Title:
A Note on Interaction Models for Heterogeneous Network QoS Systems

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Abstract: A homogeneous solution to provide end-to-end network Quality of Service (QoS) within the inherently heterogeneous Internet is not in sight. Therefore, the basic interaction models for heterogeneous network QoS systems are discussed and a case for an overlay model is made which is substantiated by weakening its main counter-argument - scalability.

Introduction: Heterogeneity in network QoS systems comes in manifold forms. Yet, as the only interesting scope of service to the user is a seamless end-to-end communication, this heterogeneity must be mapped into interaction models between the heterogeneous systems. The central component of interworking between different QoS systems is the *edge device*. Edge devices are located at the borders between network QoS systems and mediate between the different characteristics and mechanisms of these systems. Very frequently QoS systems are layered on top of each other. This kind of interaction is therefore given special attention.

Communication Patterns & Edge Devices: The basic scenarios and building blocks for the interworking of two different QoS systems lying on an end-to-end transmission path of a distributed application are depicted in Figure 1. Two communication patterns or data transmission types can be distinguished. In data transmission type A, sender and receiver are both connected to QoS system I but this system is overlaid on top of QoS system II. The resulting interaction between the QoS systems I and II is therefore called *overlay model*. For a data transmission of type B, the sender is connected to QoS system I while the receiver is connected to QoS system II. This kind of interaction between the QoS systems is denoted as *peer model*.

As illustrated in Figure 1, the central components for the interaction between different QoS systems are so-called edge devices. These “know” both QoS systems and can therefore mediate between different QoS architectures or strategies. For the overlay model they always appear in pairs as ingress and egress edge devices, thus effectively establishing a *QoS tunnel* through another (transit) QoS system.

Interaction Models: Let us return to the interaction models that have been identified above by looking at different communication patterns: the overlay and the peer model (see again Figure 1). The peer model is the more general of both as the overlay model could be decomposed into two peer interactions. However, it is easy to see that the peer model involves much more complexities than the overlay model, especially if the data forwarding technologies of the QoS systems are different. For example, if one of the peering QoS systems uses ATM and the other one uses RSVP/IntServ, then very basic communication system functionality like data forwarding, routing, and addressing needs to be *translated* between the two systems whereas for the overlay model a *mapping* is sufficient to establish a QoS tunnel. Obviously, the coupling between different QoS systems is much looser in the overlay model than in the peer model. This is usually regarded as a good characteristic of any system design which essentially leads to the conclusion that the overlay model is the more elegant solution. For an extensive discussion of peer vs. overlay models for the specific interaction between the RSVP/IntServ and ATM QoS architectures, see [1].

Layered QoS Systems: Due to the complexities of the peer model we restrict our view to layered QoS systems. Furthermore, we argue that a situation where the peer model is applicable can usually be easily resolved by adding a minimal convergence layer to end-systems. A simple example of this is IP/ATM interworking for best-effort data forwarding, where an ATM-attached host runs Classical IP over ATM [2] instead of a solution where edge devices are acting as gateways which are doing a full translation between the different communication systems. As a further example, in the case of heterogeneous network QoS systems this minimal convergence layer could be formed by an extended RSVP as a general signalling interface and thus a minimal glue between different QoS systems. Such a model has been described in [3].

There is one potential drawback of layered QoS systems that is often put forward in discussions about overlay models - *scalability*. Let us look at that in more detail since it has been raised as main counter-argument against the overlay model [4].

Scalability of Layered QoS Systems: In general for layered QoS systems, if the underlying system becomes large, then it has to keep track of many “associations” between edge devices. More specifically, the number of associations grows quadratically in the number of edge devices. By associations we mean, e.g., traffic trunks between edge devices but it could also be RSVP state as described in [4], where it is argued that RSVP is not suited for backbone usage because of its N^2 property, which is due to the fact that RSVP state is depending on sender and receiver. For the purpose of our discussion let us assume associations are bidirectional traffic trunks or QoS tunnels between pairs of edge devices. Thus, if we have N edge devices, we have in the worst-case $T = N/2 \times (N-1)$ traffic trunks. So, it can be seen that the traffic trunking problem exhibits the N^2 problem for the underlying QoS system. However, a solution to this potential scalability problem of the overlay model is the introduction of cooperation between edge devices by establishing so-called *trunking groups*. For these trunking groups, it applies that edge devices within a trunking group can establish direct trunks with each other whereas for communication between different trunking groups a route via a *trunking group leader* (which needs to be elected by some protocol mechanism during setup of the edge devices) must be taken. Let n be the number of trunking groups. Obviously, through the structure introduced by trunking groups, the overall number of trunks (T) can be reduced. The following theorem states how much can be gained by an optimal coordination between edge devices with respect to the worst-case complexity of the trunking problem.

Theorem 1: Optimal coordination between N edge devices reduces the worst-case complexity of the trunking problem from $O(N^2)$ to $O(N^{4/3})$. The optimal number of trunk groups is approximately $\sqrt[3]{N^2/2}$.

Proof: It is easy to show that equally sized trunk groups are optimal with respect to the overall number of trunks. Therefore the number of trunks of the coordinated system with n trunking groups is

$$T(n) = \frac{n}{2}(n-1) + n\left(\frac{N}{2n}\left(\frac{N}{n}-1\right)\right) = \frac{n}{2}(n-1) + \frac{N}{2}\left(\frac{N}{n}-1\right) \tag{1}$$

$T(n)$ shall be minimized, therefore we solve the equation

$$T'(n) = n - \frac{N^2}{2n^2} - \frac{1}{2} = 0 \Leftrightarrow 2n^3 - n^2 - N^2 = 0 \quad \forall n > 0 , \tag{2}$$

which solution is the minimum since $T''(n) = 1 + \frac{N^2}{n^3} > 0 \quad \forall n > 0$.

The only solution (since the discriminate is greater than 0) to (2) is

$$n^{opt} = \frac{1}{3} + \sqrt[3]{\alpha + \sqrt{\alpha^2 + \frac{1}{46656}}} + \sqrt[3]{\alpha - \sqrt{\alpha^2 + \frac{1}{46656}}} \text{ with } \alpha = \frac{1}{4}\left(N^2 + \frac{2}{216}\right) \tag{3}$$

An accurate approximation is therefore given by

$$n^{opt} \approx \sqrt[3]{N^2/2} , \tag{4}$$

which proves the second part of the theorem.

The first part is obtained by calculating $T(n^{opt})$

$$T(n^{opt}) = \sqrt[3]{N^4}\left(\sqrt[3]{\frac{1}{32}} + \sqrt[3]{\frac{1}{4}}\right) - \sqrt[3]{\frac{N^2}{2}} - \frac{N}{2} = O(N^{4/3}) \qquad (5)$$

■

In Figure 2, the growth of the overall number of trunks over the underlying QoS system is shown for different numbers of edge devices. If it is found that even the coordinated scheme is not scalable enough, then the procedure can be applied recursively to obtain a further reduction of the worst-case scalability.

Summary: In a general discussion on the respective architectural merits of the overlay and peer model for the interaction between heterogeneous network QoS systems we concluded that the overlay model is the more elegant solution. However, the overlay model is often criticised for its scalability characteristics. By means of a basic analysis it was illustrated that these concerns are not necessarily a problem if edge devices are allowed to cooperate since thus its complexity growth can be decreased from $O(N^2)$ to $O(N^{4/3})$.

References:

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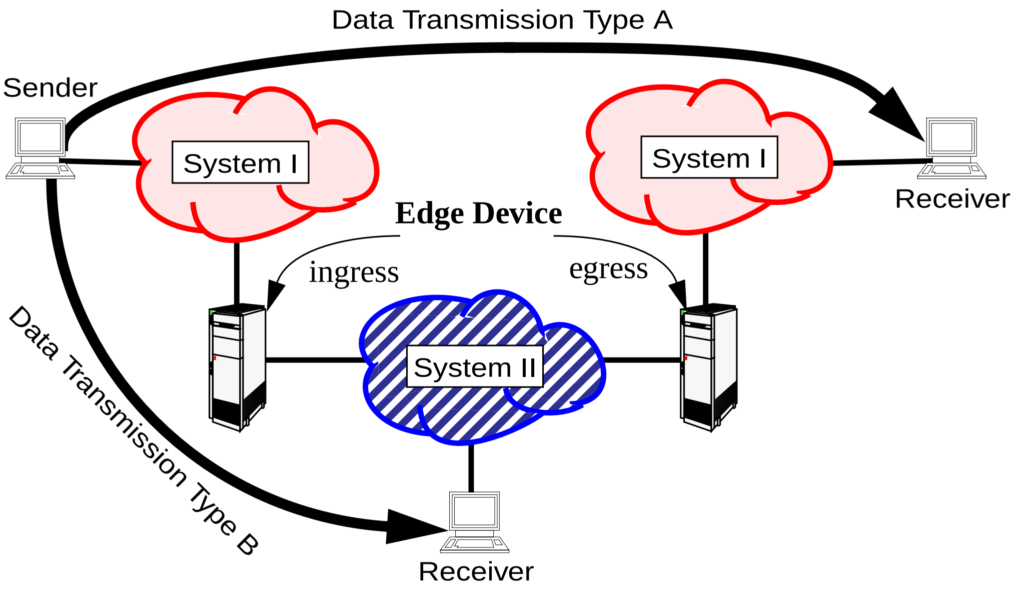
Figures:

Figure 1: Communication patterns and interaction models.

Figure 2: Coordination of edge devices.



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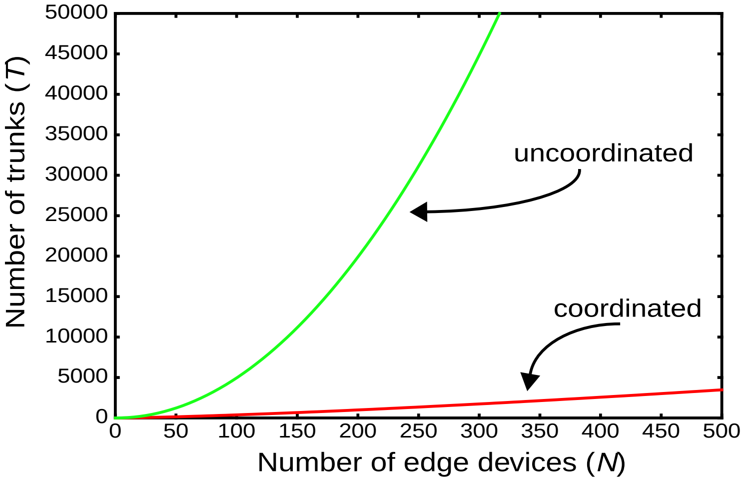

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