# Economic Modelling of Uncertain Next-Generation Network Evolution

Cs. Kiss Kalló*, J. Dunne*, Raymond Carley*, Conor O'Malley*,

Victor Lopez**, J. P. Fernández-Palacios**

* Intune Networks, Dublin, Ireland

** Telefónica I+D, Madrid, Spain

csaba.kisskallo|john.dunne|raymond.carley|conor.omalley@intunenetworks.com; vlopez|jpfpg@tid.es;

***Abstract*— In this paper the uncertainties and the implied level of risk associated with next-generation network architectures is modelled using Monte Carlo simulation, aimed at understanding network economics evolution. A high number of network parameters – like incremental network deployment, data centre location, network architecture, service mix, traffic growth and subscriber take-up – are modelled. A wide range of values is used for these parameters to gain understanding of their impact on network cost. Such an approach provides insight into the risk level undertaken by operators when building their network infrastructure based on a specific forecast.**

**Thus, the core result of this analysis is that a sub-wavelength optical packet forwarding technology can de-risk network investments by 500% when compared to a next-generation IPoDWDM solution. Second, in a scaled network scenario the sub-wavelength solution also provides 150% capital savings. Finally, on the medium and long term the sub-wavelength approach yields a cost benefit for 99.8% of the configurations, when compared to an IPoDWDM architecture.**

## I. INTRODUCTION

There is general consensus in the telecommunications industry that traffic patterns in service provider networks are dynamically changing and are hard to predict. Such uncertain behaviour is due to a series of factors, unpredictable service evolution, changing user habits and user mobility being among the most important ones.

Firstly, new Internet applications are being released every day and they introduce unpredictable bandwidth demand and traffic profiles to the network.

Second, the number of devices connected to IP networks is expected to be twice as high as the global population in 2015 [1]. This will likely lead to new user habits as they learn to use networked devices in new areas of their everyday lives.

Third, the proliferation of high quality of experience (QoE) mobile data services running on comfortably usable smartphones is making its impact on the traffic profiles. Service providers cannot be certain anymore about the geographical distribution of demand. Consumer traffic patterns can change instantaneously based on social or business gatherings' location.

Fourth, on the server side, interest for a specific content can be sparked by a single news article or a post on a social networking webpage, creating a phenomenon known as the Slashdot effect [2].

Fifth, as cloud services gain more traction, high-demand services like the Virtual Personal Computer [3] and gaming [1] will significantly contribute to the bandwidth needed for providing excellent QoE to cloud consumers.

The list can continue, but the widely accepted view in the industry is that

- traffic is going to increase in the future, but it is impossible to know by how much; and
- traffic will change very dynamically, but no-one can tell on what pattern.

This uncertainty represents an important risk in the network operators' business and addressing that risk implies a significant cost. One big chunk of this cost is stemming from some form of overprovisioning and/or inefficient use of resources (e.g., provisioning for peak customer bandwidth, stranded bandwidth on static optical paths, building out capacity for changing geographical demand distribution, scaling the network, etc). Another important cost source is operations. Traffic forecasting, frequent network re-optimizations, optical equipment installation, separate control and management for the IP and optical layers are all contributing to high staff and services costs.

Over the past decade network operators and equipment vendors have optimized their solutions and many optimizations targeted the removal of layers and protocols between IP/Layer3 and Optical/Layer1. Thus, IP over optical paths (e.g. IPo(D)WDM, IPoROADM, IPoL1) was proposed by many as a future-proof solution for unpredictably growing, dynamic next-generation networks [4]. In this paper the economic potential of a sub-wavelength optical switching technology called OPST (Optical Packet Switch and Transport) [5] is analysed in the context of next-generation services and is compared against an equivalent IPoDWDM solution. OPST is an innovative optical switching technology based on ultra-fast tuneable lasers designed with dynamic traffic patterns, efficient resource utilization and growing

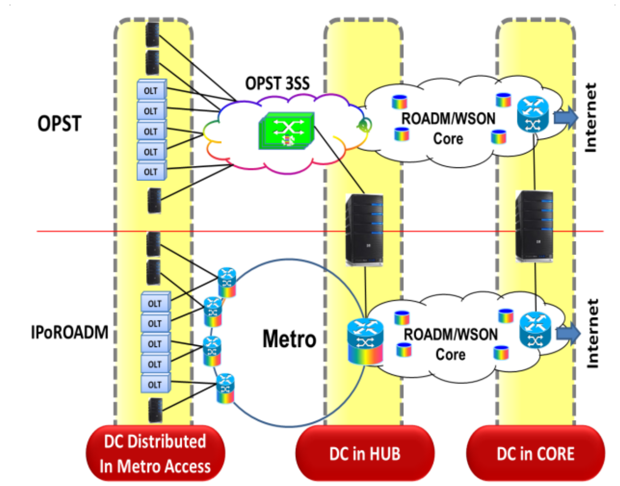


Fig. 1. Architectures and Data Center locations

networks in mind. The data path is managed through a single, unified OPST control and management plane for Layer 1 and Layer 2, which simplifies network operation. Thus, by design, OPST is capable of adapting and scaling in real time to the fast-changing demand that operators need to face in their networks.

In the remainder of this paper, Section II describes the approach and assumptions used for the presented techno-economic network models. Section III provides an analysis of the Monte Carlo modelling output, while Section IV briefly discusses the importance of the results from a broader industry perspective. Section V concludes the paper.

## II. Approach and Assumptions

Two next-generation network architectures are modelled and compared to analyse their characteristics at scale and the impact on the capital expenditure (CapEx) of uncertainty regarding service mix, service take-up, traffic growth, traffic pattern and data centre (DC) location. Monte Carlo simulation [6] is used to address the huge configuration space implied by the combination of all these input parameters. In the following subsections all of the modelling assumptions are explained in detail.

### *A. Monte Carlo Modelling*

Monte Carlo simulation is used when there is a large number of possible inputs into a model, which makes it unfeasible to calculate every possible outcome. Instead, a large number of random samples are taken, the idea being that the samples will be representative of all the possible outcomes [6].

For each service modelled over the network architecture considered in this paper, the traffic per subscriber, traffic and service mix (i.e., the destination of traffic at service granularity) and the subscriber take-up are allowed to take on random values within a relevant range. Therefore for each trial performed, the traffic for each service could take on a random value. It is impossible to forecast how the traffic for each service will increase in the future, so the Monte Carlo approach

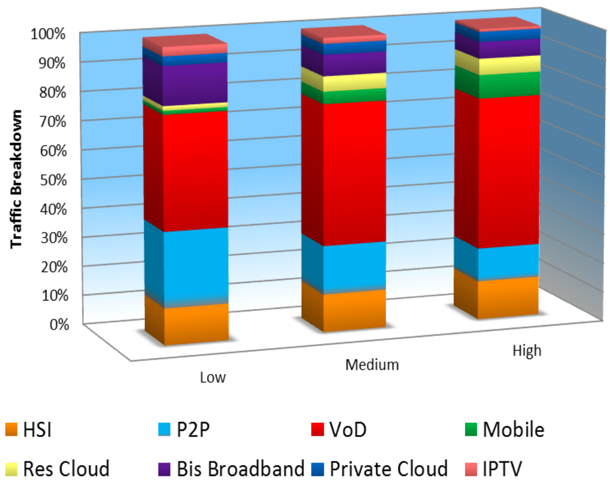


Fig. 2. Average traffic breakdown per service for the three traffic bands.

allows a valuable insight into the vast space of possibilities.

### *B. Generic Model Inputs*

Each of the modelled architectures focus on dense metropolitan areas that contain a user base of one million distributed around 60 different sites in the metro region. The model calculates all the equipment and their costs needed between the access head-end node - assumed to be one or more Optical Line Terminals (OLTs) - and the Internet exchange point (see Fig. 1).

The total traffic for the metro region is calculated as a function of the traffic per subscriber and the number of subscribers for 8 different services. Each service is allocated bandwidth per subscriber. Although the allocated bandwidth is an average value, the OLT uplinks are assumed to be filled at 25% only to allow for peaks. The models calculate the service and transport layer equipment required in the network to deliver the services when the data centre is placed in the core, at the metro hub and/or out in the metro (see Fig. 1). When the resources are derived, the models then calculate, using typical unit pricing, the capital cost of the network.

One million trials are performed (i.e. one million different combinations of traffic per service, service take-up, traffic pattern, traffic turn-around location and DC locations were taken) so that a significant range of all possible traffic makeups was examined.

Three different traffic bands are used for the models, representing short, medium and long-term evolutions of the communication environment:

- Low Traffic ~0.2-2Tbps
- Medium Traffic ~2-5Tbps
- High Traffic ~5-25Tbps

Average traffic and service take-up assumptions are visualised in Fig. 2 and Fig. 3 and further discussed later in this section.

Once the simulations are complete, the results are analysed to understand the economic implications of the network architectures going into the uncertain future.

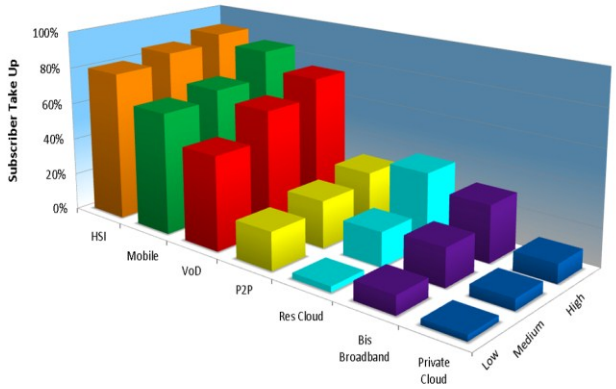


Fig. 3. Subscriber take-up per service for the three traffic bands. It shows average service popularity.

The two network architectures modelled and compared are presented in the next subsections. One of the architectures is based on IPoDWDM technology and is implemented with ROADMs at the transport layers and IP routers at the service layer. Two variants of this IPoROADM architecture are analysed, one in which the local traffic is turned around at the metro head-end, while in the second one the local traffic was turned around at the core routers. On the other hand, the second, OPST-based, architecture allows for a full optical mesh in the metro regional network, while in the core it uses the same IP and ROADM equipment as the comparative IPoDWDM models [7].

OPST merges the switching and transport functions into a single layer and thus provides a sub-wavelength optical packet forwarding platform that aggregates, grooms, switches and transports packets in a uniquely efficient manner [5]. IPoDWDM is a reasonable solution for carriers to reduce investment, while absorbing traffic increment [4].

### C. *IPoDWDM Architecture*

In the IPoROADM architecture (Fig. 1, bottom) traffic is picked up by IP access routers and is aggregated by hub routers located at the metro head-end. A dynamic Wavelength Switched Optical Network (WSON) [8] built with ROADMs is used in the backbone to transport the traffic to core routers, which in turn are connected to Internet exchange points. Routers with 2Tbps non-blocking switching capacity are used in the hub and core. When the capacity of a router is exceeded, additional routers are added to the network through stacking. Router stacks can be placed in the hub or in the core. All of the relevant combinations of router stack and DC placement are analysed.

### D. *OPST Architecture*

In the comparative OPST architecture (Fig. 1, top) a three-stage optical packet forwarding engine [5], called 3SS, carries out the aggregation, grooming, switching and transport functions. The 3SS substitutes all of the routers and ROADMs used in the IPoROADM solution for the metro space. From a service provisioning perspective, the 3SS appears as a single L2 switch, while it comprises

TABLE I
MODELED SERVICES MIX WITH INPUT RANGES FOR THE MONTE CARLO SIMULATION

| Services | Traffic per Subscriber [Kbps] | Internet [%] | Data Centre [%] | Multi-cast [%] | Local [%] | Sub. Take-up [%] |
|---|---|---|---|---|---|---|
| Residential Services | | | | | | |
| HSI | 0.01→300 | 0-100 | 0-100 | 4-6 | 0-100 | 60-100 |
| IPTV | NA | 0 | 0 | 100 | 0 | 10-40 |
| VoD | 0.3→1500 | 0-100 | 0-100 | 3-7 | 0-100 | 15-85 |
| Res. Cld | 0.9→1000 | 0-100 | 0-100 | 0 | 0-100 | 1-5 |
| P2P | 0.3→2500 | 0-100 | 0-100 | 0 | 0-100% | 15-25 |
| Mobile Services | | | | | | |
| Mobile Backh. | 9→30 | 0-100 | 0-100 | 0 | 0-100 | 55-75 |
| Business Services | | | | | | |
| Bus.BB | 3→2600 | 0-100 | 0-100 | 0 | 0-100 | 1-19 |
| Prv. Cld | 0.3→2000 | 0-100 | 0-100 | 0 | 0-100% | 1-5 |

multiple optical platforms interconnected on fibre rings from an operations and maintenance perspective.

### E. *Data Centre Location*

The data centre location can have a significant impact on the cost and performance of a network. In this study different configurations are analysed, where the data centre is placed in the core, in the metro hub or embedded/distributed in the metro access (Fig. 1).

Currently most of the data centre traffic is coming from the Internet. In order to improve performance and to include the network owners – who play a key role in delivering DC content to the end-users – into the business model of content delivery, DCs are expected to migrate closer to the user. The easiest way to do this is to build huge, centralized DCs in the network core and provide access to them through the core routers. In both cases – with the DC in the Internet and in the core – the network equipment requirements are approximately the same. The difference is that the core router ports that handle the traffic face the internet exchange routers (Internet) or the DCs located in the core. Therefore, these two cases are addressed together in the models presented in this paper.

The DCs can be also placed in the hub to achieve higher performance. The effect of this is that the hub routers carry out more of the grooming and switching functionality. Therefore, this solution results in a more expensive hub and a cheaper core, as more workload is distributed from the core toward the hub.

Finally, the DC can be distributed in many small units in the metro access. The benefit of this – beyond the desired improvement on the user experience – is that central office space can be more efficiently utilized, as servers and storage can be placed wherever there is space in a point of presence, rather than in a few dedicated locations only (i.e., in centralized DCs). The downside of such an architecture is that interconnecting the distributed DC equipment in a cost-effective way, while latency, jitter and ultimately user experience is uncompromised,

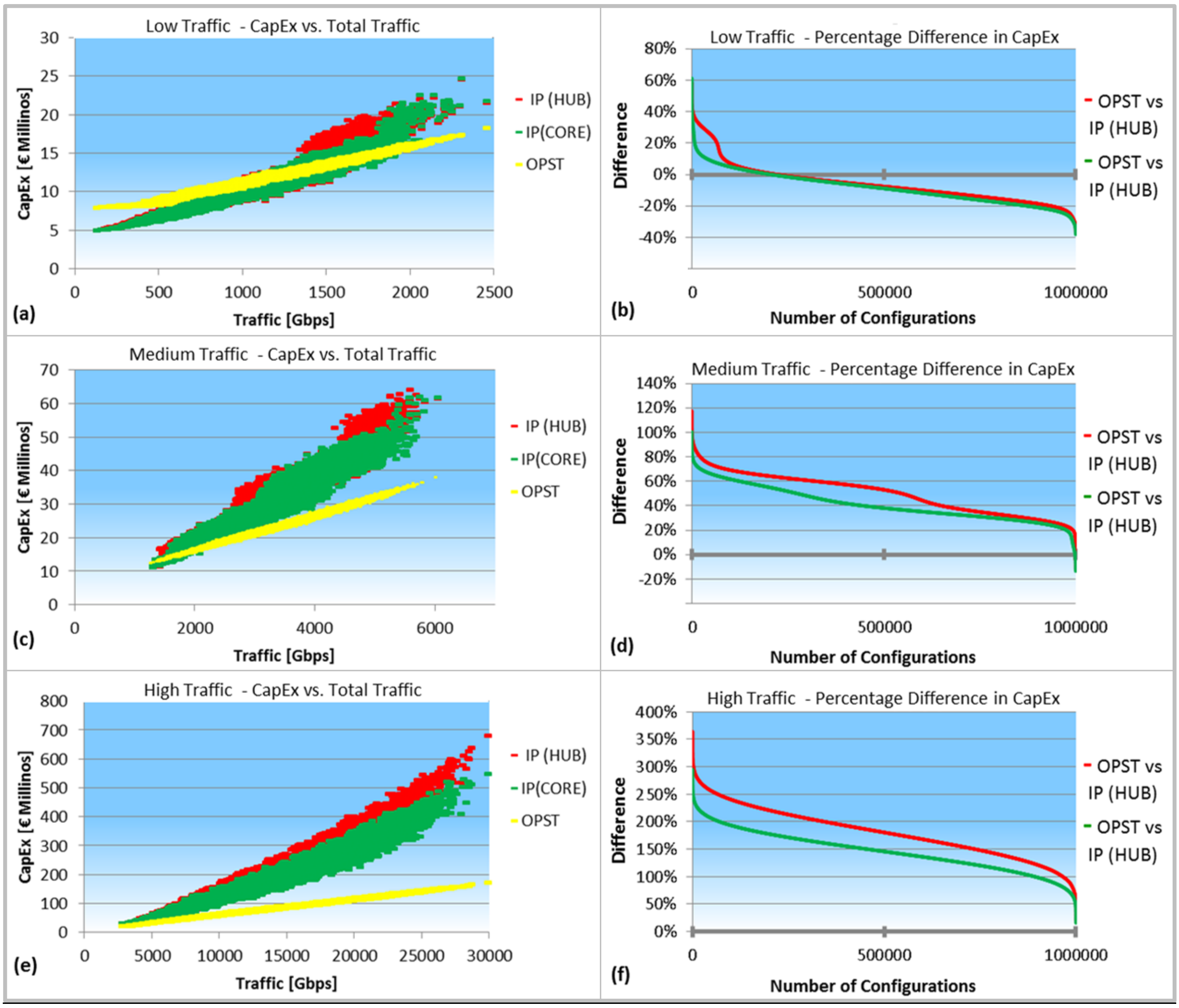


Fig. 4. CapEx Uncertainty. IPoDWDM: exponential capacity growth at exponential CapEx growth, high uncertainty; OPST: exponential capacity growth at linear CapEx growth, very low uncertainty

becomes a challenging task. This is so, because, on one hand, if distributed DC modules are interconnected through a hub router then there is no performance advantage achieved, compared to the case where the DC is placed in the hub. This would actually make the performance of the distributed DC solution worse, rather than improving it as intuitively expected. On the other hand, if the DCs are interconnected through direct optical connections then the cost increases due to the higher port requirements.

All of the above DC location considerations are addressed in the models.

### F. *Service Mix*

Eight services types of residential, mobile and business type are modelled. These services are High Speed Internet (HSI, e.g. email, browsing), Internet television (IPTV, e.g. live television), Video on Demand (VoD, e.g, Content Delivery Network (CDN) or Youtube video streaming), Residential Cloud (e.g. Virtual PC, machine-to-machine and other next generation services), Peer-to-Peer (P2P, e.g. file sharing), Mobile Backhaul (e.g. LTE, UMTS, GPRS, GSM), Business Broadband (employee browsing) and Private Cloud (e.g. corporate cloud, includes private lines) (see Table I). For each service an average bandwidth per subscriber was assumed. The traffic is categorized by destination, meaning that traffic can arrive to the metro access sites from the Internet, from DCs located in different places of the network, local metropolitan area traffic and multicast traffic. Multicast traffic is assumed to be initiated from the DCs and form a separate category for the particular way it is handled in the network. Average traffic breakdown per service and per traffic band is shown in Fig. 2.

Each service is also associated a percentage of subscribers. This percentage is a representation of the popularity of each individual service (see Fig. 3). The random values are generated according to a uniform distribution within each individual range.

Service and traffic assumptions are based on internal Telefónica data and aligned with recent traffic forecasts [9]. However, the core objective of this study is to understand the impact of inaccuracies of such forecasts. This is the reason why in Table I a very large range of

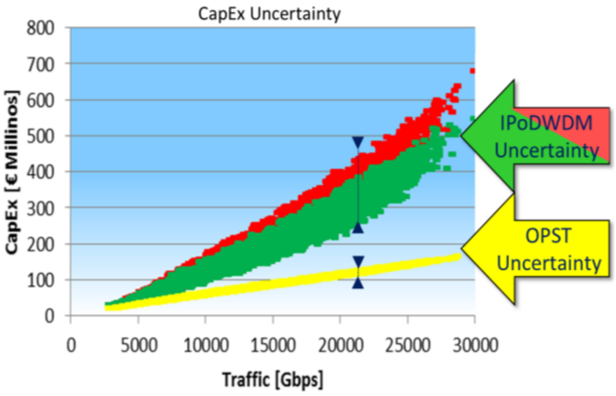


Fig. 5. CapEx Uncertainty. IPoDWDM: exponential capacity growth at exponential CapEx growth, high uncertainty; OPST: exponential capacity growth at linear CapEx growth, very low uncertainty.

possible values for each service and parameter is used and this is how the Monte Carlo simulation approach is applied to this study.

## III. Results

The CapEx results for these Monte Carlo simulations are shown for the Low, Medium and High traffic scenarios in the top, middle and bottom graph pairs, respectively, of Fig. 4. Left side graphs (i.e., Fig. 4.a,c,e) show the actual configuration CapEx while on the right hand side (i.e., Fig. 4.b,d,f) the CapEx percentage difference is shown relative to the OPST CapEx.

The Low Traffic scenario represents the current and short-term situation, as it assumes a few hundred Gbps traffic for the metro region. This scenario can be comfortably addressed with solutions based on existing single-chassis routers placed in the metro hub or the network core. Smaller IP access routers can aggregate the traffic from multiple clients connected to the same client site and pass traffic on to the metro hub in more consolidated 10G connections. The average utilization on these metro connections typically does not exceed 25%, Therefore, traffic aggregation is performed to make more efficient use of the network resources. As the traffic grows, the CapEx evolution of the IPoDWDM and OPST solutions evens out so that at 1.3Tbps the CapEx gap disappears.

As the traffic grows into the Medium Traffic band the CapEx benefits enabled by OPST become evident. For in excess of 99.8% of the configurations in this band OPST provides significant CapEx savings. This Medium band can be seen as a mid-term traffic scenario that next generation networks are currently being designed for by carriers.

Finally, the High Traffic scenario gives a longer term view over the trends of network CapEx evolution. Fig. 7.e shows a sustained linear growth for the OPST solution CapEx, while the IPoDWDM CapExes take an exponentially-looking turn upwards. The CapEx gap between the compared solutions is also quite considerable. The average percentage gap between the OPST and IPoDWDM solution CapEx is around 150%, as shown in Fig. 7.f. Also, the OPST solution CapEx in this latter case is lower for 100% of the configurations.

The main observation of this Monte Carlo analysis, however, is the level of CapEx uncertainty pertaining to the analysed solutions. The effects of uncertainty in traffic, service and data centre evolution as well as in the chosen IP routing strategy can be seen in the dispersion of the solution CapExes, highlighted in Fig. 5. This CapEx dispersion represents the risks stemming from forecast errors and unpredictable turns in the evolution of network strategy and services. The flexibility and real-time re-configurability of the OPST solution defuses network strategy decisions. Operators do not need to take a bet with OPST and live with it. Instead, they can save the cost of expensive forecasting and decision making; they can start off with a network architecture that meets the short-term requirements and adaptively change it as demand requires. This is possible because the OPST technology virtualises the optical layer. In other words, the optical resources of an OPST network can be reconfigured as easily as the electrical connections of an IP network. This deep and sophisticated optical configurability brings additional dimensions to network flexibility and enables a true virtualisation of the network resources. As shown in Fig. 5, this OPST flexibility translates into about 6 times narrower CapEx dispersion than that of the IPoDWDM solutions, which in turn means 500% less CapEx uncertainty in favour of the OPST solution.

## IV. Discussion

Carriers around the globe have been concerned for the past few years about the high cost of scaling their networks. It has been shown that the way routers and their switch fabrics can be connected together to support the rapidly growing traffic demand is not financially sustainable on the long term. The cost of network equipment is not decreasing fast-enough to compensate for the fading revenue per bit. To aggravate the situation, the uncertainty around the cost to support next generation services with IPoDWDM technology is also very high. As shown in this paper, the cost of such networks follows the exponential growth of the forecast traffic, which dampens the competitiveness of network operators. Optimizations on the many decades old base IP and optical technologies are not enough for compensating for the rapid surge in the popularity of data networking and the generated traffic.

Sub-wavelength technologies have been extensively studied over the past decade to address the inefficiencies in the financial models of traditional technology. A multitude of optical burst switching technologies have been proposed in an effort to improve network resource utilization and reduce cost as surveyed in [10]. However, as it turns out, not all of these technologies are actually capable of delivering commercial benefits and hence they never make it to commercial implementation [10]. This further proves the very high challenge that this cost-optimisation problem is posing.

The OPST sub-wavelength packet forwarding technology is currently one of the very few such technologies that is proving its commercial benefits on the market. OPST is built around a globally unique technology innovation that enables fast tuneable lasers to be used for real-time (nanosecond level) packet switching. This innovation makes it possible to bring the flexibility, efficiency and sophistication of the IP layer down into the optical layer, making it possible to truly virtualize the network infrastructure. This enables linear network cost evolution to address exponential traffic growth; hugely reduced risk in front of unpredictable demand evolution; and a light, sustainable architecture.

## V. CONCLUSION

Next-generation network design is always based on a series of assumptions about user behaviour and the resulting traffic demand. However, past experience shows that user behaviour forecasting implies a significant level of inaccuracy and, hence, risk for network infrastructure investment. This paper focuses on the quantification of this risk through economically modelling two next-generation network architectures, based on IPoDWDM and sub-wavelength packet switching. The results show that the flexibility of a sub-wavelength packet switched network reduces the risks stemming from forecasting uncertainty by 500% for 99.8% of the 1 million uniformly distributed configurations compared. Moreover, the sub-wavelength solution reduces capital expenditure by 150% on the long term. This demonstrates that there are indeed ways for using optical packet switching efficiently for building cost-optimized, future-proof next-generation networks.

## ACKNOWLEDGMENT

This work has been supported by the EC's Seventh Framework Programme through the IST STREP project MAINS (INFSO-ICT-247706).

## REFERENCES

[1] Cisco White Paper, "Entering the Zettabyte Era", June 2011.

[2] T. Lohmar, M. Elisove, "Evaluation of the File Repair Operations for Multicast/Broadcast Download Deliveries" April 2005.

[3] Cs. Kiss Kalló, M. Basham, J. Dunne, J. P. Fernandez-Palacios, "Cost Reduction of 80% in Next-Generation Virtual PC Service Economics Using an OPST Sub-Wavelength Metro Network", In Proceedings of NOC 2011.

[4] J.E. Gabeiras, V. López, J. Aracil, J.P. Fernández Palacios, C. García Argos, Ó. González de Dios, F.J. Jiménez Chico and J.A. Hernández: Is Multi-layer Networking Feasible?, in Elsevier Journal on Optical Switching and Networking, April 2009, Vol. 6, Issue 2, Pages 129-140.

[5] Intune Networks, "Optical Packet Switch and Transport. A Technical Introduction", 2009. http://www.intunenetworks.com/home/shape-up/core_innovation/opst_technical_introduction/

[6] N. Metropolis, S. Ulam, "The Monte Carlo Method", September 1949.

[7] J. P. Fernández-Palacios et al., J. Dunne et al., "IP Offloading over Multi-granular Photonic Switching Technologies", European Conference and Exhibition on Optical Communication (ECOC), Torino 2010.

[8] Y. Lee et. al., "Framework for GMPLS and PCE Control of Wavelength Switched Optical Networks (WSON)", IETF Draft, Feb. 2011.

[9] Cisco White Paper, "Cisco Visual Networking Index: Forecast and Methodology, 2010–2015" June 2011.

[10] P. Pavon-Marino et. Al., "On the Myths of Optical Burst Switching", *IEEE Transactions on Communications*, vol. 59, no. 9, pp. 2574-2584, September 2011.