Traffic Modelling and Traffic Engineering for Next Generation Transport Networks - results from the NOBEL project

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This paper introduces novel results in the areas of traffic characterization, traffic modelling and traffic engineering for future optical transport networks, obtained within the EU funded project NOBEL[*]. The work discussed here focuses on those results that are crucial for multilayer network modelling and dimensioning, considering the need to optimize resource utilization in a complex multi-service environment.

1. Introduction

Traffic engineering (TE) is a prerequisite for the deployment of new network services to satisfy the Quality of Service (QoS) requirements of multiple service classes whilst optimising the resource utilization on the different network layers, stretching from the IP to the optical layer. Whilst TE is nowadays restricted to a single layer (e.g. IP), it will be necessary to perform it across multiple layers to guarantee end-to-end QoS guarantees for each individual customer. TE tools are important for network operators to optimize the resource utilisation during operation, to react quickly to changes in the type and volume of particular traffic types.

This paper is organized as follows: Section 2 is concerned with the measurement, characterization and modelling of traffic. The understanding of different services, traffic characteristics occurring over timescales from a few milliseconds to daily and annual changes, has a significant impact on the performance of traffic engineering mechanisms and algorithms. The models derived from this data provide the input required for the techniques and algorithms required to carry out traffic engineering in multi-service, multi-layer networks, discussed in section 3. This section investigates in particular an integrated IP-over-WDM routing approach,

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where the topology information of both the IP and the optical layer are taken into account to optimize routing in the entire network. Section 4 summarizes the findings of the NOBEL project with respect to traffic modelling and traffic engineering, draws conclusions with respect to the network design, and provides and outlook on future work on TE topics within the NOBEL project.

2. Traffic Measurement, Characterization and Modelling

Traffic characterization and modelling is essential for the design and evaluation of TE concepts and mechanisms due to their great influence on traffic behaviour in networks [3]. However, only little is known about the packet traffic characteristics in metro/core networks due to reasons like the difficult handling of huge amount of data when measured at high-speed links and due to policies, restricting access to measurement data of operational networks.

Also emerging new applications (e.g. peer to peer (P2P), grid and triple play services), an increasing penetration of broadband user access and changing transport network paradigm (esp. increasingly incorporated dynamic mechanism) steadily change traffic characteristics. Thus, investigation and identification of the varying characteristics are essential as correct input for TE. As packet switched data services will be the prevalent traffic source for future transport networks their characterization and dynamics have to be well modelled. Thus, for the traffic characterization work in NOBEL three different packet-level measurement locations are employed, working in different contexts and technologies [9],[10]. The locations represent different network contexts ranging from a campus-like/SME-like (AGH) context to a residential user scenario with future broadband access (UST) to a metro-wan aggregated academic/business context.

Here, we present characterization results for IP traffic collected in two (UST, AGH) of the NOBEL measurement contexts. Packet-level traffic characterization can build the basis for derivation of demand models used in multilayer traffic engineering (MTE). The transition from packet characteristics to demands can be performed by effective bandwidth schemes, e.g., according to Guerin [6], Kelly [7], Norros [8]. This is not the topic of this paper but rather one of the objectives of the NOBEL project and has been performed therein.

2.1 Workload characterization

For planning, dimensioning and operation of a network correct traffic characteristics are needed. In order to correctly capture the variability and burstiness of the traffic on appropriate time-scales, i.e. the time interval over which the rate is averaged, is crucial for workload characterization. SNMP (Simple Network Management Protocol), which is supported by most network equipment, is widely applied for workload characterization but it works at a rather coarse time-scale of 5 minutes. Thus, the traffic load reported by SNMP is smoother and has significantly lower variability than rates calculated at finer time-scale granularities.

Fig. 2.1-1 (left) shows the utilization vs. time of a link over three different time-scales (UST). We can see that the lower the time-scale is the higher is the variability and burstiness of the trace. In Fig. 2.1-1 (right), we plot the maximal utilization for the different time-scale. The maximal utilization declines quickly for time-scales below 1min while the slope is much lower for larger time scales. For large values, a convergence to the mean can be observed.

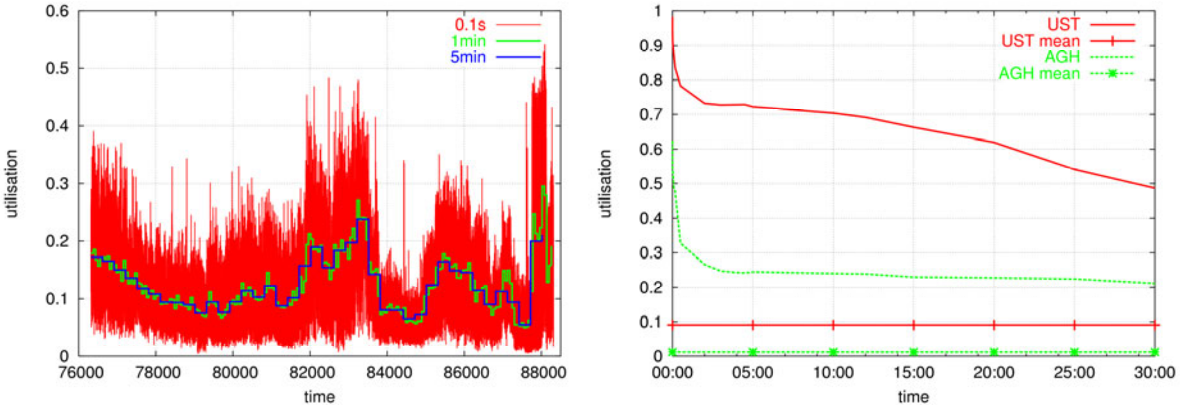

Figure 2.1-1: Variability of link utilization at different time-scale granularities

While SNMP-like 5min averages yield maximal values much higher than long-term averages and thus exhibit more of the traffic burstiness, they are still significantly lower than the values for short time-scales (0.1s max utilization of ~ 98%, 5min max ~68%).

Congestion on all time-scales beyond the critical time-scales of buffers (typically < 100ms) can decrease QoS considerably. Advanced and more dynamic TE concepts in future metro/core networks, like automatic bandwidth adaptation [4] or load balancing, also have to consider this fact and SNMP data is not sufficient.

2.2 Packet Size Distribution

Characterization of IP packet size distribution can be used for a deeper understanding of traffic behaviour and for traffic aggregation studies (e.g., for frame-switched or optical burst switched networks, [5]) and for classification.

For these considerations, packet size distributions have to be consistent across most network levels and network services. The distribution was reported to be trimodal by prior works [1],[2], and, as such, has been extensively used for performance evaluation since then. These trimodal distributions have peaks at approx. 40 bytes, 550 bytes and 1500 bytes resulting from TCP acknowledgements, from TCP implementations without path MTU discovery and from the maximum Ethernet frame size, respectively.

However, NOBEL measurements in different contexts show a packet size distribution which is (i) more bimodal than strictly trimodal and (ii) is different depending on network contexts. Both are depicted in Fig 2.2-1, where we plot packet size distribution for aggregated traffic and the split into different layer 4 protocols (TCP, UDP, ESP used for IPSec) of traffic for two of the NOBEL measurement contexts (UST, AGH). Looking at the curves for aggregate or TCP traffic, we observe only a negligible step for packet size around 550 bytes compared to results in e.g., [1]. The high value of small TCP packets in Fig 2.2-1 left stems from unidirectional capturing of upstream traffic. The characterization of packet size shows that the user applications and the network context have a significant impact and our results significantly differ from older measurements reported in literature. Therefore, TE solutions on smaller time-scales for multi-service packet networks have to be robust regarding these IP packet characteristics

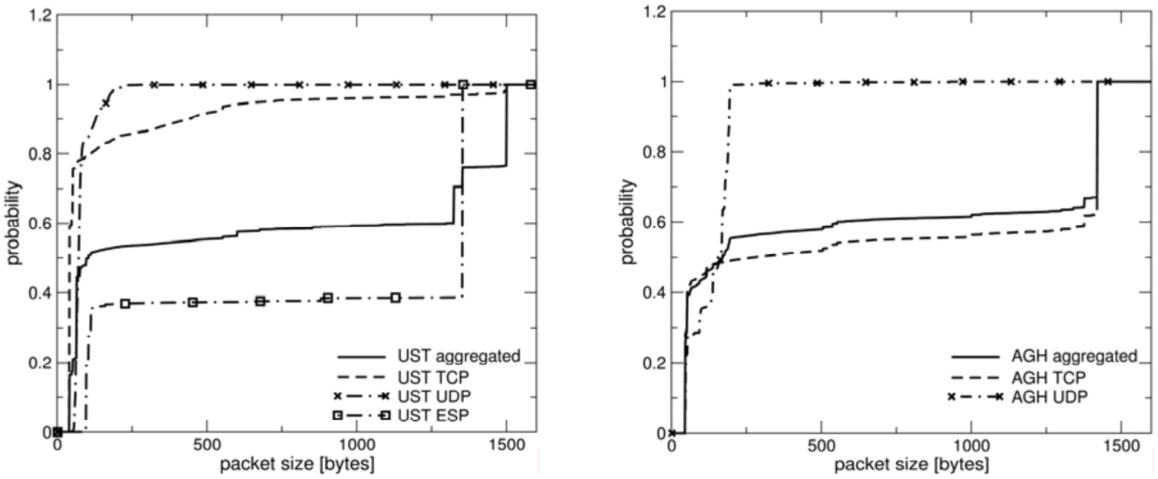

Figure 2.2-1 Packet size distribution, UST left, AGH right

2.3 Traffic Characteristics per Application

In order to perform the previously described tasks, it is also necessary to know what kind of traffic is being transported over the networks and its characteristics, so the network dimensioning, planning and choosing the most adequate Traffic Engineering mechanisms can be done properly.

Although hitherto it has been commonly assumed that Internet traffic is mostly composed by web traffic, recent studies, including the ones made in the framework of the NOBEL project conclude that in access, metro and core networks the most significant source of traffic are P2P applications. Indeed, this kind of traffic could represent up to 60%-80% ([11][12][13]) of the total traffic in these networks (late estimations point at over 80%). This fact leads to the necessity of studying the characteristics of P2P traffic, which has demonstrated that the characteristics of P2P traffic differ greatly from those of web traffic.

The following figures represent the traffic profiles from the measurements done in UST and AGH networks and they depict one of the main differences between P2P traffic and web traffic: while the latter shows an hourly pattern with peaks (during day time) and valleys (during night time), P2P traffic shows quite a flat profile, practically being a “background traffic”. The explanation for this behaviour is that web traffic is produced by human interaction, while P2P applications require very scarce human interaction to generate large amounts of traffic.

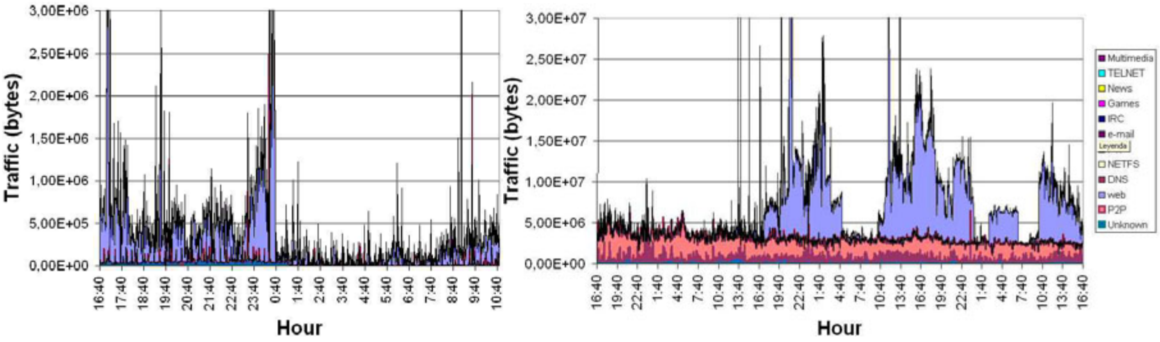

Figure 2.3-1 Traffic profile UST left, AGH right

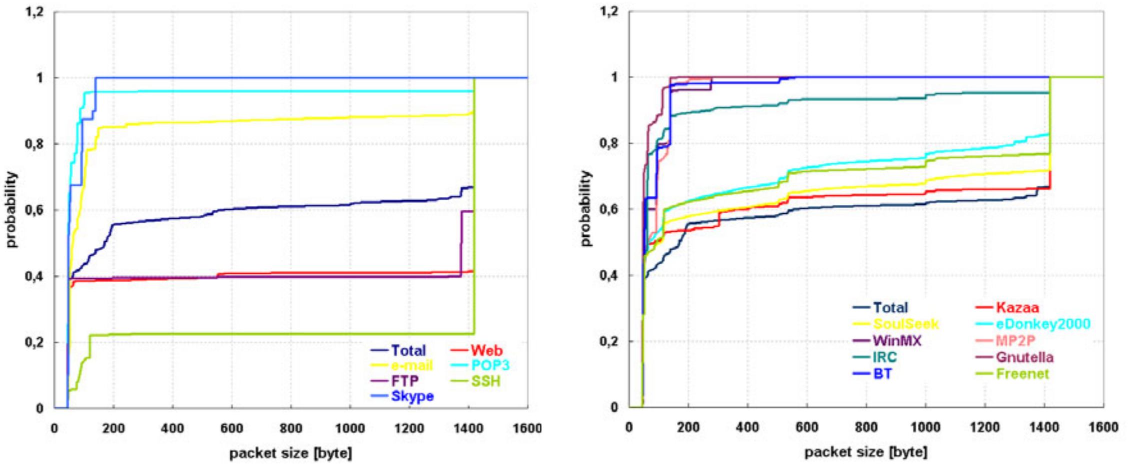

Figure 2.3-2 Packet size distribution of AGH by application, non P2P left, P2P right

3. Multilayer Traffic Engineering

In this section an IP-over-Optical peer model is investigated, where a complete knowledge of both the IP and optical layers are available for routing, namely the IP router capacities, the WDM topology and the optical switch (OXC) characteristics, etc. The unified control layer, as proposed by the Generalized MPLS (GMPLS) scheme, makes it possible to integrate both the control and management of the IP and the WDM layers into one single framework, enabling to perform intelligent peer-routing and multi-layer grooming of incoming traffic requests. An overlay model on the other hand, separates IP and optical layer so that information exchange between them is limited. However, an IP-situated multilayer traffic engineering (MTE) strategy may still be able to take optical layer considerations (e.g. resource usage) into account if there is some limited form of information exchange between the two layers.

3.1 Optical metrics for multilayer traffic engineering

Results in this section are based on a MTE strategy detailed in [14]. It uses a cost function depending on the IP link load to perform both the routing of IP traffic flows and the dynamic grooming of them (thus constructing and adapting the logical topology). This last aspect is possible because at first an IP logical full mesh is used to route the flows, the cost function is assigned such that the traffic is groomed into a limited subset of moderately filled (neither overloaded nor underloaded) links. This subset forms a meshed logical topology, which is set up using lightpaths accordingly.

In the overlay model, the MTE strategy only sees the IP layer – any information exchange from the optical layer is thus under the assumption that knowledge about the optical topology is unavailable. An optical metric transforms optical layer ‘costs’ (typically, resource usage) into a cost suitable to the MTE strategy. Similar to the IP cost function which gives a cost for each IP router node pair, the optical metric reports a value for each IP/Optical node pair (not for each fibre, for example). By multiplying the IP cost function with the optical metric, optical layer optimization was introduced into the MTE process, allowing a better lightpath selection during logical topology configuration.

The Figure 3.1-1 (left part) shows the effect of a simple optical cost metric on optical layer resource usage. This metric cost is of the form C + S × hops. Here C is a constant indicating a fixed cost for setting up a lightpath, and S a per-optical-hop additional cost (increasing the metric for longer lightpaths, i.e. for topologically distant nodes). The figure shows simulation results for four metrics with different C and S parameters (which have been normalized such that a one-hop lightpath always has the same cost).

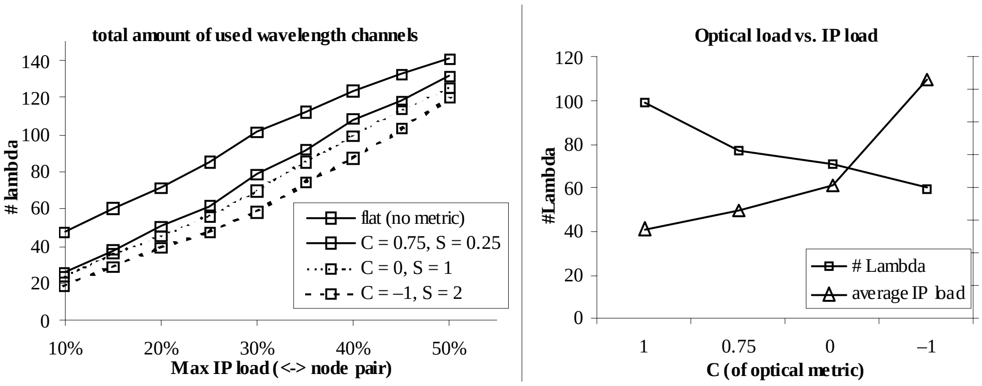

Figure 3.1-1: effect of the optical metric on performance

The special case C = 1 in fact corresponds with the case where there is no hop-dependent metric. Likewise, for S = 1, there is no fixed cost associated with lightpath setup. The case C < 0 results in a cost 'bonus' (negative cost) for lightpath setup; this will promote setting up many, but short lightpaths.

The figure shows the typical number of required line-systems ('#lambda') for a range of IP traffic volumes (X axis). We clearly see a large improvement relative to the flat (=no) metric case (especially for lower total volumes). Most of the optimization happens when introducing the optical metric. Increasing the metric slope / decreasing C (raising the cost of long lightpaths) gives some further optical improvement. The improvement tends to diminish for higher traffic loads, because at that point traffic patterns are such that the MTE strategy requires an almost full mesh anyway, meaning our range of possibilities for optimizing the selection of appropriate lightpaths is far less.

When comparing the overall performance of IP and optical layer (right part of the figure) for the same metric (characterized by their C on the figure), we see that the optical layer optimization comes at the cost of degraded IP layer performance. We see a gradual shift towards better optical layer performance for decreasing C, and slight increases in average IP router load, though once C becomes negative, the IP router load shoots up. A negative C corresponds with a fixed cost bonus for setting up lightpaths, leading to logical topologies consisting of a multitude of (very short) lightpaths, and more IP layer point-to-point grooming, thus a higher amount of transit traffic and corresponding router load. Adjusting C between 1 and 0 however, allows an operator to find a compromise between IP and optical layer performance and resource usage.

3.2 Multilayer routing policies

One of the most important questions of routing in multi-layer network architecture is undoubtedly the identification of the preferable network layer. In this section we prove with simulations that there is no one-fits-all solution thus choosing any layer of the IP/Optical architecture comes with its very own special advantages and drawbacks.

Naturally, a new request is preferred to be routed over a direct lightpath. If in the overlay model no such lightpath exists, then MTE tries to set up a new direct lightpath. If no such direct lightpath can be established, then in Peer model it is possible to create new lightpaths, to concatenate them with existing lightpaths to form a feasible connection. The resultant policy is called routing in the optical layer.

To alleviate the necessity to reconfigure the optical layer, one might try to keep the new connection setup request in the existing lightpaths as long as it is possible, and only setup new lightpaths when it is absolutely unavoidable. This policy is called routing in the IP layer.

One of the main properties of routing in the IP layer is the huge number of loops in the route of the path (there is a loop in the route if the signal passes through the same physical node more than once). According to our simulations the routing loops pose a significant obstacle in optimizing a peer-architecture. Basically loop-free paths are preferred over loopy paths, and no loopy path will be selected as long as such a path exists. To solve this, a novel heuristic is proposed called min-phys-hop algorithm, which labels the lightpath with the number of optical edges it traverses, and uses the label as link weight.

To analyze the above routing policies a unified framework is presented for the simulation. The KL-network [15] was adopted with shortest path algorithm to compute paths. The routing policy is manifested in the path selection by rescaling the weights of the IP links assigned for lightpath (w_I) and optical links (w_O) by a configurable α parameter as follows:

$$w_I \leftarrow \frac{1}{\alpha} w_I, \qquad w_O \leftarrow \frac{1}{1-\alpha} w_O \qquad (1)$$

Observe that setting *α=0* fosters routing in the optical layer, while setting *α=1* yields routing in the IP layer. Moreover, all other settings of *α* between *0* and *1* represent different trade-offs between the two policies, which was not possible by previous models (see e.g., [16]). In our simulations, we filled up the network with long lived connection setup requests one-by-one according to a traffic matrix. All optical edges can carry *3* wavelengths. For the sake of simplicity, nodes were of unlimited OEO conversion capability. We executed *500* simulation rounds in order to saturate the network.

Figure 3.2-1. shows the total number of failed connections. Figure 3.2-2. shows the number of loops as the function of simulation rounds. In this example, it is much more beneficial to encourage routing in the optical layer. A lower value of *α* results in a lower average length of the paths and fewer routing loops. However, at this point the majority of free optical resources are used up and a dramatic increase in the path length and the number of loops can be observed. This is because only (often very long) paths through existing lightpaths remain available (also called wavelength fragmentation). We note that after some peak value the length of the paths begins to drop, due to the fragmentation, no multihop paths with wavelength continuity are available and only requests between adjacent nodes succeed.

We observe that the min-phys-hop algorithm implements a decent trade-off between the two policies. It creates short paths and avoids routing loops yielding fewer blocked calls.

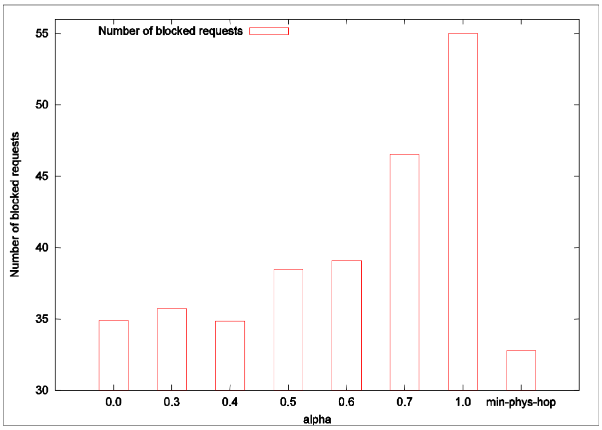

Figure 3.2-1. Average length of the last 20 paths

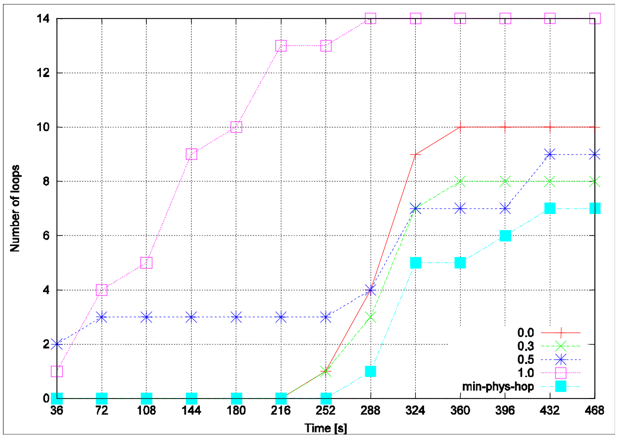

Figure 3.2-2. Number of loops in the physical network

4. Conclusion

This paper presents the results of traffic modelling and traffic engineering (TE) as obtained in the EU IST project NOBEL. TE will be a prerequisite for the operation of future multi-service, multi-layer networks to enable end-to-end service guarantees and efficient network utilization.

The investigation of packet-based traffic traces shows workloads as high as 98% for a resolution of 100ms. The understanding of the packet-size distribution and possibly long range dependence is crucial for the correct design of queues and admission policies in edge and core routers of future transport networks. The results on multilayer routing show that depending on the cost of transmission on either the optical or the IP layer, the number of required wavelengths or load of the IP tunnels can be varied. The investigation also reveals that path looping may become a serious problem in peer-model networks, and has to be counter-acted, requiring specific routing algorithms such as the *min-phys-hop* algorithm presented. The results presented in this paper show the complexity of the TE problem in future transport networks. More results on this important topic are currently obtained in the work ongoing within the NOBEL project, investigating the combined problem of TE and resilience in future networks, and developing strategies to integrate both for optimum service provisioning and network utilization.

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