Dimensioning of IP Networks for Transport of Unicast/Multicast TV Channels

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Abstract **Digital TV distribution over IP networks can benefit from carefully choosing which TV channels to unicast and which to multicast, reducing capacity demand by multicasting the most popular channels. We derive an approximative theoretical methodology to study the required capacity and we evaluate this capacity as a function of the underlying channel popularity and user behavior models. In the "static" scenario the multicast/unicast decision is taken upfront. For a bouquet of broadcast (TV) channels and user population, we can determine the boundary between which channels to multicast and for which channels to rely on unicast, such that the required capacity is minimal. In the "dynamic" scenario we consider, every channel is either unicast or multicast depending on its momentary popularity. We theoretically show that the dynamic scenario outperforms the static one and validate theoretical results by simulations. Network operators can use the methodology presented here to estimate the capacity demand.**

Keywords **capacity planning, IP TV networks, multicast**

I. Introduction

Currently we are witnessing a changing network paradigm, i.e., a vertical and horizontal convergence of network platforms delivering mixed services. The ubiquitous IP network protocol, with proved flexibility and efficiency, is at the very core of this convergence. Mobile network operators holding 3G (3rd Generation) UMTS (Universal Mobile Telecommunication Services) licenses would like to take advantage of this high-speed mobile access to migrate to enhanced telecommunication services, such as videophony or (IP-based) mobile TV. Similar trends exist in the fixed broadband networks, where traditional telephone operators are willing to offer TV services. As far as TV services offerings are concerned both evolve to the distribution of digital video over an IP-based network. IPTV is offered over fixed networks (either DSL or Cable) on many markets already worldwide. The use of IP technology for these new TV service paradigms and network architectures allows their provisioning in either unicast or multicast modes. For example, some mobile operators offer streaming TV/radio services setting a new unicast channel for every new active user which leads to capacity shortages. Recently, there have been some trials with multicast technologies for UMTS networks (i.e. Multimedia Broadcast Multicast Service (MBMS)) aiming to alleviate this problem. Other service providers offer pure multicast TV transport to unlimited audience (e.g. in a Digital Video Broadcasting-Handheld (DVB-H)) network but the return path (the interactivity feedback channel) is organized through a cellular network of a mobile operator typically. There are mixed network architectures allowing for a TV channel to be either unicast or multicast/broadcast such that the total consumed resources are kept low enough. Such networks are called hybrid and their potential to offload traffic from the unicast part of the network to the multicast-enabled part has been explored in e.g. [4]. Similarly, in broadcast TV service offerings over a fixed network care has to be taken to choose accurately which channel to multicast in which network node, to minimize the total required capacity in the TV network (see e.g. [2]). In [1] we presented mathematical models developed to estimate the resource demand in multicast-enabled networks under two dimensioning scenarios, which we called "static" and "dynamic" scenario.

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II. Network model

The model of the network under consideration is illustrated in Figure 1:

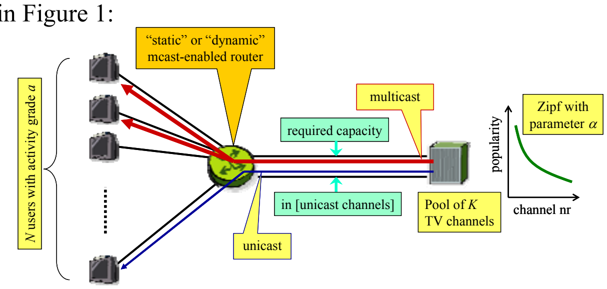

Figure 1 Example of a multicast-enabled architecture.

The models we develop apply to hybrid networks in which data can be transported both in unicast or multicast mode. This general model is applicable also to pure-unicast or pure-multicast networks. Suppose a network operator is willing to offer a pool (so called "bouquet") of K (IP-transported) TV channels. In order to save on bandwidth in (the distribution part of) the network, the operator may choose to multicast the M ($M \leq K$) most popular channels and to unicast from the others only upon request. This scenario we call *"static scenario"*.

We note that it is not efficient to multicast a channel as long as there are less than a given number of users (parameter β) tuned into it. Thus we explored also a *"dynamic scenario"* where any channel is either unicast or multicast depending on the number of viewers requesting it. In certain cases, it may take more bandwidth to multicast a channel than to unicast it, and this bandwidth ratio of multicast to unicast channel, we denote as β (this is the same parameter as above).

For proper dimensioning of the network, first of all the channel popularity model should be known. Some studies [2] show that the popularity distribution (probability of a channel being watched) has a power-law form (Zipf distribution with parameter α). We conducted a study over the popularity distribution of 15 channels as announced by a French DSL IPTV operator [3] and found this assumption to be reasonable. The channels are ordered in decreasing popularity to be watched. On top of that, each user is active with probability a.

We model the problem as a Markov chain. A state in which the system can be found is a K-dimensional vector with as components the number of users tuned onto every channel.

III. Analysis of the Resource Demand

A. *Models for the Resource Demand in Static and Dynamic Scenarios*

For both scenarios we derived closed-form expressions to estimate the capacity demand R (R_S in the static scenario and R_D in the dynamic scenario). As we ran into computational problems, we assumed that the variables of interest follow a Gaussian distribution and we found out that this approximation yields accurate results (under certain assumptions which are easily met for the systems under consideration). In the present paper we will use only the Gaussian approximation expressions to estimate the resource demand R. The formula for R_S is:

$$R_S = \beta M + NaP_u + erfc^{-1}(P_{block})\sqrt{NaP_u(1-aP_u)} \qquad (1)$$

where P_u is the probability that a unicast channel is watched and is actually the sum of the probabilities for the channels from the bouquet that are set aside for unicast on demand; N is the total number of users; the function $erfc^{-1}(X)$ is the inverse of the tail distribution function of the normal distribution with zero mean and unit variance, i.e., it gives the value which a zero mean unit variance Gaussian variable exceeds with probability X.

R_D is calculated by more complex formulae, expressing the average and standard deviations of the variables (number of unicast channels, number of multicast channels, capacity demand) as sums with the help of indicator functions.

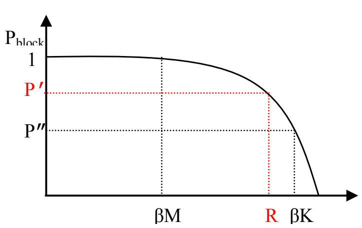

Figure 2 An example of the tail distribution function of R_S in function of the blocking probability, P_{block}.

B. *Superiority of Dynamic Resource Provisioning Scheme*

In Figure 3, a comparison is made of the resource demand in the context of static and dynamic cases (R_S or R_D respectively) in function of N (with the same network settings). The network parameters are as follows: K=150, a=0.7, α=0.6, β=2, P_{block}=10^{-4}, and M is taken to minimize the function $R_S=f(M)$ for the static scenario.

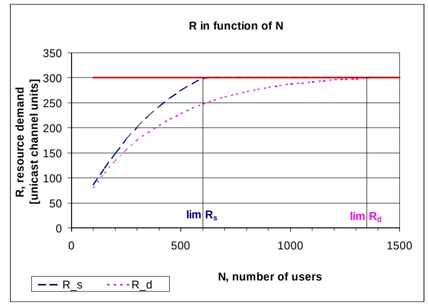

Figure 3: Resource demand in the static and dynamic scenario as a function of the number N of users.

In both scenarios we consider that as long as R_S or R_D is less than βK (300 in this example), it is feasible to deploy it while achieving a capacity gain; otherwise, when R_S or $R_D \geq \beta K$, there is no benefit in deploying such dimensioning schemes but rather multicast (broadcast) all channels. We see that in the static case R reaches this limit earlier (at smaller value of N) than in the dynamic case. This is an illustration of the superiority of the dynamic scheme. Due to space limitations, we will not give the formal proof we have.

IV. Verification of the Theoretical Model Against Simulations

We developed a C-based event-driven simulator program to verify our mathematical models. The traffic load from a user is modeled as continuous-time Markov chain, with K+1 possible states (because every user can either be tuned to any of the K channels or can be inactive). State changes are governed by a given transition matrix, determined by the (Zipf) channel popularity distribution (as the model is Markov-chain the sojourn times are exponentially distributed). We compared the results for static and dynamic dimensioning scenarios. A good match of results from both approaches was observed.

V. Conclusion

In this paper, we presented a methodology we have developed for estimating the capacity demand in multicast-enabled networks under two specific network scenarios, referred to as the *static* and *dynamic* scenario. We verified our theoretical model with a simulation tool we developed for this purpose. We show the superiority of the dynamic dimensioning scheme. A drawback of our methodology is the assumption that the channel popularity distribution does not change over time. We leave exploring the dynamicity in time of the system for future study.

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