A Pricing Model for the Generalized DiffServ Architecture

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Net Neutrality and the Fallacy of a Regulatory Market Split

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Net Neutrality Regulation ante portas in Europe

- September 2013: European Commission issued a proposal including a net neutrality regulation
  - The proposal is still going through the legislative procedure
  - approved (with some adjustments) on April 3rd 2014 by the European Parliament in the first reading

- Especially articles 23 and 24 consider the implementation of a net neutrality regulation

- Article 23(2) includes a **regulatory market split** allowing the provision of specialized services endowed with higher and guaranteed levels of traffic quality as long as general best effort traffic quality is not impaired “in a recurring or continuous manner” (EC 2013)

Starting Point (1)

- Net neutrality in broadband Internet requires that providers of traffic services are allowed to determine capacity allocation by means of price and quality differentiation strategies in order to meet the needs of heterogeneous users

- The implementation of a market driven net neutrality hence requires that each application service is priced according to the opportunity costs of used traffic capacities

Starting Point (2)

Knieps (2011): Interclass Externality Pricing

In a scenario in which differentiated levels of traffic quality are provided in different traffic classes based on prioritization strategies, a pricing scheme based on the opportunity costs of additional data packets in higher classes which are strongly determined by the delays imposed on the data packets in the lower quality classes (interclass externalities) is developed

- **Specialized services were not considered here**

Starting Point (3)

Knieps (2013): Generalized DiffServ Architecture

- Capable of providing an adequate toolkit for tailor-made quality differentiations by **combining resource reservation strategies with strategies based on prioritization**
- Continuum of active traffic management strategies can cater for different degrees and characteristics of heterogeneity in demand for traffic quality
- Technical foundations specified in several RFCs, e.g. RFC 4594 (Babiarz et al. 2006)

Motivation (1)

- As the provision of “public” Internet traffic services and specialized services require the same resources (traffic capacities), capacity allocation between these service types produces a rivalry situation

- Introducing a pricing model based on the multipurpose Generalized DiffServ architecure, we can illustrate the effect of a marginal increase in bandwidth reservation for the provision of specialized services on “public” Internet traffic services

Motivation (2)

- Whereas in the context of pure DiffServ architecture an incentive compatible pricing scheme has been developed based on interclass externality pricing, **we extend this pricing model to fit a Generalized DiffServ architecture**
    - **The more general principle of rivalry for network resources used for different traffic classes can be applied**
        - **Opportunity costs of network usage**

A Pricing Model for the Generalized DiffServ architecture (1)

- Analysis of capacity allocation problem of an arbitrarily chosen traffic service provider under competition

- There are n traffic classes:
  - Data packets are classified and grouped into different traffic classes
  - Data traffic belonging to traffic class i in period t: $\boldsymbol{Q_{it}}$
  - Traffic class i with deterministic traffic quality: $\boldsymbol{i = 1, \dots, m}$
  - Traffic class j without deterministic traffic quality: $\boldsymbol{j = m + 1, \dots, n}$
  - We consider time periods $t = 1, \dots, T$

A Pricing Model for the Generalized DiffServ architecture (2)

- Capacity (measured in bandwidth)
  - Total traffic capacity (bandwidth): $\boldsymbol{w}$
    - Share of reserved capacity for traffic class i giving deterministic guarantees for traffic quality: $\boldsymbol{w_i}\ with\ i = 1, \dots, m$
    - Total share of capacity reserved for deterministic traffic classes: $\boldsymbol{0 \leq \sum_{i=1}^{m} w_i \leq w}$
    - Residual capacity $\boldsymbol{w^r = w - \sum_{i=1}^{m} w_i}$ is used for the provision of non-deterministic traffic classes $j = m+1, \dots, n$
  - Total cost of capacity: $\boldsymbol{\rho(w)}$
    - As we model a multipurpose architecture, gains from multiplexing are ensured as all traffic classes use the same resource pool $\boldsymbol{w}$:
    - E.g. in the case of two traffic classes (one with deterministic guarantees w.r.t. traffic quality: $\boldsymbol{\rho(w) < \rho(w_1) + \rho(w - w_1)}$

A Pricing Model for the Generalized DiffServ architecture (3)

- Inverse demand functions for bandwidth reservation not varying over time:

  - In traffic classes $i = 1, \dots, m$ "bandwidth" is sold and reserved
  - It is used for the provision of traffic services endowed with guarantees for specific levels of traffic quality irrespective if actual usage
  - Reserved bandwidth reduces residual (available) bandwidth for subsequent traffic classes
  - The corresponding demand functions for bandwidth in traffic class i in period t are denoted:

$$\boldsymbol{P_{it}} \equiv \boldsymbol{P_i}(\boldsymbol{w_i})\ \forall\ \boldsymbol{t}$$

A Pricing Model for the Generalized DiffServ architecture (4)

- Inverse demand functions for aggregated traffic in traffic class j:
  - Based on residual bandwidth $\boldsymbol{w^r} = \boldsymbol{w} - \sum_{\boldsymbol{i=1}}^{\boldsymbol{m}} \boldsymbol{w_i}$ traffic services in traffic classes j= $m+1, \dots, n$ are provided and corresponding inverse demand functions for aggregate traffic in period t are denoted by:

$$\boldsymbol{P_{jt}(Q_{jt})}$$

  - Data packets belonging to higher traffic classes are strictly prioritized vis-à-vis data packets belonging to lower traffic classes

A Pricing Model for the Generalized DiffServ architecture (5)

Variable costs of transmission of a packet in traffic class j in period t:

$$k_{jt}(Q_{m+1t}, \ldots, Q_{nt}, w - \sum_{i=1}^{m} w_i \quad)$$

- A **marginal increase in bandwidth reservation in traffic class i leads to an upward shift in $\boldsymbol{k_{jt}}(\cdot)$**, $i.e.$

$$\frac{\partial k_{jt}(\cdot, w - \sum_{i=1}^{m} w_i \quad)}{\partial w_i} > 0$$

A Pricing Model for the Generalized DiffServ architecture (6)

Variable costs of transmission of a packet in traffic class *j* in period *t:*

$$k_{jt}(Q_{m+1t}, \dots, Q_{nt}, w - \sum_{i=1}^{m} w_i \quad)$$

- Given constant capacity, an increase in traffic flows in traffic channel j in period t slows down any data packet in this traffic class:

$$\frac{\partial k_{jt}(\cdot, w - \sum_{i=1}^{m} w_i \quad)}{\partial Q_{jt}} > 0 \; \forall \, j = m+1, \dots, n \text{ and}$$

- Data packets in downstream traffic classes:

$$\frac{\partial \partial k_{kt}(\cdot, w - \sum_{i=1}^{m} w_i \quad)}{\partial Q_{jt}} > 0 \; \forall \, j \neq k \; with \; k > j$$

A Pricing Model for the Generalized DiffServ architecture (7)

Resulting marginal externality costs consist of:

- Marginal intraclass externality costs:

$$\frac{\partial k_{jt}(\cdot, w - \sum_{i=1}^{m} w_i \;)}{\partial Q_{jt}} Q_{jt} > 0 \text{ and}$$

- Marginal interclass externalities costs:

$$\sum_{\substack{k=j+1 \\ k \neq j}}^{n} \frac{\partial k_{kt}(\cdot, w - \sum_{i=1}^{m} w_i \;)}{\partial Q_{jt}} Q_{kt} > 0$$

A Pricing Model for the Generalized DiffServ architecture – Case (1)

- Special case with three traffic classes:
  - **Traffic class 1:**
    - Designed to cater demand for highly quality-sensitive application services (e.g. video conferences)
    - Similar to **specialized services**, it provides deterministic guarantees for pre-specified levels of (minimum) traffic quality (***hard QoS***) irrespective of actual usage
    - Implementation by means of **resource reservation** (and strict admission control

A Pricing Model for the Generalized DiffServ architecture – Case (2)

– **Traffic class 1:**

- In our case, a **share of capacity is exclusively reserved** for traffic class 1:

$$\mathbf{0 \leq w_1 \leq 1}$$

- The **residual capacity** can thus be used for service provision in traffic classes 2 and 3:

$$w^r = w - w_1$$

A Pricing Model for the Generalized DiffServ architecture – Case (3)

– **Traffic class 1:**

- Traffic class 1 is the only traffic class which guarantees minimum traffic qualities on a deterministic basis

- The corresponding **inverse demand function** for bandwidth reservation in period t is denoted:

$$P_{1t} \equiv P_1(w_1) \; \forall \, t$$

➢ Corresponding opportunity costs result from reflect traffic quality ensured by means of resource reservation

A Pricing Model for the Generalized DiffServ architecture - Case (4)

– **Traffic class 2 (based on bandwidth $w - w_1$):**

- Designed to cater demand for rather quality-sensitive application services (e.g. video streaming)
- Desirable levels of (minimum) traffic quality are based on statistical probabilities (***soft QoS***)
- This is achieved by strict prioritization vis-à-vis traffic class 3
- The corresponding **inverse demand function** for aggregate traffic in class 2 in period t is denoted:

$$P_{2t}(Q_{2t})$$

A Pricing Model for the Generalized DiffServ architecture - Case (5)

- **Traffic class 3 (based on bandwidth $w - w_1$):**

- Designed to cater demand for rather quality-tolerant application services (e.g. email)

- There are no guarantees for pre-specified levels of (minimum) traffic quality (***best effort***)

- The corresponding **inverse demand function** for aggregate traffic in class 3 in period t is denoted:

$$P_{3t}(Q_{3t})$$

A Pricing Model for the Generalized DiffServ architecture – Case (6)

In a competitive environment the welfare maximization problem is defined by:

$$\max_{(Q_{2t}, Q_{3t}, w_1, w)} S$$

$$= \int_0^{w_1} P_1(\widetilde{w}_1) d\widetilde{w}_1 + \sum_{t=1}^{T} \left[\int_0^{Q_{2t}} P_{2t}(\tilde{Q}_{2t}) d\tilde{Q}_{2t} + \int_0^{Q_{3t}} P_{3t}(\tilde{Q}_{3t}) d\tilde{Q}_{3t} \right]$$

$$- \sum_{t=1}^{T} [k_{2t}(Q_{2t}, w - w_1) Q_{2t} + k_{3t}(Q_{2t}, Q_{3t}, w - w_1) Q_{3t}] - \rho(w)$$

A Pricing Model for the Generalized DiffServ architecture – Case (7)

- Necessary conditions for the resulting welfare maximum can be derived by differentiating w.r.t. w_1, Q_{2t}, Q_{3t} for each $t = 1, \dots, T$ and w.r.t. and w
- We can derive optimal pricing rules based on the opportunity costs for packet transmission in each traffic class

A Pricing Model for the Generalized DiffServ architecture - Case (8)

Optimal price for traffic class 1:

- Irrespective of actual traffic flows Q_{1t} the negative externality on lower traffic classes is solely determined by the share of reserved bandwidth w_1

$$\tau_1 = P_1 = \frac{\partial k_{2t}(Q_{2t}, w - w_1)}{\partial w_1} Q_{2t} + \frac{\partial k_{3t}(Q_{2t}, Q_{3t}, w - w_1)}{\partial w_1} Q_{3t}$$

$$with\text{: } \frac{\partial k_{2t}(Q_{2t}, w-w_1)}{\partial w_1} > 0 \text{ and } \frac{\partial k_{3t}(Q_{2t}, Q_{3t}, w-w_1)}{\partial w_1} > 0$$

A Pricing Model for the Generalized DiffServ architecture - Example (9)

Optimal congestion fee for traffic class 2:

- The optimal congestion fee depends both on intraclass and interclass externalities

$$\tau_{2t} = P_{2t} - k_{2t}(Q_{2t}, w - w_1)$$

$$= \underbrace{\frac{\partial k_{2t}(Q_{2t}, w - w_1)}{\partial Q_{2t}} Q_{2t}}_{\text{Intraclass externalities}} + \underbrace{\frac{\partial k_{3t}(Q_{2t}, Q_{3t}, w - w_1)}{\partial Q_{2t}} Q_{3t}}_{\text{Interclass externalities}}$$

A Pricing Model for the Generalized DiffServ architecture - Example (10)

Optimal congestion fee for traffic class 3:

$$\tau_{3t} = P_{3t} - k_{3t}(Q_{2t}, Q_{3t}, w - w_1) = \frac{\partial k_{3t}(Q_{2t}, Q_{3t}, w - w_1)}{\partial Q_{3t}} Q_{3t}$$

A Pricing Model for the Generalized DiffServ architecture - Example (11)

- **Optimal investment rule:**

$$\frac{\partial \rho}{\partial w} = -\sum_{t=1}^{T}\left[\frac{\partial k_{2t}(Q_{2t}, w - w_1)}{\partial w} Q_{2t} + \frac{\partial k_{3t}(Q_{2t}, Q_{3t}, w - w_1)}{\partial w} Q_{3t}\right]$$

- Due to deterministic traffic qualities, there is no benefit from capacity expansion and thus investment in traffic class 1
    - ➢ A marginal increase in reserved bandwidth w_1 cannot generate benefits to traffic class 1 but would rather constitute a waste of resources

A Pricing Model for the Generalized DiffServ architecture - Example (12)

- **Conclusion of the Model :**

- The opportunity costs of a marginal increase in bandwidth reservation w_1 in traffic class 1 on subsequent traffic classes 2 and 3 are equal to a corresponding increase in private average variable costs
  - Shift in $k_{2t}(Q_{2t}, w - w_1)$ and $k_{3t}(Q_{2t}, Q_{3t}, w - w_1)$

- The optimal bandwith dimension is solely determined by the marginal benefits of capacity expansion in traffic classes 2 and 3

Implications & Conclusions (1)

- The provision of specialized services cannot be considered isolated and thus outside the public Internet
- Rather, they are necessarily provided inside the Internet based on a common resource pool
- Any IP-based data transmission ultimately requires the use of the same traffic capacities irrespective which application services they are serving as inputs for

Implications & Conclusions (2)

- The regulatory market split in TCP/IP-based best effort traffic services in the public Internet and quality-ensured specialized services is artificial and hampers entrepreneurial search processes for the efficient provision of the heterogeneous demand for traffic qualities

- The recent proposal for a net neutrality regulation turns out to be a fallacy

- The resulting market split leads to economical inefficiencies and can by no means prove stable in a competitive environment

References

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Implications & Conclusions (ext.)

- From network economic perspective, only a price and quality differentiation strategy based on the opportunity costs of traffic capacity can be stable
- Best effort TCP cannot provide required differentiations reflecting heterogeneous demands for traffic quality
- A transition to a more “intelligent” Internet architecture based on active traffic management for all data traffic is inevitable
- The Generalized DiffServ architecture enables the provision of a multitude of heterogeneous application services

Net Neutrality Debate in the U.S.

2005

Madison River v FCC

2006

Beginning of issuing proposals in Congress, e.g. "Net Neutrality Act"

2008

Comcast v FCC

2009

FCC's *Open Internet Order*:

- future role of net neutrality regulation
- „reasonable" vs. „unreasonable" traffic management
- role of „specialized services"

2010

D.C. Circuit struck down FCC's sanction vis-à-vis Comcast

2013

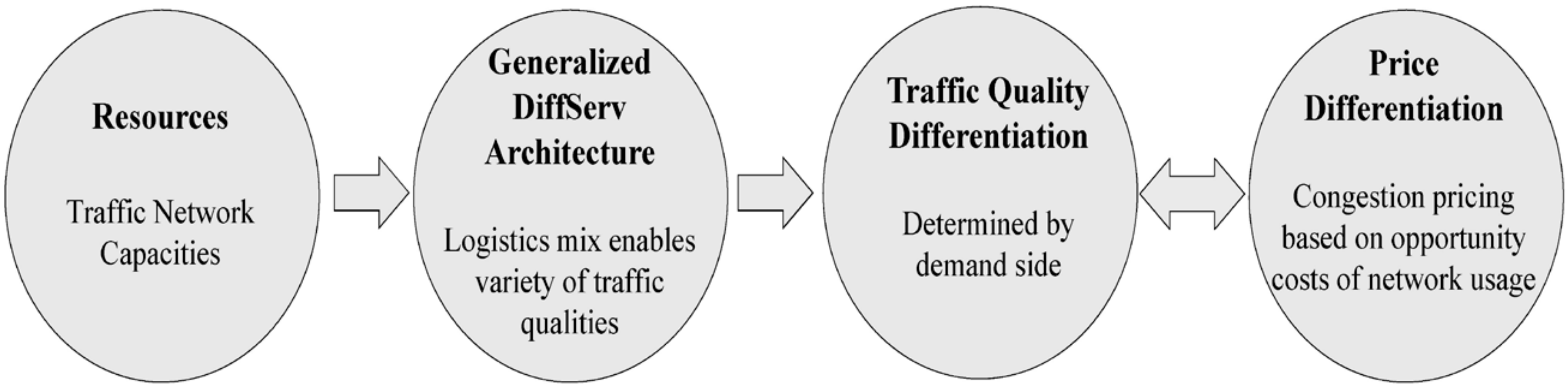
2014

D.C. Circuit struck down parts of FCC's *Open Internet Order*

FCC's latest proposal for regulation from May 15^{th} 2014

Market driven net neutrality and the Generalized DiffServ architecture (3)

- Generalized DiffServ architecture:



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