

RESEARCH ARTICLE

# Quality of network economics optimisation using service level agreement modelling

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## ABSTRACT

This paper analyses the relationships between different service level agreement (SLA) components, that is, the different types of quality metrics employed by infrastructure and service providers. We propose that the quality of network economics (QoNE) be used to evaluate the quality of a network path for a given SLA model. Our evaluation indicates the usefulness of the QoNE metric, and it provides a new mechanism for the networking community to address network design problems when incorporating new challenges, such as the Internet of Things. We show how the proposed model can be implemented in software-defined network architecture applicable to networking technologies that include the interconnection of autonomous systems. Copyright © 2016 John Wiley & Sons, Ltd.

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## 1. INTRODUCTION

Considerable effort is focused on the design and development of technologies that simplify the assignment and management of resources of telecommunication networks. An important aspect to consider is the heterogeneity of the telecommunication networks, where an end-to-end path may involve very different technological domains.

The relationship between a client and a network or service provider (SP) is governed by a service level agreement (SLA), and SLA fulfilment remains an open issue. We address this problem by proposing a model that adopts an SLA that encompasses a broad range of quality metrics: technical performance, energy efficiency, resilience and economic results.

One of the most promising approaches to simplify the assignment and management of resources of telecommunication networks is the separation of the data and control planes (CPs) that enables easier implementations of software defined network (SDN) applications.

According to the Open Networking Foundation, *Software-defined Networking is an emerging architecture that is dynamic, manageable, cost-effective, and adaptable, making it ideal for the high-bandwidth (BW), dynamic nature of today's applications. This architecture decouples the network control and forwarding functions enabling the network control to become directly programmable and the*

*underlying infrastructure to be abstracted for applications and network services. The OpenFlow (OF) protocol is a foundational element for building SDN solutions.*<sup>†</sup>

An SDN should be able to select paths and assign network resources in such a way that the SLA is fulfilled.

We adopt an integrated approach that includes the interconnection of autonomous systems (AS) and a comprehensive set of technologies to implement the physical network. The SDN architecture we adopt is such that not all switching nodes have to implement any SDN signalling protocol, but the SDN works in association with specific technology domain signalling systems, such as the SS7. This last characteristic of the proposed model makes deployment practical.

In Section 2, we present the definition of an SLA. Section 4 describes the proposed SLA modelling methodology, the associated quality of a path evaluation and applies the methodology to identify the conditions to achieve an economic objective along with maximising the percentage of satisfied quality of service (QoS) requirements. Section 5 shows how the SDN paradigm can implement SLA policies. In Section 6, we discuss some of the research challenges to be faced to achieve SLA fulfilment

<sup>†</sup>Definition extracted from <https://www.opennetworking.org/sdn-resources/sdn-definition>.

across different domains, and we present our conclusions in Section 7.

## 2. SERVICE LEVEL AGREEMENT DEFINITION

The SLA is the technical part of the service contract that defines business rules, responsibilities, service description, QoS, metrics to measure SLA violations, guarantees and penalties. In case of SLA violation, the clients will receive an economic compensation proportional to the seriousness of the violation. Rules (or policies) can be applied to be used during service operation, to manage unexpected events concerning the SLA, such as resource overloading or system failures [1–3].

The Service Level Specification (SLS) is the technical specification deriving from the SLA. SLS can be a precise specification directly related to the SLA, but it can also be an interpretation of the SLA, depending on the provider or the service.

To propose an end-to-end solution to SLA/QoS management, it is necessary to define the services, SLS parameters and a classification of these services depending on the SLS parameters.

Some examples of SLA related definitions are

- Availability: the amount of time per month the network is down (or up).
- Performance: can take several forms, such as QoS, where higher QoS generally implies a higher cost. Traditional parameters often considered are throughput, packet loss ratio, delay and jitter.
- Latency: the time it takes for a packet to traverse from the customer point of demarcation to the closest egress (hand-off) location on the network.
- Security.

In a typical scenario, an SLA involves three entities: the end user (EU), the SP and the infrastructure provider (InP).

Figure 1 illustrates the SLA scenario where the EU buys services from the SP, and this relationship is ruled by an SLA between them designated as  $SLA_{EU-SP}$ ; the SP leases resources from the InP, and this relationship is ruled by an SLA between them designated as  $SLA_{InP-SP}$ , and subsequently, the InP provides connectivity to the EU, but there is no formal SLA between them.

The  $SLA_{InP-SP}$  is a list of requirements that the SP (client) (e.g. a content provider) agrees with the InP so that the EU (residential or business) is provided with the expected quality and is enabled to generate useful knowledge. In the wide sense, the expected quality is usually verified using quality of experience (QoE) tests: traffic demand rate versus available network resources, estimated failure and repair frequencies of network elements, monitoring network behaviour, etc. Useful knowledge is evaluated by the quality of knowledge (QoK) associated with the efficacy of the EU's decision-making processes.

Accordingly, the SLA concept consists of different requirements namely

- Quality of Service (QoS): thresholds in transmission delay, jitter, throughput and packet loss rate (PLR) experienced within the network.
- Quality of Transmission (QoT): tolerance to the physical impairments as bit error rate, optical signal to noise ratio, quality factor (Q-factor), etc. that impact optical/wireless connections.
- Grade of Service (GoS): imposes a lower bound for network resource utilisation to optimally satisfy the estimated traffic demand with the available resources.
- Quality of Resilience (QoR): service outage time from a failure to its restoration.
- Quality of Energy (QoEn): minimising the levels of energy consumption and maximising the green to dirty ratio of the energy consumed.
- Quality of Knowledge (QoK): accuracy of the facts inferred from the available information.
- Quality of Information (QoI): A measure of how the data collected from the physical world can be

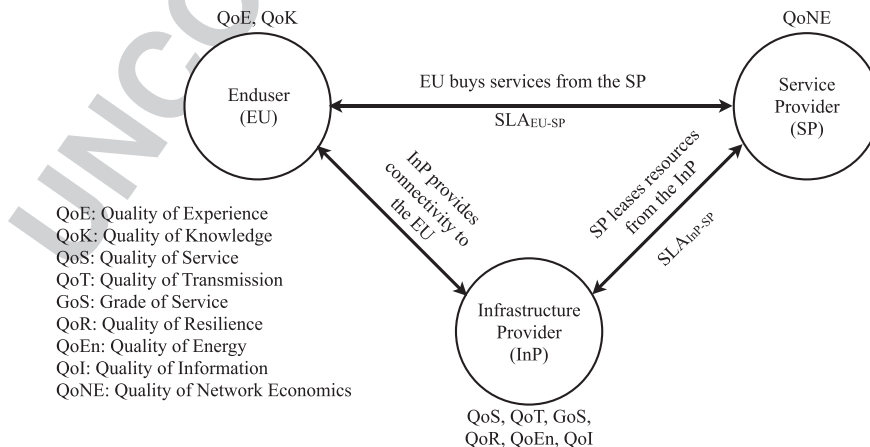


Figure 1. Service level agreement scenario.

transformed into useful information to generate knowledge, evaluated by the QoK, which can drive decision-making processes.

Our approach for an SLA focuses on achieving a trade-off between the quality criteria and the quality of network economics (QoNE), in the sense that the resource assignment has to optimise the relationship between Cost (C) and Revenue (R). The QoNE is the metric used by the SP to evaluate the economics of results achieved by the relationships established between itself, the EU and the InP.

### 3. RELATED WORK

We have made an extensive literature review related to networks and services performance evaluation with respect to SLA behaviour-based QoS. Four large areas of work were identified:

- (i) evaluation of the fulfilment of SLA models for web-based services;
- (ii) evaluation of the fulfilment of SLA models for cloud computing-based network services;
- (iii) proposals to ensure the QoS under SLA constraints in mobile networks;
- (iv) proposals to guarantee the SLA fulfilment in general backbone networks, with centralised and non-centralised CPs.

The focus and objectives of this work relate to the last category.

A first group of papers deals with the negotiation to establish SLAs taking into account QoS criteria and ways to evaluate if the SLAs are being fulfilled or violated.

In [4], the authors present a bilateral negotiation protocol using the alternate offers model for scheduling and resource allocation in grid-federation. This method, considering the user's and resources owner's criteria aims to meet the users' QoS requirements and improves job migration conditions. The contributions include a protocol negotiation, a pricing policy and an SLA structure.

In [5], the concept of policies is introduced to enhance the efficiency of calculated trust values. SLA policies, when integrated with trust management schemes, guarantee QoS and increase the satisfaction level of the customers. Load balancing algorithms are applied between providers to reduce idle time and to facilitate uniform distribution of load.

According to [6], the quality assurance techniques developed to supervise the SLAs fulfilment at runtime present some drawbacks: (i) the SLAs they support are not expressive enough to model real-world scenarios; (ii) they couple the monitoring configuration to a given SLA specification; (iii) the explanations of the violations are difficult to understand and even potentially inaccurate; and (iv) some proposals either do not provide an architecture or present low cohesion within their elements. In

this paper, the authors propose a comprehensive solution, from a conceptual reference model to its design and implementation, that overcomes these drawbacks. The resulting platform, SALMonADA, receives the SLA agreed between the parties as input and reports timely and comprehensive explanations of SLA violations.

Contrary to previous models, the focus in [7] is not only on network reliability in terms of maintaining connectivity but rather on the network's QoS and its ability to meet a certain SLA. Therefore, reliability analysis becomes a special case of this general model. Various parameters are used to realistically represent the properties of end-to-end routes. These properties include the number and composition of multipaths, the degree of multihoming and as the number of hops in each serial path.

In [8], a game model of the SLA negotiation among SPs is proposed in order to study how some learning algorithms converge to stable conditions, which are mixed Nash Equilibria in this case. It has been observed how such algorithms can, according to different policies, converge to mixed Nash Equilibria and also how profitable they are for the SPs.

In a differentiated services environment, traffic flows are assigned specific classes of service, and SLAs are enforced at routers within each domain. In [9] a model for QoS configurations that facilitates efficient property-based verification is presented. Network configuration is given as a set of policies governing each device. The model efficiently checks the required properties against the current configuration using computation tree logic model checking. The model also covers configuration debugging given a specific QoS violation. Efficiency and scalability of the model are analysed for policy per-hop behaviour parameters over large network configurations.

A second group of papers deals with the risks and cost to fulfil and maintain an SLA.

A relevant question for information and communication technology (ICT) SPs is: how to guarantee the SLA availability in a cost efficient way? In [10], the authors study how to combine different fault tolerant techniques with different costs and properties, in order to economically fulfil a given SLA requirement. GEARSHIFT is a mechanism that enables ICT providers to set the fault tolerance technique (gear ratio) needed, depending on the current service conditions and requirements. The proposed model is illustrated in a backbone network scenario, using measurements from a production national network. Finally, it is shown that the total costs of delivering an ICT service follow a simple convex function, which allows an easy selection of the optimal risk by tuning properly the combination of fault tolerant techniques.

In [11], a modelling framework is proposed that uses queueing-model-based approaches to estimate the impact of SLAs on the delivery cost. A set of approximation techniques to address the complexity of service delivery and an optimisation model to predict the delivery cost subject to service-level constraints and service stability conditions is proposed.

In [12], the authors model the time and network element failure dynamics of network operators' SLA risks. This involves identification of events interrupting service and stochastic modelling of failure events. The dynamic SLA-risk gives rise to a component importance measure, which prioritises repairs or indicates the importance of operability of a component in terms of SLA-risk in the current network and SLA state.

A third group of papers of interest deals with the evaluation of SDN centralised CP based networks to fulfil SLA requirements.

In [13], the virtual network and SDN approaches are mixed creating the virtual SDN, which enhances the customisation capacity of the networks. Based on this context, this work proposes a similarity metric and a fuzzy decision-making model to support the virtual SDN negotiation.

In [14], the authors propose a novel architecture and algorithm to address QoS across Internet with open opportunity for future enhancements by introducing dynamic relationship among service providing entities. The simulation results reveal that proposed SDN architecture dealing with interactions among Internet SPs with dynamic SLA is advantageous for QoS enabled applications.

In [15], the authors present the design of PolicyCop, an open, flexible and vendor agnostic QoS policy management framework targeted towards OF-based SDN. PolicyCop provides an interface for specifying QoS SLAs and then exploits the CP's API to enforce them. PolicyCop also monitors the network and autonomously readjusts network parameters to meet customer SLAs. Experimental results to demonstrate PolicyCop's effectiveness in ensuring throughput, latency and reliability guarantees.

In [16], an approach towards SLA policy refinement for QoS management (based on routing) in SDN is proposed. It consists of an initial manual process performed by an administrator, followed by an automatic policy refinement process executed by an OF controller. The approach is capable of identifying the requirements and resources that need to be configured in accordance with SLA refinement, and can successfully configure and execute reactive dynamic actions for supporting dynamic infrastructure reconfiguration.

In [17], the authors identify that SDN poses more complex high availability (HA) issues because of a new network domain between the control and data planes, which is called the control path. It poses many critical challenges on the existing HA mechanisms to achieve the same SLA of HA for the services in the SDN environment. To address this problem, they propose and implement several control path HA algorithms that enhance performance as well as simplify management of control path HA.

The study [18] investigates how the SDN paradigm can be used to ensure high-quality uninterrupted Voice over Internet Protocol service accompanied by video for prioritised users in a network congested with background traffic. Guaranteeing a level of QoS and resource prioritisation is vital in an emergency situation such as an international disaster recovery operation. Providing

QoS in such scenarios with the help of SDN is very feasible, via limiting BW, assigning flows to different switch queues and/or adapting routing decisions depending on network conditions.

Last but not least, the current status of the proposed and implemented SDN architectures is such that the fulfilment of a SLA remains an open issue. This aspect is left to be tackled by the SDN applications and the proposed architectures do not provide means to describe the interplay between different technology domains. According to the best of our knowledge, only our previous work [19] provides an in depth analysis of the current proposed architectures and identified important challenges to be addressed by a novel integrated SDN architecture.

The research effort has concentrated on proposing methodologies and models to guarantee and evaluated the SLA fulfilment under QoS constraints. Our contribution distinguishes from the reported works in the following ways:

- it extends extends the SLA requirements from QoS to QoX allowing to take simultaneously into account performance, reliability and economical constraints;
- it is based on the paths algebra harmonised framework that provides a flexible environment to explore different policies;
- it focuses not only on the  $SLA_{InP-SP}$  but also on the  $SLA_{EU-SP}$  and provides means to optimise the EU's QoE and achieve a positive QoNE.

#### 4. SERVICE LEVEL AGREEMENT MODELLING

It is important to be able to objectively evaluate the QoE and the QoK as a function of the  $SLA_{EU-SP}$ . Or, conversely, to define  $SLA_{EU-SP}$  in such a way that its fulfilment ensures the EU's QoE and QoK.

The treatment of QoK is out of the scope of this work and will be handled in the future in relation to the Internet of Things (IoT) context.

QoE is an assessment of the human experience when interacting with technology and business entities in a particular context [20, 21]. In this work, we consider that a good QoE is achieved if the EU receives the requested service, with the demanded quality, at minimum cost.

Suppose an EU  $E_i, i \in \{1, \dots, N\}$  demands a set of services,  $S_{ij}, j \in \{1, \dots, K\}$ , from its SP. The problem is to find an SLA,  $(SLA_{EU-SP})_{ij}$ , for each service,  $S_{ij}$ , such that  $(SLA_{EU-SP})_{ij}$  satisfies  $(QoE, QoK)_{ij}$ . From the perspective of the SP, the problem is to propose an SLA,  $SLA_{InP-SP}$ , optimising their economic outcome.

Let  $\overline{Q}_{InP} = (QoS, QoT, GoS, QoR, QoEn, QoI)$  be the set of quality metrics of service provided by the InP. Despite there being no SLA between  $E_j$  and the InP, it is clear that  $(QoE, QoK)_{ij}$  is a function of  $\overline{Q}_{InP}$ .

QoNE has to simultaneously consider the perspectives of the EUs, SP and InP,  $QoNE = \mathcal{G}(\overline{Q}_{InP})$ , where  $\mathcal{G}$  is a

function to be specified by the InP that translates  $\overline{Q_{InP}}$  into economical results, according to an adopted market policy. An example of such translation is given in Section 4.2.

#### 4.1. Evaluation of path quality

Consider a packet switched network that can be represented by a directed graph,  $G = \langle V, E \rangle$ , where  $V$  is the set of nodes and  $E$  is the set of links.  $F$  is the set of flows, and each flow,  $f_i$ , has several parameters: source,  $s$ ; destination,  $d$ ; start time,  $t_0$ ; and arrival curve,  $A_i(t)$ . Each flow has a QoS requirements vector  $Q_i = \langle w_1, w_2, \dots, w_m \rangle$ , where each element indicates one QoS parameter requirement. In the case of a packet switched network, the vector  $\langle w_d, w_j, w_t, w_p \rangle$  is usually employed, which includes the requirements for delay, jitter, throughput and PLR, respectively [22].

Let  $X_i(p) = \langle x_d, x_j, x_t, x_p \rangle$  be a vector in which each element represents the end-to-end delay, jitter, throughput and PLR of flow  $f_i$ , when using path  $p$ , respectively. The problem is to find a path,  $p$ , from source to destination node for each flow, such that  $x_d \leq w_d$  and  $x_j \leq w_j$  and  $x_t \geq w_t$  and  $x_p \leq w_p$  for each flow  $f_i$ .

Consider a path,  $p$ , with  $QoS(p)$ , which may be evaluated using a fitness value,

$$\begin{aligned} FIT(p) = & \left[ \alpha \frac{w_d - x_d}{w_d} + \beta \frac{w_j - x_j}{w_j} + \gamma \frac{x_t - w_t}{w_t} + \delta \frac{w_p - x_p}{w_p} \right] \\ & \times H\left(\frac{w_d - x_d}{w_d}\right) \times H\left(\frac{w_j - x_j}{w_j}\right) \\ & \times H\left(\frac{x_t - w_t}{w_t}\right) \times H\left(\frac{w_p - x_p}{w_p}\right) \end{aligned} \quad (1)$$

where  $H(n)$  is the step function given by

$$H(n) = \begin{cases} 0 & \text{if } n < 0 \\ 1 & \text{if } n \geq 0 \end{cases} \quad (2)$$

$\alpha$ ,  $\beta$ ,  $\gamma$  and  $\delta$ ,  $\alpha + \beta + \gamma + \delta = 1$ , are weighting factors of the QoS parameter, which depend on the application.

Equation (1) can be simplified to  $FIT(p) = FIT\_Part\_A \times FIT\_Part\_B$ , where

$$\begin{aligned} FIT\_Part\_A = & \left[ \alpha \frac{w_d - x_d}{w_d} + \beta \frac{w_j - x_j}{w_j} \right. \\ & \left. + \gamma \frac{x_t - w_t}{w_t} + \delta \frac{w_p - x_p}{w_p} \right] \end{aligned} \quad (3)$$

and

$$\begin{aligned} FIT\_Part\_B = & H\left(\frac{w_d - x_d}{w_d}\right) \times H\left(\frac{w_j - x_j}{w_j}\right) \\ & \times H\left(\frac{x_t - w_t}{w_t}\right) \times H\left(\frac{w_p - x_p}{w_p}\right) \end{aligned} \quad (4)$$

$FIT\_Part\_A$  produces a real number, and  $FIT(p)$  will be different from 0 only if the QoS requirements are satisfied for all parameters. Fitness can be used in its complete

form (Equation (1)), where value would be a measure of closeness to an established objective, or in the simplified form ( $FIT\_Part\_B$ ), which is restricted to  $\{0, 1\}$ , where 0 means that the QoS has not been satisfied and 1 otherwise.

The proposed approach can be extended for the context where different technology domains may be traversed by a path. In this case a path may be expressed as  $p = p_1 \| p_2 \| \dots \| p_l$ , where  $\|$  is for the concatenation of two vectors; and  $p_i$ ,  $1 \leq i \leq l$  are subpaths across different technology domains. Each subpath is characterised by a set of quality metrics from  $\{QoS, QoT, GoS, QoR, QoEn, QoI\}$ . Not all quality metrics are always used, for example, QoS is an adequate metric for a packet switched domain, whereas QoT should be used for an optical circuit switched domain. Each subpath may also be characterised by more than one quality metric. Considering then that a subpath  $p_i$  is characterised by the quality vector  $Q_i = \langle q_{i,1}, \dots, q_{i,m_i} \rangle$ , in which  $m_i$  is the number of quality metrics, using Equation (1) in its simplified form allows evaluation of a vector of fitness values  $FIT_i = \langle FIT_{i,1}, \dots, FIT_{i,m_i} \rangle$ , with the final fitness value being  $(FIT)_i = \prod_{j=1}^{m_i} FIT_{i,j}$ . The overall path fitness is  $(FIT)_p = \prod_{i=1}^l (FIT)_i$ , where  $(FIT)_p = 0$  if the path does not satisfy EU expectations and 1 otherwise.

A path,  $p$ , is established by assigning adequate network resources that have associated costs. Equation (1) can be used to evaluate the QoNE and define adequate  $SLA_{EU-SP}$  and  $SLA_{InP-SP}$ .

#### 4.2. Example of fitness evaluation and associate economical result

Consider the packet switched network shown in Figure 2 that has a direct link connecting the source ( $s$ ) and destination ( $d$ ) nodes. There is also a path connecting the source ( $s$ ) and destination ( $d$ ) nodes given by  $p = (s, i, j, d)$ , with corresponding values for the link characteristics, QoS parameters and associated weight factors.

All simulations were made using R software<sup>‡</sup>.

Initially, one PLR sample was generated from an exponential distribution with mean = 8 per cent, and jitter was generated from an exponential distribution with mean = 15 ms. Fitness for paths  $p_1 = (s - d)$  and  $p_2 = (s - i - j - d)$  are

- path  $p_1 = (s - d)$ 
  - $FIT\_Part\_A(p_1) = 0.999975$
  - $FIT\_Part\_B(p_1) = 1.000000$
  - $FIT(p_1) = 0.999975$
- path  $p_2 = (s - i - j - d)$

<sup>‡</sup>R is a free software environment for statistical computing and graphics. It compiles and runs on a wide variety of UNIX, Windows and MacOS platforms. It is available from <http://www.r-project.org>

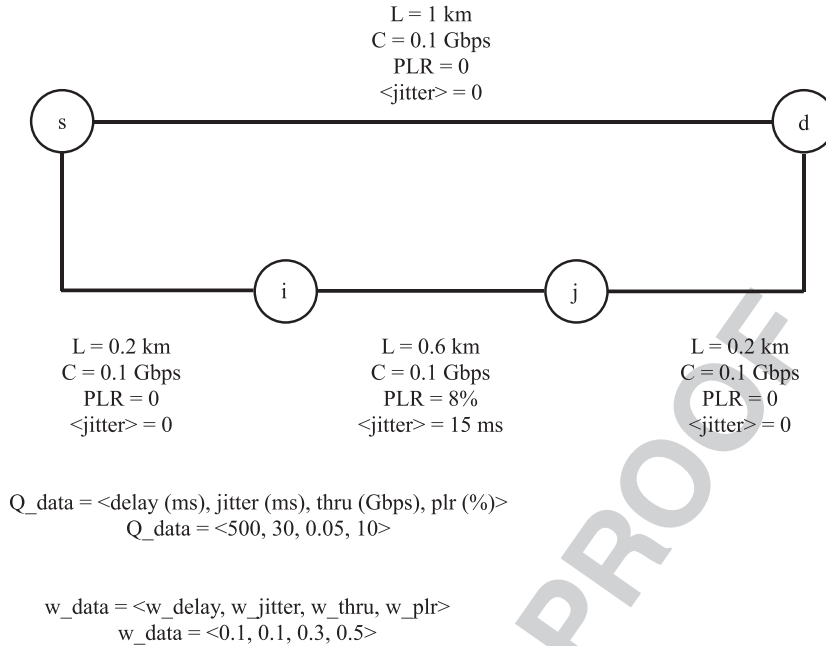


Figure 2. A simple packet switched network.

- $FIT\_Part\_A(p_2) = 0.497867$
- $FIT\_Part\_B(p_2) = 1.000000$
- $FIT(p_2) = 0.497867$

In the direct path, the QoS is almost perfect, because this path has been defined with enough resources to address the demand and with no degradation whatsoever. In the alternative path, we observe a degradation of more than 50 per cent of the QoS but without violating any threshold. Thus the connection would be accepted and the SLA respected.

A sensitivity analysis to the variation of jitter and packet loss ratio was performed using 100 PLR and jitter samples generated from the earlier exponential distributions. The fitness,  $FIT(p_2)$ , was evaluated for all jitter and PLR combinations, and the QoS success rate was 59 per cent.

To analyse the impact of the QoS success percentage in terms of QoNE, a simple economical model was developed that included the assumptions

- (1) 1 Gbps corresponds to 100 BW units.
- (2) 2.66 GHz corresponds to 100 CPU processing power units.
- (3) EU throughput demand is directly translated into BW units. The associate cost is directly proportional to the demand, and it is taken as equal to the BW demand.
- (4) Along the  $p_2 = (s - i - j - d)$  path, the packets must be processed at the intermediate nodes,  $i$  and  $j$ , (hidden nodes), consuming CPU processing power. Packets are 1500 bytes long and consume 40 000 CPU cycles to be processed. EU throughput

demand can be translated into CPU processing power demand of the hidden nodes.

- (5) EU demands a minimum CPU processing power of the terminal nodes. The CPU demand was varied from to 10– 100 CPU units in steps of 10. The associated cost is directly proportional to the demand and is taken as equal to the CPU demand. The same is valid for the hidden nodes.
- (6) The potential revenue associated with EU demand is directly proportional to the sum of CPU and BW demands. That is, in general  $R = k_1 \times CPU + k_2 \times BW$  for some constants  $k_1$  and  $k_2$ , where  $R$ , CPU and BW are the revenue, CPU demand and BW demand, respectively. We set  $k_1 = k_2 = k$ , so that  $R = k \times (CPU + BW)$  for some constant  $k$ .

Let  $C\$(p)$  and  $PR\$(p)$  be the cost and potential revenue associated with a path,  $p$ , respectively. Then,

$$C\$(p_1) = PR\$(p_1) = PR\$(p_2) = CPU(s) + BW(sd) + CPU(d) \quad (5)$$

and

$$C\$(p_2) = CPU(s) + BW(si) + CPU(i) + BW(ij) + CPU(j) + BW(jd) + CPU(d) \quad (6)$$

The selection of path  $p_2$  increases the cost because of the use of more network resources without increasing the potential revenue. In addition, the QoS is not always satisfied. Let  $QoS$  represent the QoS success proportional

value and  $P\$$  the penalty to be applied when the QoS is not satisfied. The actual revenue is then

$$R\$(p_2) = \overline{QoS} \times PR\$(p_2) + (1 - \overline{QoS}) \times PR\$(p_2) \times (1 - P\$) \quad (7)$$

The net revenue is

$$NR\$(p_2) = R\$(p_2) - C\$(p_2) \quad (8)$$

which is negative for  $\overline{QoS} < 1$ .

The InP leases its infrastructure to the SP and charges  $SP_{InP-SP}$ , obtained by multiplying  $PR\$(p)$  by a selling factor, SF. The InP's gain when the  $p_2$  path is used is  $G_{InP} = SP_{InP-SP} - C\$(p_2)$ . The SP sells its services to the EU for  $SP_{SP-EU}$ , and its gain is  $G_{SP} = SP_{SP-EU} - SP_{InP-SP}$ .

The selling prices,  $SP_{InP-SP}$  and  $SP_{SP-EU}$ , are defined by internal policies of the InP and SP respectively and are not openly disclosed. However, to show possible criteria to establish an SLA, the following general principles are proposed:

- (1) To have a sustainable business, both the InP and the SP must achieve positive gains. The gain is taken as a measure of the QoNE.
- (2) In the absence of a better criterion, it is considered fair that both the InP and SP have equal gains.

- (3) The EU expects to receive the requested service, with the demanded quality, at minimum cost.

A simulation scenario was defined with the following parameters:

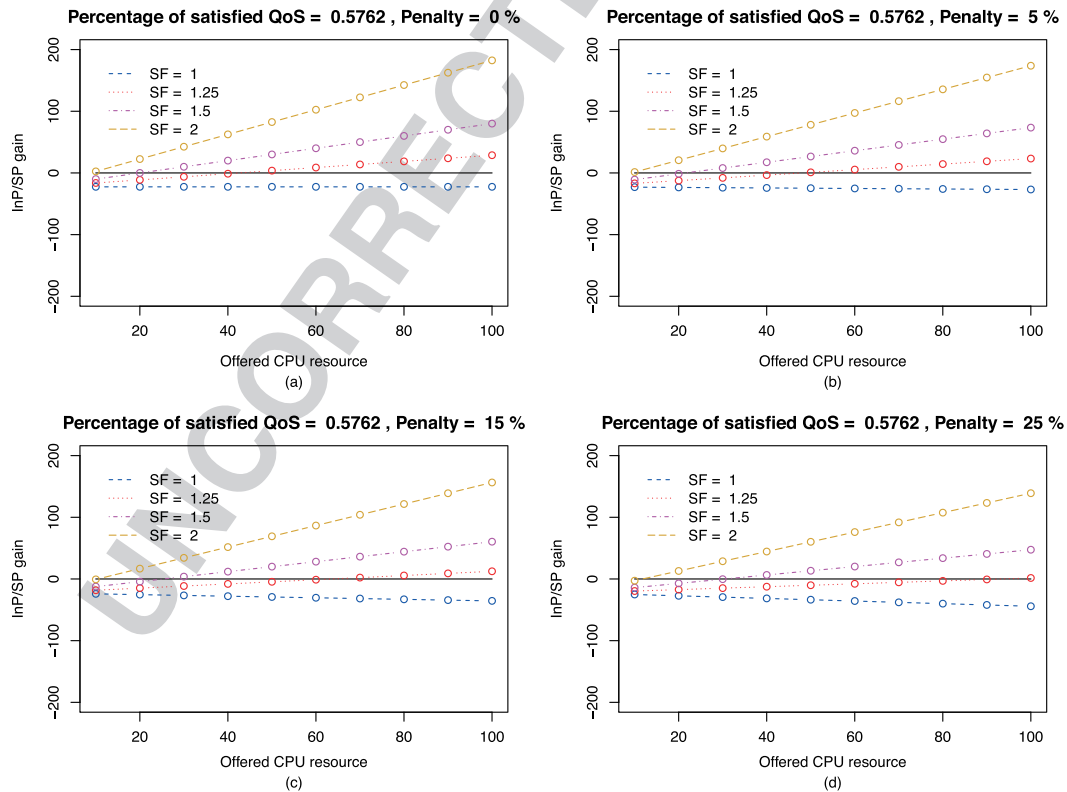
- (a) selling factor  $SF \in \{1.00, 1.25, 1.50, 2.00\}$ ;
- (b) penalty  $P\$ \in \{0, 5\%, 15\%, 25\%\}$  in steps of 1.

A typical simulation run produced 57 per cent satisfied QoS requirements. Figure 3 shows the QoNE relationship with Offered CPU resource for selling factors in (0, 2.0) and four different penalty levels.

The results are summarised as follows:

- positive gains for the InP and the SP, independent from the offered CPU resource, are obtained only for a selling factor  $SF = 2.0$ ;
- the minimum offered CPU resource that produces positive gains depends both on the selling factor and the penalty policy. For a selling factor of 1.25, when the penalty changes from 0 to 25 per cent, the minimum offered CPU resource to provide positive gain rises from 40 to 100.

The simulated condition produced a relatively low value of satisfied QoS requirements, and as a consequence, the



**Figure 3.** Quality of network economics results for four values of the selling factor and the applied penalty policy. SP, service provider; QoS, quality of service; InP, infrastructure provider.

EU is forced to pay a high price so both InP and SP achieve positive gains.

Figure 4 shows how a penalty policy (i.e. an SLA) can be used in favour of both technical performance and QoNE. In this scenario, it was assumed that the economical goal was  $G_{InP} = G_{SP} = 50$ , and the problem was to find the optimal SP selling price as a function of the percentage of satisfied QoS requirements.

Figure 4 (a) and (b) shows the results for a low offered CPU cost (20 units). As the QoS requirement increases, there is little effect on the optimal selling factor. However, while for a given penalty the selling price increases, it can be decreased by increasing the penalty applied to the InP. For example, for 60 per cent of satisfied QoS requirements and penalty of 15 per cent, the optimal selling price is approximately 102. If the penalty is increased to 25 per cent, the same QoNE is achieved, at the same selling price, but provides 80 per cent satisfied QoS requirements.

Figure 4 (c) and (d) shows the results for a high offered CPU cost (70 units). In this case, for a given penalty level, as the QoS requirements increase, the selling factor always decreases. Figure 4 (d) shows a complicated behaviour of the optimal selling price, but a penalty policy may be applied to optimise the selling price and make it always decrease for improved QoS. For example, at the 25 per cent

penalty level, it is possible to guarantee a gain of 50 monetary units for both InP and SP by increasing the percentage of satisfied QoS requirement to 95 per cent and achieving a slight selling price reduction to the EU from 270 to 262 monetary units.

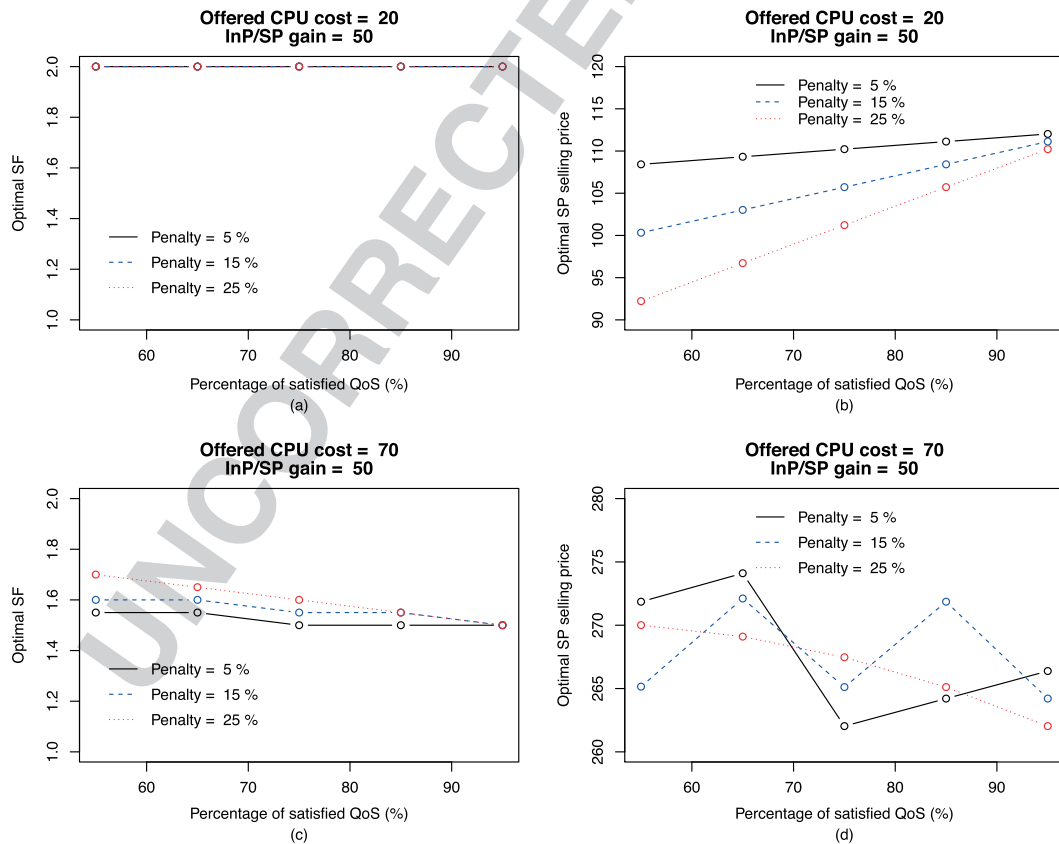
Despite being preliminary and a very simple scenario, these outcomes indicate the possibility of developing a method to translate the technical performance of a packet switched network into QoNE metrics and SLS clauses that may be incorporated into an SLA.

The example can be easily extended to a scenario with different technological domains. The only difference would be the evaluation of the quality of each subpath using the appropriate metrics. The end result would also be a percentage of satisfied QoS requirements and the conditions to achieve an economical objective could then be identified.

## 5. SOFTWARE DEFINED NETWORK-BASED IMPLEMENTATION OF SLA POLICIES

The question remains as to how the proposed methodology can be applied in practice. We conjecture that the adoption

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**Figure 4.** Optimal selling factor (SF) and service provider (SP) selling price for gain = 50. QoS, quality of service; InP, infrastructure provider.



of network function virtualisation (NFV) implemented according to the SDN paradigm is a possible option.

There are no restrictions concerning the NFV functions to be considered. Any of the functions proposed by ETSI in [23] are of interest and PCE as described in [24] as well.

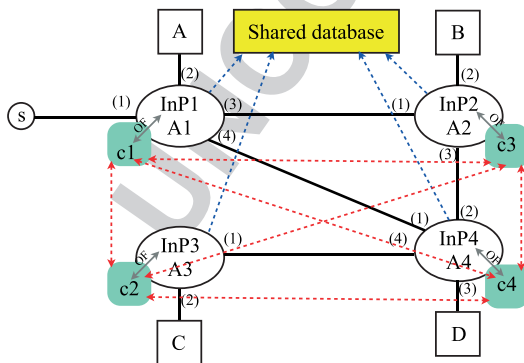
Figure 5 shows a possible SDN implementation of NFV functions among different AS, which has the following characteristics:

- (i) each autonomous system has its own SDN controller. The controller communicates with the switching elements using the OF protocol (represented in grey in the figure);
- (ii) the controllers gather statistics of the underlying substrate network (represented in black in the figure), process the information and publish in the shared database;
- (iii) the shared database can be accessed by all controllers (represented in blue in the figure). It can be either a centralised or distributed database physically hosted in the cloud;
- (iv) the controllers form a logical full connected network (represented in red in the figure).

In this work, we adopt the SDN architecture and terminology as proposed in [25]. Accordingly, this proposal focus on two planes, namely:

- Control Plane - the collection of functions responsible for controlling one or more network devices. CP instructs network devices with respect to how to process and forward packets. The CP interacts primarily with the forwarding plane and, to a lesser extent, with the operational plane.
- Application Plane - the collection of applications and services that programme network behaviour.

The controllers shown in Figure 5 are entities of the CP, and the PCE is the main NFV function considered in this



**Figure 5.** Software defined network implementation of network function virtualisation functions among different autonomous systems. InP, infrastructure provider.

work and is an entity of the application plane. There is also a clear distinction between the InP that owns, controls and publishes the statistics about its infrastructure in the shared database, and the SP that access the shared database and using the PCE running in the application plane identifies and selects the routes that maximise its technical and economic objectives.

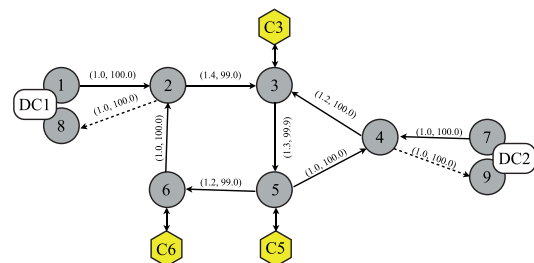
Figure 6 shows a network topology that could be used to evaluate a QoNE and QoR scenario.

In the figure

- each grey node represents an autonomous system and is identified by a number;
- there are seven AS in the network. The AS 1 and 7 are split in two just to avoid the use of bi-directional links;
- the AS 1 and 7 give access to the data centres DC1 and DC2, respectively;
- each autonomous system has its own SDN controller and publishes its reachability, performance and business-related information in the shared database. This is represented by the vectors on top of each arc meaning the cost/revenue and availability, respectively.

Let's assume that a SP wants to access to provide Big Data processing services to IoT customers identified as C3, C5 and C6. Cx means a client attached to the autonomous system x. Because of the nature of their critical applications related to health care, they want to establish an SLA in which the QoR is assured. As the SP will lease resources from the InP, it needs to know if an economical balance is achieved and if it can offer the same price to any customer, independently of its location.

It is out of the scope of this work to detail the QoNE and QoR fitness evaluation, as an example was described in Section 4.2. An interested reader may refer to [26] for a complete description. The final result is if the SP offers access to only one data centre, it always achieves a positive fitness and can use the price models to increase either the attractiveness of its service by lowering the prices or to its gains by increasing the price. If it offers simultaneous access to both data centres for a same customer, there is no



**Figure 6.** Network topology used in the evaluation of a quality of network economics and quality of resilience scenario.

policy that may provide positive gains for the price models adopted in this study.

To implement the service, each InP in charge of an autonomous system must provide information of reachability of its immediate neighbours, the associated cost and availability of the connection. The SP has commercial agreements with all ASs. Based on these agreements, it has instances of its service running at the application layer of each AS network controller. The SP has a master service running somewhere that has access to the shared database that decides to provide access to a customer, for example, in AS 3 to the DC1 and triggers the following actions:

- (1) The master services contacts its instance in the AS3 network controller and informs that a connection to AS 5 has to be established. The flow is identified by (source IP, destination IP, source port, destination port). It also informs the required availability and maximum acceptable price.
- (2) The action earlier is repeated in ASs 5, 6, 2 and 8 to establish the required paths and provide access to the DC1.
- (3) Each AS network controller accepting the SP request creates a new entry in its flow table and configures

its switching elements accordingly. An SLA is established between the SP and each AS.

- (4) Each AS gathers the statistics of the established flow and sends them to the SP service instance.
- (5) Each SP service instance informs the SP master service about any change in the statistics so it can check if the SLAs are being fulfilled.

The SDN paradigm and its associate OF protocol was originally defined to IP networks. The Open Networking Foundation has been working to extend OF to work with optical networks, but much remains to encompass the complexity and heterogeneity of telecommunication networks.

Figure 7 shows what could be a comprehensive extended SDN architecture. The main elements are as described in [27]: (i) data plane; (ii) control plane; and (iii) management plane. The southbound interface is used to implement communication between the control and data planes using a standardised protocol; the northbound interface is used to provide communication between the control and management planes. However, this interface is not standardised. The east/westbound interface is used to enable communication between multiple instances of the network

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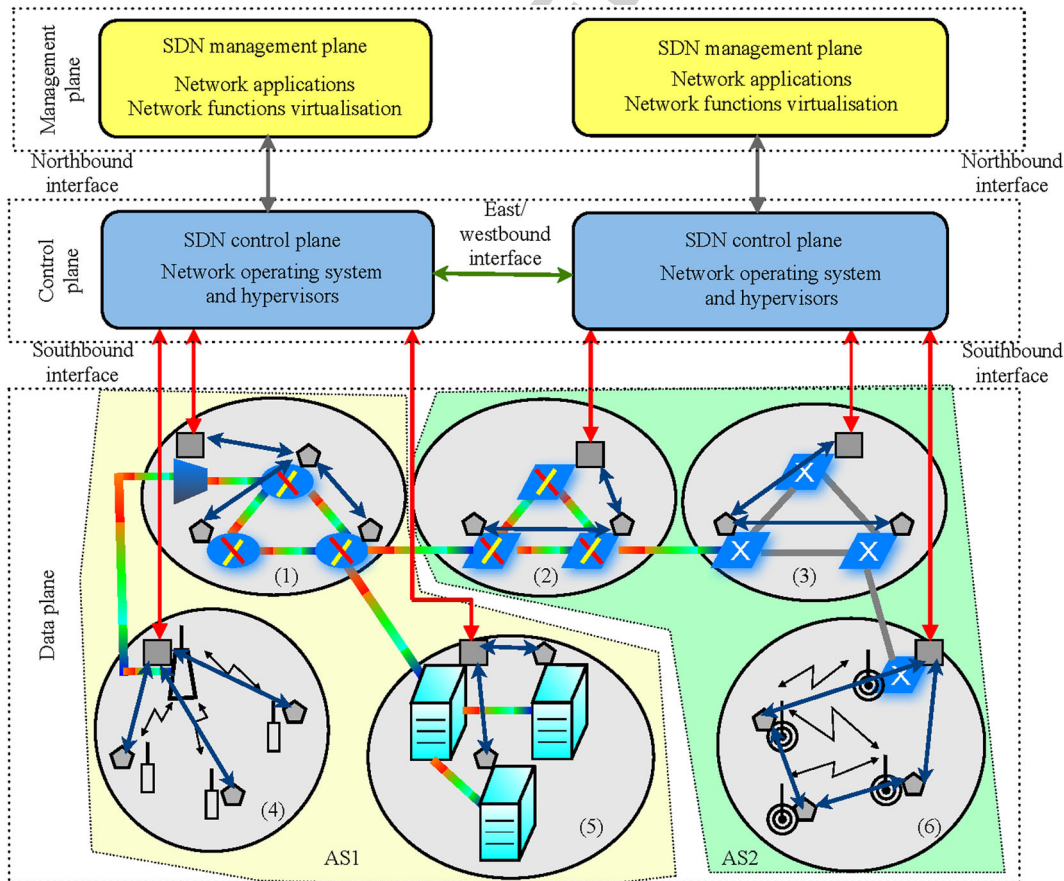


Figure 7. Extended software defined network (SDN) architecture.

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01 controller. Thus, a single logically distributed network  
02 controller or multiple network controllers across different  
03 AS may be implemented.

04 The lower part of Figure 7 illustrates the heterogeneous  
05 data plane of the extended SDN architecture. We note the  
06 following characteristics:

- 07 • It includes three new technological domains, namely:
  - 08 (a) a wireless access network that could be a
  - 09 (b) a data centre network representing the provi-
  - 10 (c) a wireless constrained resources network

11 (a) a wireless access network that could be a  
12 mobile phone network and/or an IEEE 802.11  
13 WiFi network;  
14 (b) a data centre network representing the provi-  
15 sion of cloud computing services;  
16 (c) a wireless constrained resources network  
17 representing network connected objects.  
18 Such objects may have different levels of  
19 intelligence associated with them, from a  
20 simple bar code or RFID identifier, through  
21 data processing and sensing capabilities,  
22 up to objects with autonomous networking  
23 capabilities. It is the domain of Machine-to-  
24 Machine communications (M2M) or the IoT.  
25 Such domains are characterised by a huge  
26 number of elements generating data transmit-  
27 ted across the network to be remotely pro-  
28 cessed in a distributed way. In general, the  
29 nodes have very limited resources in terms  
30 of available power, processing capacity and  
31 storage memory.

- 32 • It considers different ASs. It is a challenge to ful-  
33 fil an SLA across different ASs, because network  
34 providers usually do not share the details of their  
35 network topologies and available resources to other  
36 providers. Packet routing and forwarding remains  
37 a challenge in modern networks. In terms of the  
38 Internet, large backbone operators are facing enor-  
39 mous problems with the scalability of the Internet  
40 routing system.

41 The major contributing factors are the growth  
42 of routing tables, constraints in routers technology  
43 and the limitations of Internet addressing architec-  
44 ture. The traffic volume, routing tables sizes and AS  
45 growth rates are  $50 \pm 5$  per cent, 15–25 per cent and  
46 10 per cent per year, respectively. Between January  
47 2006 and January 2009, the border gateway protocol  
48 prefix update and withdrawal rates per day increased  
49 by a factor of approximately 2.25–2.5, representing  
50 an average of 2–3 per second up to peaks of O(1000)  
51 per second.

- 52 • This model is not OF-binded [28]. It is a generic  
53 model that can be used with any other SDN protocol  
54 [29], such as ForCES [30]. We rename the usual OF  
55 agent as a signalling point, and in each technology  
56 specific domains, there may be two types:

- 57 – Software defined networking signalling control  
58 point: This is an SDN capable signalling  
59 point. There is at least one of them in  
60 each technology specific domain. They are  
61 in charge of communicating with the SDN  
62 controller using a standardised SDN protocol.  
63 They also communicate with other signalling  
64 points in the domain using either the SDN  
65 protocol or a technology specific protocol.
- 66 – Domain and technology specific signalling  
67 point: This is a signalling point that may be  
68 SDN capable or not. It communicates to other  
69 signalling points in the domain, but it does not  
70 communicate with the SDN controller.

71 It is important to emphasise that all network elements  
72 are signalling points, but not all of them are necessar-  
73 ily SDN capable, and only a few of them are allowed  
74 to communicate with the SDN controller.

75 The important characteristics of the depicted architec-  
76 ture are

- 77 (a) The extended architecture is assumed to be inte-  
78 grated in the sense that the controller controls  
79 nodes in all technology domains. For example, [31]  
80 introduces an SDN-enabled optical network CP  
81 based on OF. This architecture relies on an abstrac-  
82 tion mechanism, implemented by an extended OF  
83 controller and the OF protocol. The architecture  
84 also uses an inter-domain flow table to enforce  
85 cross technology constraints for BW allocation  
86 when traffic traverses from one technology domain  
87 to another. This does not mean that the southbound  
88 interface available protocols are already prepared to  
89 perform such task but that they must be extended to  
90 achieve this goal.
- 91 (b) The extended architecture includes a hypervisor  
92 functionality. Hypervisors enable distinct virtual  
93 machines to share the same hardware resources.  
94 FlowVisor is one of the early technologies to virtu-  
95 alise an SDN [32].
- 96 (c) The management plane is based on the NFV con-  
97 cept. Typically, network flows go through several  
98 network functions (NFs). Thus, a set of NFs is spec-  
99 ified and the flows traverse these in a specific order,  
100 so that the required functions are applied to the  
101 flows. This concept is known as network function  
102 chaining or network service chaining [33, 34].

103 The methodology proposed in this paper shows that  
104 SLA clauses can be translated into SLSs. The SLSs may  
105 be further translated into QoX objectives, where X stands  
106 for S, T, En, etc., according to the technological domain.  
107 These objectives can be achieved by adequate chaining and  
108 configuration of network elements provided by NFV and  
109 implemented by the extended SDN architecture.

At this stage, the proposed architecture remains at the conceptual level and must be tested and evaluated to be fully validated.

## 6. RESEARCH CHALLENGES

As far as the extended SDN architecture implementation is concerned, an adequate definition and representation of network-related information from different technological domains has to be developed to be transported through the southbound interface using a single control protocol. An abstraction of network-related information to be transferred across different AS remains to be developed.

As far as SLA fulfilment oriented resources assignment is concerned, QoE and QoK-bounded QoNE objectives must be established, translated into SLAs and used as target outcomes for NFV algorithms.

Network complexity must be addressed. The multiplicity of technologies, data forwarding techniques and signalling protocols do not scale appropriately given the huge amount of information to be dealt with for a given deployment of IoT applications and services. Harmonisation, standardisation and interoperability must be addressed.

## 7. CONCLUDING REMARKS

A mechanism for SLA modelling and translation into performance requirements was proposed. An objective QoS model based on a fitness equation allows measurement of how far the quality of offered services falls from an ideal scenario ( $FIT(p) = 1$ ), and a mechanism to check the SLA fulfilment based on threshold values. In the simulated scenario with a value of  $FIT(p) = 0.498$ , only 57 per cent of the requests have their QoS requirements satisfied, implying an economic burden on the EU as it is necessary to apply a selling factor ( $SF$ ) = 2.0 over the cost for both InP and SP to achieve positive gains. We also showed that it is possible to guarantee a gain of 50 monetary units for both InP and SP by increasing the percentage of satisfied QoS requirement to 95 per cent and achieving a slight selling price reduction to the EU from 270 to 262 monetary units.

The SDN paradigm is a suitable way to address the current and future resource assignment problem. It offers the required flexibility to allow the optimisation of network performance considering the multiplicity of constraints that span from EU satisfaction to achievement of positive economical results for the InP and SP.

We proposed and discussed the use of the SDN paradigm to implement the fulfilment of the SLAs established among EUs, InP and SPs.

The requirement of a harmonised way to control and assign resources from different network technologies is essential at both design and implementation levels.

Software defined network developments show interesting results for packet switched networks but much remains to be developed to tackle the challenges of technological heterogeneity and scalability resulting from IoT.

## ACKNOWLEDGEMENTS

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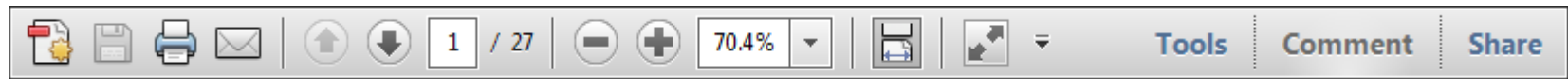
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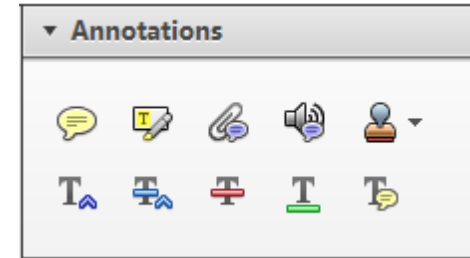
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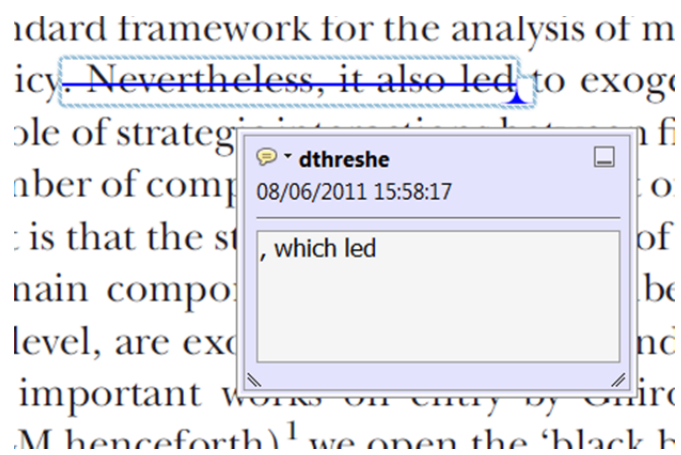
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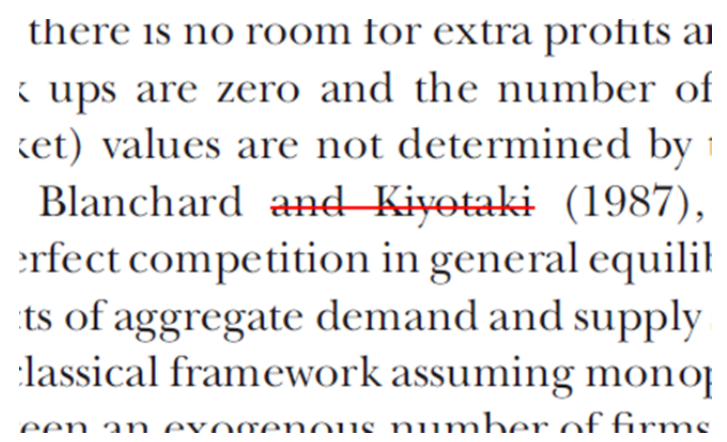
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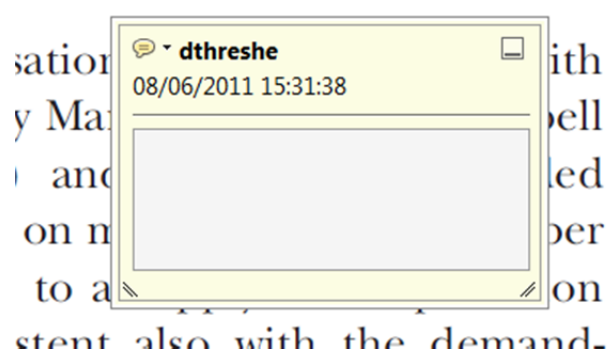
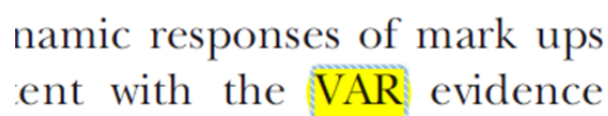
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- Click on the [Add note to text](#) icon in the Annotations section.
- Type instruction on what should be changed regarding the text into the yellow box that appears.



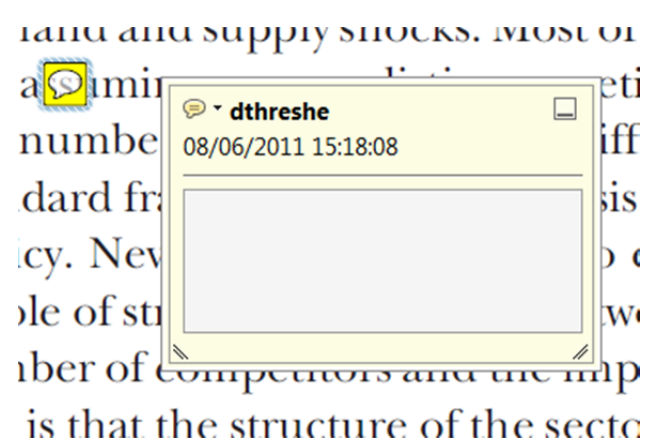
**4. Add sticky note Tool – for making notes at specific points in the text.**



Marks a point in the proof where a comment needs to be highlighted.

**How to use it**

- Click on the [Add sticky note](#) icon in the Annotations section.
- Click at the point in the proof where the comment should be inserted.
- Type the comment into the yellow box that appears.





USING e-ANNOTATION TOOLS FOR ELECTRONIC PROOF CORRECTION

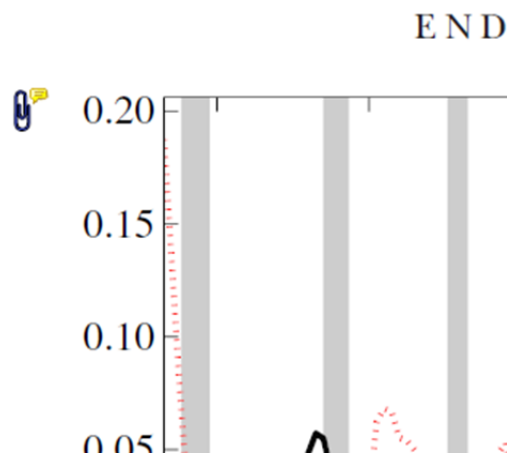
**5. Attach File Tool – for inserting large amounts of text or replacement figures.**



Inserts an icon linking to the attached file in the appropriate place in the text.

**How to use it**

- Click on the [Attach File](#) icon in the Annotations section.
- Click on the proof to where you'd like the attached file to be linked.
- Select the file to be attached from your computer or network.
- Select the colour and type of icon that will appear in the proof. Click OK.



**6. Add stamp Tool – for approving a proof if no corrections are required.**

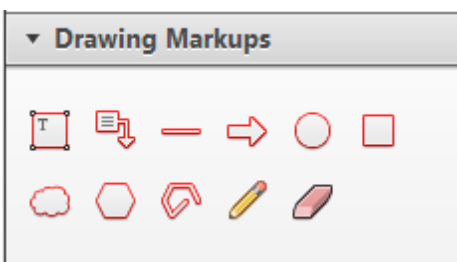


Inserts a selected stamp onto an appropriate place in the proof.

**How to use it**

- Click on the [Add stamp](#) icon in the Annotations section.
- Select the stamp you want to use. (The [Approved](#) stamp is usually available directly in the menu that appears).
- Click on the proof where you'd like the stamp to appear. (Where a proof is to be approved as it is, this would normally be on the first page).

of the business cycle, starting with the  
 on perfect competition, constant ret  
 production. In this environment goods  
 extra profits and the number of firms  
 he number of firms is determined by  
 determined by the model. The New-Key  
 otaki (1987), has introduced produc  
 general equilibrium models with nomin  
 ed and supply shocks. Most of this literat

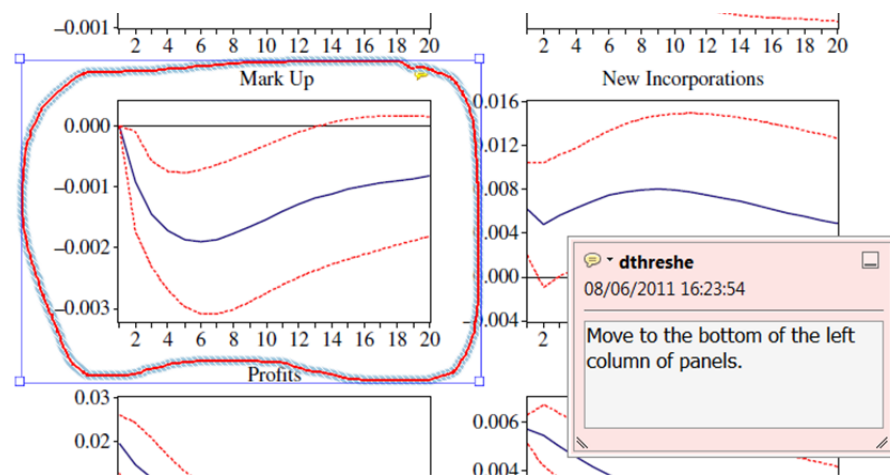


**7. Drawing Markups Tools – for drawing shapes, lines and freeform annotations on proofs and commenting on these marks.**

Allows shapes, lines and freeform annotations to be drawn on proofs and for comment to be made on these marks..

**How to use it**

- Click on one of the shapes in the [Drawing Markups](#) section.
- Click on the proof at the relevant point and draw the selected shape with the cursor.
- To add a comment to the drawn shape, move the cursor over the shape until an arrowhead appears.
- Double click on the shape and type any text in the red box that appears.



For further information on how to annotate proofs, click on the [Help](#) menu to reveal a list of further options:

