VIDEO DISTRIBUTION WITH EDGE STATIONS AND WI-FI DELIVERY NETWORKS

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ABSTRACT

A video distribution architecture with edge stations and Wi-Fi delivery networks as connection to residential homes is described in this paper. An edge station is configurable and controllable by a central server. It is placed in the access point of Wi-Fi networks and has multiple usages. Due to its large storage space it can be used as a mirroring/caching proxy for continuous media. Replicating popular video contents in many small mirroring sites can significantly reduce the network bandwidth requirement. When this structure is used with a cable or Hybrid Fiber/Coax (HFC) network, it turns to be a Hybrid Fiber/Coax/Wi-Fi (HFCW) structure, particularly suitable for Video-on-Demand (VoD) applications. There are many advantages of this architecture. First, the central server load and network traffic can be reduced to a small percentage. Second, the response time of most video playing requests can be significantly reduced. Third, true VoD can possibly be provided with a one-way cable system. Finally, noise from STBs (Set-Top Boxes) is absorbed by the edge station in a two-way cable system.

1. INTRODUCTION

Rapid advances in computer, storage and network technologies make it feasible and imperative to build video servers capable of providing a large variety of services, ranging from Video-on-Demand (VoD) for home entertainment to distance learning for education. This interactive on-demand service must satisfy users in terms of its high availability and quick responsiveness.

The current VoD systems have some problems. First, high throughput video servers and sufficient bandwidth in the residential access networks are required for this service, since every request must be allocated a certain amount of server and network bandwidth. Second, a two-way access network is required to provide interactive service. The response time, depending on the locations and distances as well as the availability of the server, can be very long. Finally, the noise from many STBs (Set-Top Boxes) in a two-way cable brings the most difficult problem in deploying interactive VoD. The Near VoD (NVoD) system was proposed to provide video distribution for the one-way cable broadcasting system. However, only tens of movies can be provided with the limited number of channels. The users must wait for a substantial amount of time, say, 15 minutes, to start viewing a movie. Some methods were proposed to broadcast the former segments of the video more frequently than the latter segments to reduce the waiting time [1, 2, 3]. It can only improve the waiting time if the viewer watches the video from the beginning, but one cannot jump to the middle of a video without initiating a separate video stream.

Wi-Fi provides up to 54 Mbps bandwidth with IEEE 802.11a standard [4] which is good enough for future applications such as VoD and video conferencing. A typical coverage area of a Wi-Fi has a diameter of 100 meters. With an antenna, it is able to transmit data up to 5 kilometers, which is able to cover hundreds of single houses. Thus, it is an ideal networking scheme for residential access networks with high bandwidth and low cost.

Mirroring is a general approach to minimizing the response time for a request [5, 6]. It also reduces the network traffic. Normally, a mirroring site serves thousands of customers or more. It is not a common practice to place a mirroring site for a small number of clients. The Content Distribution Network (CDN) [7] provides certain mirroring functions, however, it has not been used within the residential access networks. Our approach uses small mirroring stations with Wi-Fi to solve the last mile problem for residential VoD service.

In this paper, we propose a video distribution architecture which places edge stations in the Wi-Fi access points. Wi-Fi connects the edge station to residential homes. The edge stations are configurable and controllable by a central server. The most popular video contents are stored in the storage space of the edge station. Clients can access these contents directly from the station. The video content that is requested but not in the station's storage will be served by the central server. Because the popular video contents stored in this local storage represent a large percentage of clients' demand [8, 9], the capacity requirement of the central server and the bandwidth requirement of the network can be significantly reduced. The response time to the normal play and interactive plays is also reduced. When this structure is used with a cable or Hybrid Fiber/Coax (HFC) network, it turns to be Hybrid Fiber/Coax/Wi-Fi (HFCW). A major application of this method is for the one-way cable system, where the edge station provides a return path for each user through the internet. Thus the requests that cannot be satisfied locally will be forwarded to the central server through this return path.

2. EDGE STATION ARCHITECTURE

The base architecture of an edge station with Wi-Fi connection to homes is shown in Figure 1. This station is equipped with low-cost, large-capacity storage devices such as two or three 100GB IDE disks. This edge station is able to mirror tens of most popular 2-hours MPEG-2 videos, or hundreds of MPEG-4 videos. Each station supports tens of 3Mbps MPEG-2 video streams, or hundreds of 300Kbps MPEG-4 video streams. It can support tens to hundreds of residential homes. It is programmable and suitable for deploying different services. Capital investment is preserved because software and hard disks are upgradable.

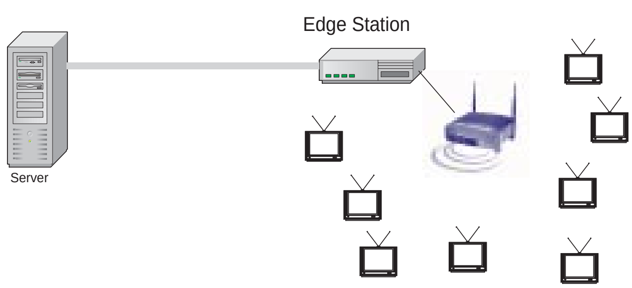

Figure 1: The Edge Station with Wi-Fi.

The input to the station could be fiber optics, DSL, or one-way/two-way cables. For the one-way cable, the return path can be a DSL or phone modem. The central server is able to control the contents stored in the edge stations and update the contents by broadcast, using a relative small amount of network bandwidth. How to determine which contents are most popular can be done by prediction or on fly. The central server monitors the requests from the clients and determines which contents need to be mirrored. At the same time, the edge station can collect the usage information. This information will be sent to the central server so the server can determine which contents will be replaced.

At the client side, a simple diskless Ethernet STB with a wireless card is sufficient. Only a few seconds buffer space is required. The STB can even be eliminated if the user uses a computer to view the videos. The edge station is transparent to the client software, that is, a normal VoD client software can be used.

This architecture can be used for different purposes. Normally, a large percentage of the storage is used as a mirroring proxy which stores videos. Most requests can be satisfied locally. Those requests that cannot be satisfied locally will be forwarded to the central server, and the video streams from the central server is forwarded to the clients through Wi-Fi. A smaller portion of storage can be used for caching Web contents.

The major advantages of this architecture include:

- Wi-Fi provides a low-cost, high-bandwidth last-mile connection to homes;
- the network traffic from the central server and edge stations can be reduced to a small percentage;
- the response time can be reduced significantly;
- two-way interactive functions can be provided with the one-way cable system;
- the station absorbs the noise from many STBs in a two-way cable system; and
- simple diskless Ethernet STB with a wireless card can be used at the residential home which is inexpensive.

For Fiber-to-the-Building (FTTB) or Fiber-to-the-Curb (FTTC), the edge station and the Wi-Fi access point can be plugged into the Optical Network Unit (ONU) to provide mirroring and caching functions to reduce the bandwidth requirement as well as the response time. The station can also be used with DSL. The bandwidth requirement is lowered so that a DSL line can support multiple residential homes. As an example, a 10Mbps DSL line can support tens of homes. The edge station structure is probably best suitable for the cable (HFC) system which will be described in the next section.

3. HFCW (ONE-WAY OR TWO-WAY CABLES)

In the Hybrid Fiber/Coax/Wi-Fi (HFCW) architecture, HFC is used to connect the central server to the edge stations. The edge station should be able to decode a few digital channels. The required number of digital channels depends on the number of clients and the hit ratio. An edge station is able to decode at least one analog channel which has about eight 3Mbps digital channels. It should be sufficient in most situations. However, all digital channels required by a single edge station must be packed into the analog channel. We will discuss this issue in the next section.

HFCW can provide two-way on-demand services with a one-way cable system as shown in Figure 2. The edge station provides a return path for each residential home. The method is superior than Near VoD (NVoD) which also uses

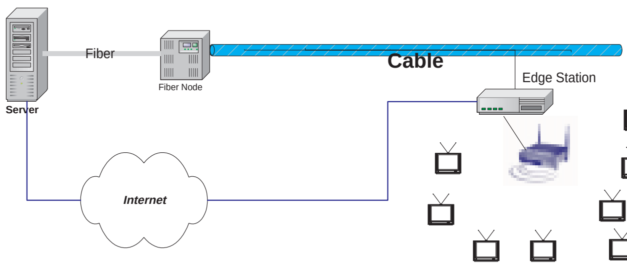

Figure 2: Edge Station in a One-Way Cable System.

the one-way cable. NVoD transmits video data repeatedly and requires a huge amount of network bandwidth.

Due to the low bandwidth requirement, even analog cable can be used to provide many on-demand movies. In this case, the edge station captures the analog video signal and stores it in its local storage or forwards it to the users.

When HFCW is used for the two-way cable, the edge station combines the requests from the users and sends them to the return path together. The noise from residential homes is absorbed instead of being carried to the return path. Thus, it almost eliminates the noise problem in the cable return path.

4. CHANNEL ALLOCATION AND PERFORMANCE OF HFCW

In HFCW, most requests can be satisfied by the edge station. The requests for the videos that are not in the edge station will be forwarded to the central server. The bandwidth from the central server to edge stations is limited. In an HFC system, up to 100 analog channels or about 800 digital channels for MPEG-2 (3Mbps) or 8,000 digital channels for MPEG-4 (300Kbps) will be available for transmission of digital videos. In addition, an edge station may have limited capacity for analog channel decoding, that is, it may be able to decode only one or two analog channels. Thus, all videos from the central server to an edge station must be transmitted through the limited number of analog channels. Algorithms are needed to allocate required digital channels to the same analog channel as much as possible.

We conducted a performance study by simulation. Assume that an edge station uses a server machine with two 100GB IDE disks. The current street price for such a machine is less than US$700. To determine the hit ratio and storage requirement, we assume a movie repository of 1,000 movies and the movie length is two hours. To determine the number of homes that can be supported by an edge station, the utilization ratio is set to be 28%, that is, no more than 28% of households watch the on-demand video simultaneously. For each request made, a video is selected using a Zipf distribution [9]. The probability of choosing video V_j is C/j, where C is a normalized constant. The performance data for 3Mbps MPEG-2 and 300Kbps MPEG-4 videos are reported. The performance metrics shown in Table 1 are: (1) the number of movies that can be stored in the edge station; (2) the number of streams can be provided by the edge station; (3) the number of home the can be supported; (4) the hit ratio; (5) the input bandwidth required by the edge station; and (6) the number of digital channels.

Table 1: The Performance Data for a Single Edge Station

	MPEG-2	MPEG-4
number of movies	74	740
number of streams	16	166
number of homes	57	570
hit ratio	63.8%	94.6%
input bandwidth	17.4Mbps	2.6Mbps
number of digital channels	6	9

Unlimited Analog Channel Decoding Capacity

The requirement of the number of digital channels with unlimited analog channel decoding capacity shows the bandwidth requirement. A simulation has been conducted to determine the total number of channels required for a large number of edge stations. The simulation setting is as follows. Each edge station holds 74 MPEG-2 videos, The request arrival pattern is Poisson distribution and there are 57 requests per day. Each edge station serves a maximum of 16 MPEG-2 streams. Table 2 shows the number of channels required for different number of edge stations. For 100 edge stations which can serve 5,700 home, 182 digital channels or 23 analog channels are required.

Limited Analog Channel Decoding Capacity

Normally, an edge station is able to decode only a few analog channels. It is possible that though empty digital channels are available, they are not in the analog channels that can be decoded by the edge station since it is decoding other analog channels. Thus, the newly arrived requests must be rejected. Analog channel allocation algorithms are designed for minimization of the request rejection rate. Assume that the edge station is able to decode only one analog channel. An algorithm simply finds available channels to transmitting video streams from the central server to the edge station. When more than one video stream needs to be transmitted simultaneously, these streams must be allocated to the same analog channel. The algorithm for m analog channels are similar: all streams to an edge station must be allocated to m analog channels. An improved algorithm selects the analog channel with the largest number of available digital channels.

Table 3 shows the rejection rate of the improved schedul-

Table 2: The Number of Channels Required for Different Number of Edge Stations

Number of edge stations	10	20	30	40	50	60	70	80	90	100
Number of digital channels	30	48	62	83	99	118	136	154	163	182

ing algorithm with different decoding capacities. This performance is for 80 edge stations and 30 analog channels. Each analog channel has eight digital channels. Simulation is conducted for one year. The rejection rate can be significantly reduced if the edge station is able to decode more than one analog channel. Usually, a cable STB can be used for the demodulation and decoding, and some STBs have the capacity to decode two analog channels.

Table 3: The Rejection Rate for Different Decoding Capacities

Decoding capacity = 1	0.6%
Decoding capacity = 2	0.036%
Decoding capacity = 3	0.0025%

This experimental result shows the efficience of the proposed approach. Thirty analog channels (240 digital channels) are able to serve 5,700 households, each of them makes one request per day. When the edge station can decode only one analog channel, the rejection rate is only 0.6%.

Finally, we compare the edge station approach to true VoD and near VoD. Assume we have 300 digital channels and assume the hit ratio to an edge station is 80%. The true VoD is able to serve 300 clients, each of that can watch a different movie. The near VoD is able to serve unlimited number of clients, but they can only watch one of 60 movies, assuming each movie uses five digital channels. The edge station approach can serve 1,500 streams with any movie in the movie repository.

5. CONCLUSIONS

An edge station architecture has been proposed for Wi-Fi delivery networks. Wi-Fi is a low-cost approach to solve the last-mile problem and able to transmit high-bandwidth video streams to homes. This architecture has many advantages compared to the current VoD systems. Compared to simple VoD, it reduces requirement for the server and the network. That means that the same infrastructure can support much more homes. It can provide two-way functions with a one-way cable system. It can absorb the noise from STBs in a two-way cable system. Each NVoD video needs five or six digital channels and 300 digital channels can only provide 60 videos. The edge station provides the same number of videos with no waiting time. Even better, it provides true on-demand videos with no limitation on the number of videos provided. In addition, it requires no disk storage in STBs. All the cost for these advantages is that the cost of the edge station, Wi-Fi access points, and maintenance. The cost for the edge station and Wi-Fi access point with an antenna is less than $20 per home which is much cheaper than a disk in the STB. The Ethernet STBs are also inexpensive. This architecture achieves scalability, flexibility, and economic benefit simultaneously. In the future work, we will build a Wi-Fi network to exchange video contents between the access points to increase the hit ratio and to reduce the requirement of wired connections.

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