation from separated SDH/SONET and IP backbones towards converged packet transport networks following the more and more dominating IP and packet based services. The widely applied practice to electronic processing of the entire packet traffic by large IP routers will require particular consideration in view of the huge growth rates.

A. Scalability issues of core nodes

The overall traffic growth of factor 100 over 10 years indicates the need for core nodes with a total capacity of 100-150 Tb/s, which need to be realized in the most cost and energy efficient way.

Speaking in technical terms, the related electronic processing speed is still following Moore's Law, but recently more by deploying multi-core and massive parallelization rather than raising clock frequencies accordingly. Moreover, the throughput of memories, being essential for all electronic packet storage and processing, is also not able to follow with a growth rate of only 15 over 10 years.

Even if massive parallel deployment of equipment could cope with the traffic, energy will become the most critical factor, since the energy consumption of routers is increasing with throughput, despite of all improvements in semiconductor technologies. If we continue with all-electronic processing of packet traffic, a study from Japan, for example, shows that by 2020 routers will consume ~50% of the nation's 2005 total energy generation, thus becoming unsustainable [3].

B. Strategies for network architecture design

Given the need for novel architectural and technological approaches, we identified three key strategies.

Strategy 1: **Reduce processing effort per transported bit**. As a matter of fact, the majority of future services are IP based and multi-Gigabit packet processing and switching requires significantly more energy than the old circuit-switched analog services. This finding from telecom history, on the other hand, shows the potential way for improvements. Since 80-90% of the traffic in a core node is transit traffic and doesn't need to be processed by the electronic packet switching/routing blocks of this node, this traffic can be bypassed on less complex and less energy hungry means.

If the traffic still requires packet switching granularity, we can use traffic aggregation into large macro-frames, by which we can reduce header processing complexity by a factor of 200 and the energy consumption of related line cards by 30%. The highest savings can be achieved by moving the traffic to circuit switching layers, in best case to wavelength switching in the optical layer (Fig. 1).

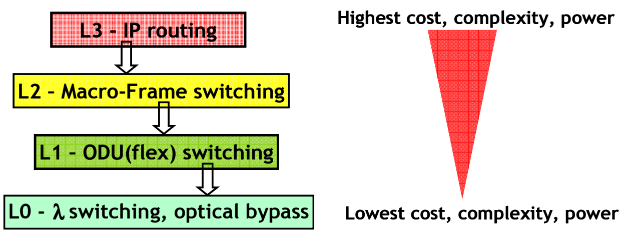

Fig. 1: Cost, complexity and energy in different switching layers

Strategy 2: **Optimize and minimize network resources**. This applies both to the deployed equipment and the spare resources to provide the required resiliency as well as the overhead to route the data through the network.

Strategy 3: **Reduce energy per processing step**. This is a more technology related topic not being detailed here. Though we need to keep in mind that further reduction of feature sizes in CMOS technology will not result in considerable energy savings.

C. Sample architectures and solutions

Building architectures strictly following strategy 1 would result in a full mesh of optical links without electronic processing in the core, following strategy 2, however, would end up in a star configuration with a single, huge central node processing all the traffic. Neither one is cost efficient (Fig. 2), the optimum lies in between. Although the optimization will give different results for individual topologies, countries or regions, a structure with IP routers only at the edges and a mostly optical core will be a good starting point for cost and energy efficiency.

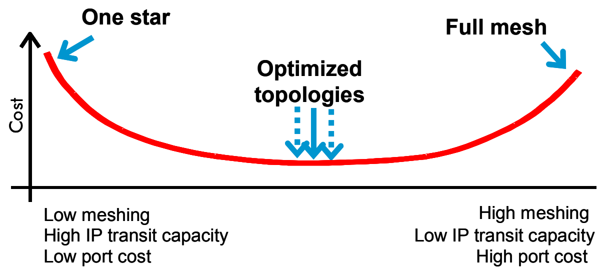

Fig. 2: Network topology optimization.

The packet traffic should be aggregated at the edges into large macro-frames resulting in a first level of savings as mentioned earlier. As far as traffic composition allows, a further aggregation should be done to push the traffic into the circuit switching domain, at best on a wavelength channel to provide the most cost and power efficient transport means. This optical bypassing of electronic processing can be implemented in static manner, i.e. at network planning state, providing CAPEX and OPEX optimization for a given maximum traffic demand matrix.

During network operation under varying traffic conditions, the dynamic set-up and release of optical bypass links –adapted to the actual traffic distribution- could further contribute to energy savings in deployed networks up to the extreme case of switching off unneeded ports or network elements. Traffic measurements at input and output ports of packet nodes will detect transit traffic crossing certain thresholds as basis for a central or distributed intelligence to coordinate dynamic setting-up and releasing optical bypass links. Several bypassing algorithms exist for different efficiency strategies.

Special use cases for optical bypass links are content distribution scenarios with ‘express lanes’ specifically for video signals, the traffic type already dominant today. The typical amount of data of video streams suggests their transport in segments of a few up to several tens of Megabytes even in predominantly IP based service environments, just for complexity and efficiency reasons. Store-and-forward routing schemes are more or less prohibited for these large segments due to required buffer sizes. Fast circuit switching is rather the best transport method here and, at the same time, can benefit most from photonic techniques, which could offer energy and cost saving potentials by a factor of 50 compared with all-electronic packet processing. A novel approach for the interaction between service provisioning and transport layers could further improve efficiency, e.g. by bypassing these video fast lanes even around the edge routers or, on the other hand, by offering new features which couldn’t be provided by the service or the transport layer alone.

Based on a new approach for dimensioning and operating packet networks [4], a mechanism can be designed for a reliable real-time estimation of packet traffic characteristics and an efficient traffic management without the explicit knowledge of user behavior, service profiles and their evolution, i.e. parameters which are normally unknown and very hard to detect. This mechanism is simple to implement and has already been shown in the lab, as well as the macro-frame traffic aggregation scheme. Experiments on efficient packet processing schemes at 100 Gbps are under preparation.

III. Conclusions

Traffic on the Internet is expected to grow by a factor of 100 until the year 2020 with video as dominating part. The current all-electronic packet switching paradigm using IP routers everywhere will face serious scalability, cost and energy challenges. To cope with these, novel architectural and technological solutions are indispensable. The strategies proposed here encompass the minimization of processing effort by aggregating traffic and pushing it into the optical layer as far as possible, as well as the optimization of network resources. This leads to transport network architectures with IP routers only at the edges and a mostly optical core exploiting static and dynamic bypassing to minimize energy and cost. The handling of huge video segments may benefit most from further simplifications like circuit-switched optical express lanes avoiding packet processing even in the edge routers. Novel mechanisms for monitoring and analysis of packet traffic will enable simple dimensioning and re-configuration of packet based networks. Some key factors of the proposed concepts have already been demonstrated in the lab, but major research efforts need to be performed to achieve the Internet vision for 2020.

Acknowledgment

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