Tariff Dependent Error Control for Heterogeneous Real-Time Multicast Services

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Abstract

Multicast transport of audio and video is becoming an important application for IP-based networks. Application-level QoS requirements can be met by network-layer QoS provision, by transport-layer error control, or by a combination of both. Which approach is most suitable depends on the tariffs set by the provider for network services with different QoS, the overhead introduced by error control, and the user requirements.
In this paper we introduce an architecture that provides QoS support for audio and video in heterogeneous multicast scenarios by combining network layer QoS with transport layer QoS enhancement by Forward Error Correction (FEC). We present the Charging Information Protocol (CIP) for the distribution of tariff information. For the representation of tariff information the Tariff Formula Language (TFL) is defined. We introduce the utility-price optimization tool to select the best combination of IP service and transport layer error control based on user preferences and charging information. User preferences describe quality requirements and price limits in terms of a utility function. The optimization tool is supported by loss measurements, allowing to react to changing network conditions.

Keywords

Multicast, Real-Time, RTP, FEC, Tariffing, Charging and Accounting

1 Introduction

In order to meet the requirements of a real-time application, it is possible to use a network service that directly provides the required QoS. Two service models for QoS-enhanced IP services have been deployed within the IETF: Integrated Services (IntServ) and Differentiated Services (DiffServ).
In a non-cooperative environment, QoS-enhanced IP services require charging and accounting in order to give incentives to the users to limit the usage of premium quality IP. A large number of approaches have been presented on charging of IP services. Among these are Clark and Fang who propose an approach called Expected Capacity Framework which does not only provide usage sensitive pricing but also introduces soft QoS guarantees [ClFa97]. In [MacK97], it is shown how the auction-based "Smart Market" approach with dynamic pricing can be applied to flow reservation. In [FaSP98] an example implementation of a pricing and charging system for reservation in an RSVP-based Internet is presented. In [KaSW99], models for deriving costs from an IntServ flow specification are given. For multicast communication, cost splitting between receivers is a desired feature especially for groups with heterogeneous QoS, for which RSVP-based solutions are presented in [HeSE95].

Since users typically try to reduce their costs, charging for QoS-enhanced IP services gives an incentive to reserve only the required quality. A further way of reducing cost is to use cheap network services that do not directly meet reliability requirements of the application, and to apply transport level error control in order to reduce the impact of packet loss to a level which is acceptable by the user. For audio and video transport using RTP [RFC1889], an FEC scheme based on Reed-Solomon codes can be deployed [CaBi97, RoSc98].
For networks that support QoS and for end systems that support FEC, the problem of choosing the right service and dimensioning of FEC can become a challenging task.
In this paper we describe an architecture that allows a tariff dependent selection of IP QoS and the amount of redundancy for transport layer error control. The selection of the service that meets user requirements with the best utility-price ratio is supported by a tool that allows to process utility functions and tariff information. Chapter 2 gives a short introduction to charging for best effort and integrated services and introduces the tariff formula language. The mechanisms to use FEC for end-to-end QoS enhancement for unicast and multicast data flows are shown in chapter 3. Chapter 4 gives an overview of the charging information protocol (CIP) that informs users about offered services and tariffs. Chapter 5 presents the utility-price optimizer that can be used to find an appropriate service selection.

2 Charging for Multiple Service Class Networks

In this chapter we introduce charging schemes for best effort IP services and for IP services with QoS support. The tariff formula language (TFL) is used to express tariffs.

2.1 Charging for Best Effort IP Services

Approaches to charge for best effort services range from the simple flat rate scheme over volume based approaches to complex congestion based charging schemes. Flat rate charges are simple, predictable, easy to understand and require no accounting effort. On the other hand, flat rates cause unfairness for heterogeneous user groups. As users pay the same regardless of their resource usage, lightweight users subsidize heavy users.
Volume based charging may reflect resource usage by best effort traffic. A possible charging formula for best effort traffic is introduced in [FeDe98], which is based on the number of transmitted bytes V and the number of hops between sender and receiver h:

$$C = K_{BE} \cdot h \cdot V \qquad (2)$$

K_{BE} denotes the usage charge coefficient for best effort. The number of hops may be considered as relevant because resources are used in each router.
A congestion based approach for charging of IP services is presented in [MacK97]. The approach is based on the assumption that network costs are primarily fixed costs and that the additional transmission of a packet does not incur further costs. Only in times of congestion an additional transmission of a packet influences the overall welfare and therefore causes social costs which should be expressed in a congestion based charge. With congestion based schemes, optimal prices can be set that optimize the network utilization and therefore avoid congestion.

2.2 Charging for Integrated Services

In the presence of reservation, charges can be applied to both, reservation of resources, and usage of resources. Since the reservation of resources can prevent further reservation, charging for the reservation is needed even in the absence of traffic. As resources not used by reserved flows can be used by best-effort traffic, it can be justified to charge in addition to reservation also for usage. This approach rewards users which do not fully use their reserved rate.
In [FeDe98] a charging formula based on a reservation charge and a usage charge is presented, that takes the three resources buffer space B, computing capacity C and schedulability D (delay resource) into account. Furthermore, the charges depend on the duration (lifetime L) of the connection and the number of hops h between sender and receiver:

$$C = L \cdot \sum_{i=1}^{h} \big(b \cdot P(B) + c \cdot P(C) + d \cdot P(D)\big) + K_{IS} \cdot h \cdot V \qquad (3)$$

P(B), P(C) and P(D) denote the price for buffer space, computing capacity and schedulability, respectively. The fraction of the resources in each hop is represented by the factors b, c and d. The parameter K_{IS} denote the usage charge coefficient.
The approach in [KaSW99] bases the charging on the resources rate and buffer space. The authors show that for today's low memory prices, it is sufficient to focus on bandwidth while neglecting buffer space. The authors define three virtual resource parameters: token rate q_T, clearing rate q_C and residual rate q_R, which can be determined using the two IntServ rate parameters r and R. The following formulas allow to calculate the charge from the reservation parameters for guaranteed services (C_G), controlled load (C_{CL}) and guaranteed rate (C_{GR}):

$$\begin{aligned} C_G &= a \cdot r + b \cdot (R - r) \\ C_{CL} &= a \cdot r + c \cdot e \\ C_{GR} &= c \cdot r \end{aligned} \qquad (4)$$

The parameter e denotes the extra rate that is statistically available occasionally for controlled load flows in addition to the token rate represented by r. The coefficients a, b and c represent the prices per resource unit and are set equal to the costs.

2.3 Tariff Formula Language

A tariff contains the information on how the price of a service is calculated. It includes not only the charging scheme needed to calculate the current price (for the current time of day, network situation etc.) but also the general rules (how would the price be in a later time period etc.). That means a tariff can consist of multiple charging formulas and some rules under which conditions each formula is valid. An example would be to have different formulas for business hours than for the night time.
For the representation of tariffs we have developed the Tariff Formula Language (TFL). This context-free language contains essential mathematical operations (e.g. addition, multiplication) and basic mathematical and logical functions (e.g. exponential function, square root, AND, OR etc.). Furthermore, conditional expressions (if/then/else) allow to express the variation of prices for different time phases. A set of commonly used charging variables (including volume, duration, time of day) are pre-defined. The TFL provides a

simple structured way to represent even complex tariffs. Tariffs are expressed in plain ASCII characters and therefore easy to parse and human-readable.
A TFL expression consists of one or more lines. In the following an example for a volume (v) and time (t) based tariff expressed in TFL is given, where the price for a time unit is based on the time of the day (variable td):

```
# setup charge
sc = 0.5
# volume unit in bytes
vu = 800000
# price per volume unit
pv = 0.5
# time unit in secs
tu = 100
# price per time unit
pt = IF(AND(td>=TIME("00:00:00"),
td<TIME("05:00:00")), 0.5,
IF(AND(td>=TIME("05:00:00"),
td<TIME("21:00:00"), 0.8, 0.5))
# tariff formula
p = sc + (v/vu)*pv + (t/tu)*pt
```

The formula from [KaSW99] for guaranteed services expressed in TFL is given in the example below. The globally defined variables tr and sr denote the reserved token bucket rate (r) and the service rate (R), respectively.

```
# parameter a
a = 0.5
# parameter b
b = 0.2
# tariff formula
p = a*tr + b * (sr-tr)
```

3 FEC for End to End QoS Improvement

Resource reservation may be an expensive way to increase the quality of a flow. Using error control mechanisms provides a further possibility to increase end-to-end quality without the need for signaling protocols and state keeping in network nodes. For certain applications loss reduction by transport layer error control is an attractive alternative to network layer resource reservation.
Under consideration of the charging schemes proposed for best effort and IP integrated services (chapter 2), error control can provide a cheap alternative to resource reservation. If volume-based charges are applied for best effort, the increase of bandwidth due to the sending of redundancy must be taken into account for the optimization (see chapter 5).
Error control is a lightweight possibility to improve quality. It can solve a set of partial problems, but is limited in its capabilities. Error control reduces loss at the expense of increased delay due to additional transmission of redundancy and required processing time for coding and decoding. Redundancy packets increase the overall network load. Therefore sending of additional packets in times of congestion can cause a deterioration of the network situation. In order to limit the amount of redundancy a TCP-friendly rate adaptation algorithm can be applied [PaWa98].
The choice of the optimal amount of redundancy depends on user preferences (a utility function reflecting quality requirements and price limit), tariffs and current network

conditions. FEC provisioning and choice of FEC parameters differ between unicast and multicast, so we treat these cases separately.

3.1 Unicast Case

In the unicast case, redundancy can be sent using the same flow as the data traffic, or using a separate flow. The amount of redundancy can be adapted individually to the requirements and preferences of the receiver. All possible parameters of the FEC scheme can be specified individually. In our scheme, the receiver explicitly defines n and k, based on its loss measurements, and sends this information to the FEC process. For this control message we use UDP with a well known port.

3.2 Multicast Case

Provisioning of FEC in the multicast case is more complex. Receivers may have different loss probabilities on their access links, and users may have different application level QoS requirements. That leads to a situation where members of the same group may desire different FEC values. If the redundancy is sent on the base layer, the choice of the optimal amount of redundancy in a heterogeneous environment becomes difficult. Possible solutions are to use the highest desired value of the user preferences, or a mean value. Nevertheless, with this model individual adaptation to heterogeneous network conditions are not possible. Furthermore, charging becomes difficult, because receivers may not want to pay for a redundancy they did not order.

A possibility to avoid this problem is the provisioning of FEC using separate layers. Redundancy is not sent to the base layer but to additional multicast groups. Receivers that like to receive redundancy packets just join one or more groups on which redundancy is presented. We consider three possibilities to provide redundancy on separate multicast groups [RhJL99]:

- Static constant: Layers carry a fixed percentage of redundancy. The difference between the layers is constant (equal steps) (e.g. each layer carries 5% redundancy).
- Static variable: Layers carry a fixed percentage of redundancy. The difference between the layers is not constant (unequal steps) (e.g. layer1=2%,layer2=5%, layer2=10%).
- Dynamic: The amount of redundancy that the layers carry is chosen dynamically.

With the static constant approach receivers can chose for example to get 5% redundancy by joining one group or to increase the redundancy to 10 % by joining an additional layer. This reduces the granularity of the FEC parameter choice. On the other hand this parameter limitation reduces the optimization effort. With the static variable approach each layer carries a different percentage of redundancy. The possible combinations lead to a larger amount of possible redundancy values.

In order to design a solution that is more aware of receiver preferences the amount of redundancy on the FEC multicast groups can be adjusted to values based on receiver feedback (dynamic approach). With this approach a suitable policy is needed for choosing the amount of redundancy for certain layers from a set of receiver requests. Rules are required to identify when to increase redundancy on existing layers and when to create a new FEC layer. This problem is similar to the problem to find an appropriate value for the approach to redundancy on the base layer. This problem is addressed in [RhJL99].

4 Charging Information Protocol

Providers frequently adapt their tariffs to the market situation (see current telephone market situation where newspapers hardly can follow up the tariff changes). They may want to offer special rates at times where the network is only lightly loaded. Furthermore, offering of different tariffs for the same service is possible (see business and spare-time tariff models in the mobile phone market). In an environment where multiple providers compete, tariff information gives the basis for a provider selection.
An essential requirement for charging models that comes from users perspective is the predictability of the charge [CANC96] [FeDe98]. In order to keep control over their costs and to choose the optimal service class, users need information about the current tariff.
For this purpose we developed the charging information protocol (CIP). The protocol follows the classical client-server approach. A charging information server maintains the information and distributes it to clients on demand.
The protocol is flexible with regard to the transport protocol. Furthermore, it can be adapted to the special needs of a small or large group of clients by using either unicast or multicast for the announcement of tariff information.

4.1 Announcement of Service Classes and Tariff Information

Distribution of charging information can be done by unicast or multicast transmission. Tariffs for the offered service classes are sent in a sequence of information messages (INFO). In order to allow clients to recognize a loss of a packet, the INFO messages contain sequence numbers. With this numbers it is possible to request a retransmission of lost packets.
If a unicast connection is used for the announcement of tariffs, all clients that want to receive information about current tariffs have to register with the CIP sever first. In the registration request clients can choose between two modes to get information from the server. In the push mode (default setting) information messages are sent periodically to the client. In order to prevent sending to non-existent or non-operational stations, messages are acknowledged by the client.
In the pull mode information is only sent on demand. Clients need to send an request (GET_INFO) in order to get the information messages. In the unicast case CIP uses timeout and retransmissions to provide a reliable transport. Besides the reliability and the possibility to use TCP for transport, unicast distribution allows selective individually adapted advertisements. This means that the information can be reduced to tariffs that are new to a particular client. Furthermore, special offers for certain customers can be easily conveyed individually.

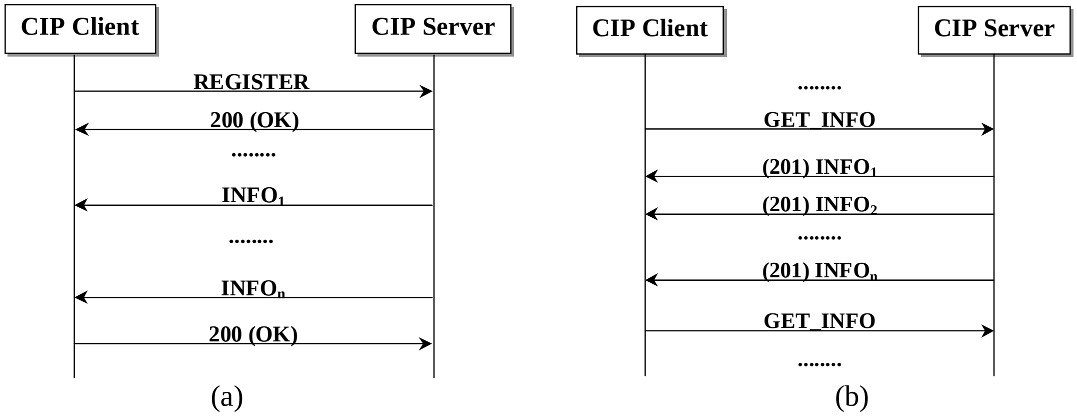

Figure 1: CIP protocol messages for push mode(a) and pull mode(b)

An alternative that provides a better scalability is the distribution of the tariff information via multicast. Clients that want to get charging information just need to join this group. With multicast only the push mode is used. Since no acknowledgements and retransmissions are provided in this case, reliability is lower than for the unicast case. If an INFO message gets lost, the client can recognize this because of the sequence numbers, but he has to wait until a new INFO message is transmitted within the next regular announcement.
The information messages (INFO) contain the following fields:

- Identification (service name, provider)
- Validity
- Tariff
- QoS guarantees
- Information about the reservation
- Transaction ID

The identification field contains the name of the service class and the provider identification. The validity field defines the time interval for which this tariff is valid. This can be used for example to offer special rates only on certain dates (e.g. Christmas special tariff) . The tariff field contains the tariff in TFL. The QoS guarantees give a service description regarding the offered QoS. Furthermore, the message gives information about the mechanism used for the reservation. Each INFO message contains a transaction ID to allow the detection of lost messages.

4.2 Selection of a service

The selection of an IntServ service can be done by sending an RSVP reservation message to the sender. Nevertheless, a service selection mechanism is provided by the CIP in order to inform the CIP sever about the chosen tariff. In order to choose a service, the client sends a SELECT message to the server. The message is acknowledge by the server. SELECT messages are sent until the server responds or a timer exceeds.
This service selection mechanism is especially useful if multiple tariffs are offered for the same service class (for different user groups or from different providers). Furthermore, this allows the control of policy rules, if the CIP server is combined with a policy server that enforces the rules within the network (accept or reject reservation requests). Besides this it is helpful in networks that provide service classes without signaling protocol (e.g. differentiated services). If the charging information is sent via multicast, an additional unicast connection is required to use the selection mechanism.

4.3 Selection of the amount of redundancy

If the user decides to use a best effort service and just wants to add FEC, the receiver communicates the desired FEC parameters (n, k) to the FEC gateway. For this a control message is sent to a dedicated UDP port.
For the multicast case, where original data is sent to a base layer and redundancy to additional multicast groups, receivers only need to join the appropriate multicast group to receive the redundancy. For unicast the FEC parameters n and k can be selected according to the requirements of the receiver. For multicast the offered redundancy with fixed granularity reduces the degrees of freedom for the decision of the receiver.

5 The Utility-Price Optimizer

The possibility of using FEC for meeting reliability requirements as alternative to resource reservation leads to a wide variety of selections for the user. Since selection of the best alternative is not trivial, we developed a utility-price optimizer. This tool helps the user to find the optimal service class choice under consideration of the possibility to use FEC for increasing the quality.
It maximizes the utility-price-ratio (UPR) under consideration of the individual utility function and the offered tariffs. The result is a recommended service class or the suggestion to use BE service and error control with a specific setting of FEC parameters.

5.1 Utility Functions

Utility functions (see e.g. [ReIz97] and [BoFT98]) translate from a given quality of service (e.g. bandwidth, loss) to a degree of satisfaction, or utility. Figure 2 from [ReIz97] shows how the utility of a variable bit rate video application decreases if the actual provided bandwidth falls below the required bandwidth. The satisfaction index reflects the user observation in a more accurate way than the current standards that are based on a binary (yes/no) characterization of the user satisfaction. In [BoFT98] utility curves for the relation between bandwidth and audio quality are presented. The utility is expressed as Mean Opinion Score (MOS) reflecting the subjective observed quality as observed by a chosen set of users.

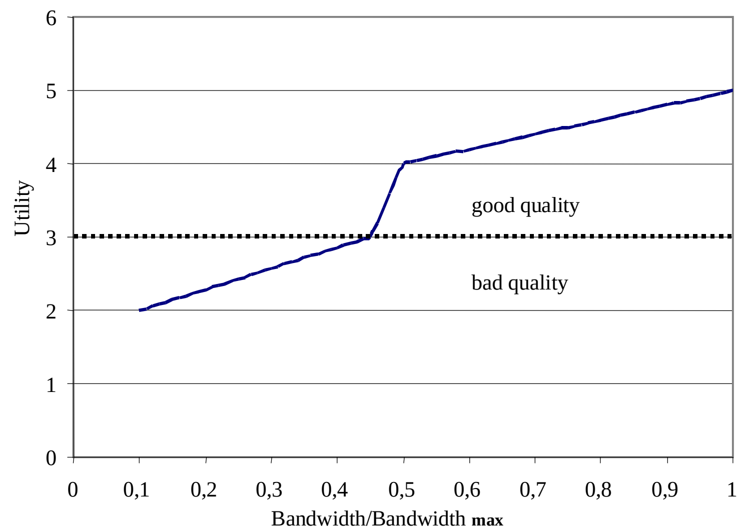

Figure 2: Example utility function for video application

For use within the utility-price optimization tool, we describe utility curves as adjunctive sections of linear functions. For this a subset of the Tariff Formula Language (TFL) is used. The description of the utility function presented in Figure 2 is given below where bn denotes the normalized bandwidth and A,B,C stand for the points on the X-axis where the gradient changes. The expression to describe the curve shown in Figure 2 in TFL is given below.

```
utility = IF(AND(bn>=C, bn<B), 1/(B-C)*bn+2-C/(B-C),
          IF(AND(bn>=B, bn<A), 1/(A-B)*bn+3-B/(A-B),
          IF(AND(bn>=A, bn<=1), 1/(1-A)*bn+4-A/(1-A),-1)))
```

Unlike the simple examples from [ReIz97] and [BoFT98], utility functions can reflect additional factors such as losses (c.f. [GrSt85]).

5.2 Optimization Algorithm

An optimization algorithm is used to maximize the utility-price-ratio UPR. It uses as input a utility curve and the tariff functions of the offered tariffs. Both are specified in TFL. Furthermore, the user can specify a minimum utility u_{min} and a maximum price p_{max}. These values set the boundary conditions for the optimization.
We first consider a simple case where both utility u and price function p depend only on the bandwidth. In this first case the provisioning of FEC is not taken into account.
With his assumptions the problem is reduced to a simple maximum search on the two-dimensional function

$$UPR(B_n) = \frac{u(B_n)}{p(B_n)} \tag{5}$$

with the boundary conditions $u(B_n) \geq u_{min}$ and $p(B_n) \leq p_{max}$. Figure 3 shows an example for the utility function given in [ReIz97] and the UPR under consideration of the following charging scheme:

$$p(B_n) = S + \frac{P_V}{U_V} \cdot B_n \cdot B_{\max} \tag{6}$$

In the formula S denotes the setup charge, U_V the size of a volume unit and P_V the price per volume unit. $B_n * B_{max}$ gives the actual used bandwidth. In our example we set B_{max}= 15900, S=1, U_V= 3000, P_V= 1. The minimum utility u_{min} was set to 2.5 and maximum price p_{max} to 5 (dotted lines in Figure 3). It can be seen that the optimal utility-price-ratio is found at the point where the actual bandwidth is half of the required bandwidth (0.5). It can also be seen that a higher UPR would be possible if the user accepted a lower quality than u_{min}.

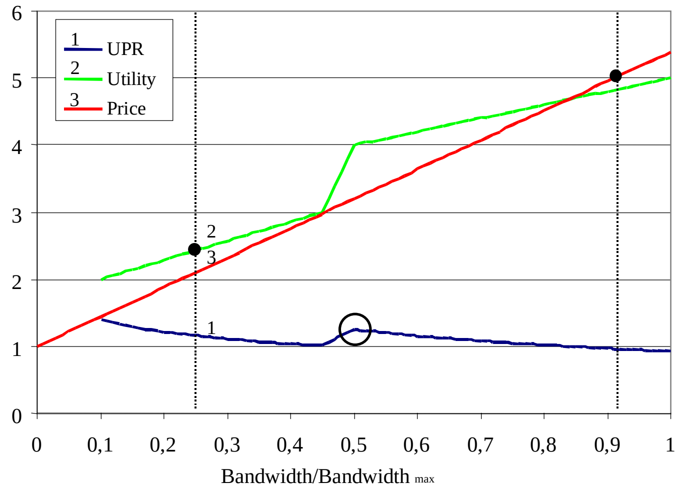

Figure 3: Optimization Example

In order to find the optimal choice under consideration of all offered service classes, we have to find the maximum of the UPRs for all offered services n.

$$UPR_{\max} = \max\{Y : Y = UPR_i(B)\}, \qquad i = 1...n \tag{7}$$

Utility functions and tariffs may depend on more than one parameter. A multi-dimensional utility or tariff function leads to an UPR that also depends on multiple parameters. The maximization problem becomes more complex.
As an example we consider a utility function that depends on bandwidth and loss. For accurate statements about the utility for different bandwidth and loss combinations, it would be needed to obtain the MOS of a statistically relevant number of users. For simplicity we assumed that the three dimensional utility curve can be represented with sufficient accuracy by a combination of two two-dimensional functions. This allows to express in our example the utility function depending on bandwidth and loss to

$$u(B_n, p_l) = u(B_n) \cdot u(p_l) \tag{8}$$

where B_n denotes the normalized bandwidth, $u(B_n)$ is the function presented in Figure 2, and p_l is the loss probability. For $u(p_l)$ we assume an exponential function

$$u(pl) = e^{-3p_l} \tag{9}$$

As price function we assume the volume based formula presented above. Under consideration of the increased bandwidth due to the redundancy the UPR for a best effort service with FEC can be calculated as:

$$UPR(B_n, p_l, n, k) = \frac{u(B_n, p_l^{*})}{p(\frac{n}{k} \cdot B_n \cdot B_{\max})} \tag{10}$$

The improved loss probability is denoted as p_l*. The amount of redundancy is given by ratio of all packets n to the number of data packets k. In our example we set the boundary conditions to u_{min}=3 and p_{max}=10. We set the number of data packets per transmission group to k=5 and the maximum size of a transmission group to n_{max}=10. The initial loss rate is assumed to be 0.3.
With these boundary conditions we calculate the number of redundancy packets h that maximizes UPR. In our example we get an optimal value for h=4. With this value an UPR=0.746 can be achieved. At this point the normalized bandwidth is B_n=0.5, the utility is u=3.358 and the price is p= 4.5.
For multidimensional UPR functions we use the Direction Set Method [PFTV88] to find the maximum. Since this accurate method is slow under certain conditions, we implemented as second algorithm the Downhill Simplex Method [PFTV88].

6 Conclusion

In this paper we have presented an architecture for audio and video transport with QoS support in heterogeneous multicast scenarios. Customers can choose between reservation of network resources and the usage of a transport-level real time error correction mechanism in order to meet their quality requirements within their price limit.
The choice of the optimal solution for a user depends on the tariff formulas for IP services with resource reservation. We have developed a charging information protocol (CIP) that allows to inform clients about tariffs. A prototype of this protocol has been implemented in C++. Furthermore, we show how a customer can select an appropriate service by using a utility-price optimization tool that finds the optimal utility-price-ratio (UPR) based on tariff information and utility functions. Both are expressed in a tariff formula language (TFL). A TFL parser has been implemented based on the GNU Bison tool.

Acknowledgements

The authors would like to thank the members of the Competence Center for Global Networking (GloNe) at GMD FOKUS for valuable discussions. Special thanks are to Sebastian Zander for implementation of the charging information protocol and the TFL parser.

References

[BoFT98] J. Bolot, S. Fosse-Parisis, D. Towsley: Adaptive FEC-Based Error Control for Interactive Audio in the Internet, IEEE Infocom ’99 , New York, U.S.A., March 1999

[CaBi97] G. Carle, E. W. Biersack: Survey on Error Recovery for IP-based Audio-Visual Multicast Applications, IEEE Network Magazine, November/December 1997, pp. 24-36.

[CANC96] CANCAN AC014 Consortium: ATM Charging Schemes, ACTS Project AC014 – CANCAN: „Contract Negotiation and Charging in ATM Networks“, Deliverable D5, October 1996

[ClFa97] D. D. Clark, W. Fang: Explicit Allocation of Best Effort Packet Delivery Service, Technical Report, Laboratory for Computer Sciences, MIT, 1997.

[FaSP98] G. Fankhauser, B. Stiller, B. Plattner, Arrow: A Flexible Architecture for an Accounting and Charging Infrastructure in the Next Generation Internet, in Netnomics: Economic Research and Electronic Networking, Vol. 1, No. 2, 1998.

[FeDe98] Domenico Ferrari, Luca Delgrossi: Charging for QoS , Keynote Paper IWQoS'98 - Sixth IEEE/IFIP International Workshop on Quality of Service, Napa, California, U.S.A., May 1998.

[GrSt85] John G. Gruber, Leo Strawczynski: „Subjective Effects of Variable Delay and Speech Clipping in Dynamically Managed Voice Systems“, IEEE Transactions on Communications, Vol. COM-33, No. 8, August 1985.

[HeSE95] S. Herzog, S. Shenker, D. Estrin: Sharing the Cost of Multicast Trees: An Axiomatic Analysis; In Proceedings of SIGCOMM 95, August 1995.

[KaSW99] M. Karsten, J. Schmitt, L. Wolf, and R Steinmetz: Cost and Price Calculation for Internet Integrated Services, KiVS'99, March 1999, Darmstadt, Germany.

[MacK97] J. MacKie-Mason, A Smart Market for Resource Reservation in a Multiple Quality of Service Information Network, Report, University of Michigan, July 1995, Revised: September 8, 1997.

[PaWa98] Kihong Park, Wei Wang: „AFEC: An Adaptive Forward Error Correction Protocol for End-to-End Transport of Real-Time Traffic“, International Conference on Computer Communications and Networks, Lafayette, Lousiana, October 12-15, 1998

[PFTV88] W. H. Press, B. P. Flannery, S. A. Teukolsky, W. T. Vetterling: Numerical Recipes in C – The Art of Scientific Computing; Cambridge University Press, Cambridge, 1988

[ReIz97] D. Reininger and R. Izmailov, Soft Quality of Service with VBR+ Video In Proceedings International Workshop on Audio-Visual Services over Packet Networks, AVSPN '97, Aberdeen, Scotland, September 1997.

[RFC1889] H. Schulzrinne, S. Casner, R. Frederick, V. Jacobson: RTP: A Transport Protocol for Real-Time Applications, RFC 1889, Januar 1996.

[RFC2205] L. Zhang, R. Braden, S. Berson, S. Herzog, and S. Jamin, Resource ReSerVation Protocol (RSVP) - Vesion 1 Functional Specification. RFC2205, IETF, September 1997.

[RhJL99] I. Rhee, S. Joshiy, M. Leey, S. Muthukrishinanz, V. Ozdemiry: Scalable Reliable Multicast with Layered Recovery and Low-Overhead Network Delay Estimation, Technical Report TR-99-05, Department of Computer Science, North Carolina State University, May 1999

[RoSc98] J. Rosenberg, H. Schulzrinne: An RTP Payload Format for Reed Solomon Codes, Internet Draft, Work in Progress, IETF Audio Video Transport Working Group (AVT), draft-ietf-avt-reedsolomon.txt, November 1998.

[SiSc98] D. Sisalem and H. Schulzrinne, The loss-delay based adjustment algorithm: A TCP-friendly adaptation scheme, NOSSDAV 98, Cambridge, U.K., July 1998.