

Virtual Tuner Network for Video Services over the CATIUS Cable Access Network

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Abstract— The CATIUS access network is a hybrid between CATV and Ethernet (using Cat5 cable) that enables the cable operator to provide triple play services. CATIUS uses digitized channels on CATV cable for downstream and Cat5 cable for upstream traffic. Optimum utilization of channel bandwidth is critical due to the cost of allotted digital channels and needs effective use of the available network resources especially digital channels. The present design of CATIUS has limitations on effectively utilizing the channel bandwidth when multiple channels are allotted for video delivery. In this paper, we introduce a technique called Virtual Tuner Network (VTN) to optimally utilize the CATV channels. VTN establishes a peer network to analyze and share video streams available on different channels. VTN enables provisioning of triple play services to increased number of users while maintaining the same cost of infrastructure.

I. INTRODUCTION

As there is already cable TV network infrastructure setup all over India, it would be advantageous to provide triple play services over this network. With around 70 million wired homes, cable TV networks can be a good way for providing video services with less investment. By 2011, India will have over 100 Million Cable TV Homes which can be leveraged by providing triple play service at low cost. Generally the cable networks provide 40-50Mbps of bandwidth per one channel and majority of the cable networks are one-way.

There are two -way cable network systems using two-way amplifiers, but not used widely because of high cost and maintenance. The radio spectrum for cable networks ranges from 5-42MHz for upstream and 54MHz-750MHz for downstream [7]. Ethernet is also used as access networks in last mile for providing Internet services, due to widespread use and less cost of Ethernet networks. CATIUS, developed by Midas & TeNet group of IIT Madras, is a low cost asymmetric cable access network solution that provides triple play services

to the subscribers. It uses Ethernet for upstream and cable for downstream.

Though CATIUS provides the data services with QoS, the system supports limited number of subscribers especially when the video services are simultaneously accessed. Video services are bandwidth intensive and delay sensitive, and also require huge bandwidth and QoS. In CATIUS the Video traffic is transported using the CATV cable, which are traditionally designed to carry video.

In this paper we outline the CATIUS network architecture and its limitations in section II. In section III, we look at Virtual Tuner Network, its architecture, design and implementation. Section IV gives the results and compares with that of earlier system.

II. CATIUS NETWORK ARCHITECTURE

A. Architecture

In CATIUS network, the subscribers are provided internet services and video services from service provider (ISP). Requests are directed to ISP using Ethernet Uplink and the downlink content is delivered using cable medium through digital cable Headend. The CATIUS network diagram is shown in Fig.1. It contains the Digital Headend (CATV cable network) coupled with IP (CAT5) network. The key components of CATIUS network are Cable Router and a video switch, called VSwitch. Cable service providers use combiners for integrating the existing analog cable systems for transmitting both analog and digital video over cable network. For transmitting digitized video over cable, MPEG2 transport stream is used. Generally Video data is encoded in MPEG frames using MPEG coders and encapsulated inside an UDP/IP packet [5]-[6], [12]. Cable Router acts as a bridge between IP network and Cable network. Cable Router converts the MPEG stream encapsulated in the UDP packet into ASI format suitable for QAM modulation at the Cable Headend [2]. Also the Cable Router adds custom headers to the MPEG transport video data. These headers are used at VSwitch, to decode the MPEG TS frames.

VSwitches are deployed in the last mile (at subscriber end) and provide Ethernet connectivity to the subscribers as shown in Fig 1. VSwitch is a managed Ethernet switch with a single cable Tuner, to receive data from CATV cable.

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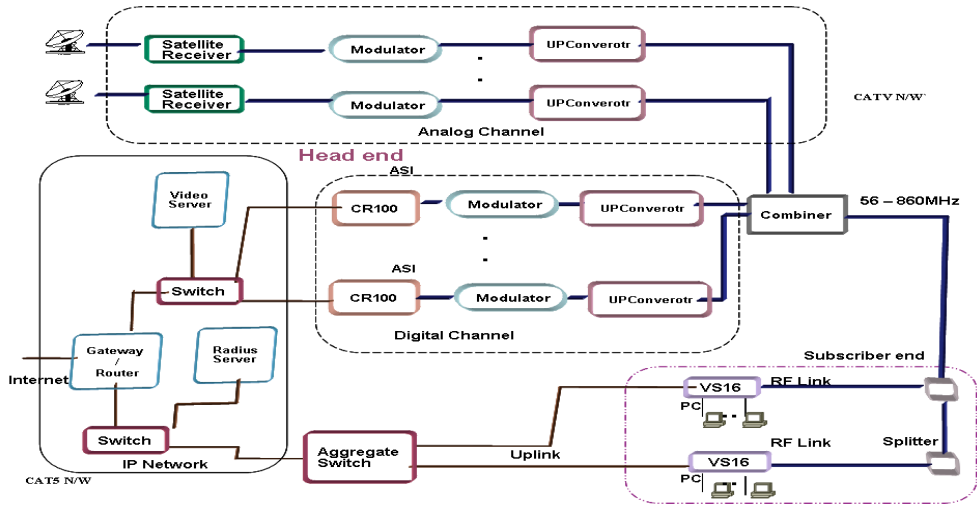


Fig 1 CATIUS architecture

VSwitch extracts the IP packets from the received MPEG TS frames. These packets are switched to the subscribers based on the IP address to which the data has to be delivered. VSwitch maintains all the user information for checking and filtering the data.

A. VSwitch

VSwitch is a manageable edge switch. It contains a switch controller, RAM for buffering MPEG and Ethernet packets, a management processor and a Tuner/Demodulator section. Its block diagram is shown below in Fig.2. Switch controller has 16 ports and supports switch features like VLAN configurations, port trunking, flow control and port mirroring.

B. Limitations of CATIUS System

The major limitation is that VSwitch has only a single tuner demodulator section, which limits it to tune to a single digital channel of 40-50Mbps bandwidth. More number of subscribers can be connected to VSwitch using normal Ethernet switches.

If a single video stream occupies 2-3 Mbps of bandwidth, the switch can only support upto 10-15 video streams simultaneously. Assuming 10% concurrency of VoD access users, it can serve 100 subscribers.

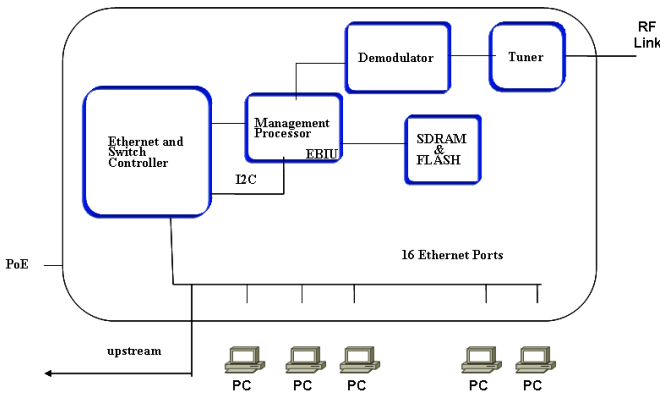


Fig 2 VSwitch

Though CATIUS is good at providing Internet services, it serves limited number of video services to subscribers and thus suffers from addressing more number of users. It also lacks the ability to effectively use the critical network resources such as bandwidth of allotted digital channels. For example if five digital channels are assigned for digital video services, each digital channel offers 40 Mbps bandwidth for a total of 200Mbps. If one digital channel has some free bandwidth and if another channel is fully occupied, some of the VoD requests can not be serviced in the latter channel as shown in Fig 3 due to lack of multiple tuners in VSwitch. There can be many channel domains in the CATIUS network.

When one digital channel is allotted to a particular video content, this video content is not accessible to the subscribers, who are tuned to some other digital channel. This causes severe problem if multicast video services are being offered, while multicast users are present in different frequency segments (frequency domain). All of the multicast users are not serviced as they are distributed among different frequency channel domain segments.

These limitations can be removed if VSwitch is able to tune to multiple digital channels and filter the video services across multiple channels. But changing VSwitch design to support multiple tuners increases cost and has its own design issues such as inter channel interference, noise pick up etc.

To solve these limitations, we propose a solution called Virtual Tuner Network (VTN), which enables VSwitches to receive video content from multiple channels without having multiple physical tuners.

III. VIRTUAL TUNER NETWORK

A. Architecture

Existing CATIUS network can be enhanced to support Virtual Tuner Network using peer to peer concept [1]. Each VSwitch (here after called as VTNSwitches to distinguish from VSwitches) can act as peer node and be able to communicate with other VSwitches. All the VTNSwitches are

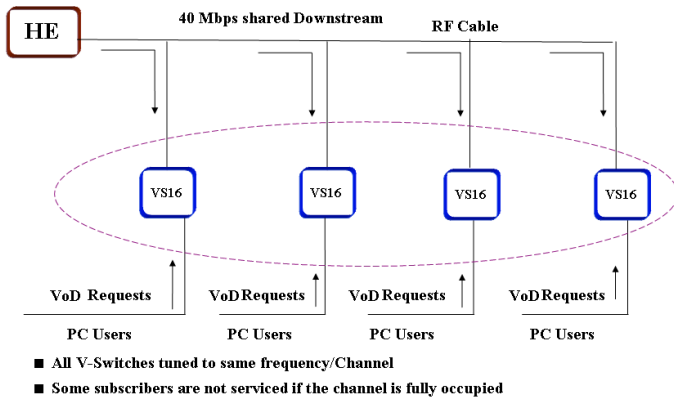


Fig 3 Single channel frequency domain scenario in CATIUS. Similarly there can be many such frequency domains with same characteristics.

connected and reachable through upstream path. VTNSwitches exchange their device, stream-filtering information using the custom p2p messages called capability descriptors. These p2p messages are subnet broadcasted and are received by all the VTNSwitches present in the network. We form a group of VTNSwitches as a peer Group called VTNGroup. It contains all the VTNSwitches which are connected to different frequency segments in the system. All the VTNSwitches are connected using dedicated Ethernet link for relaying the Video stream data to other VTNSwitch subscribers. Thus each VTNSwitch has access to all the frequency segments and have virtually tuned to the entire allotted and available channels in the system. This also makes effective utilization of the bandwidth and channels allotted. Virtual tuner network is shown in Fig 4.

The only difference with CATIUS network is that all VSwitches (VTNSwitches in VTN network) are interconnected with dedicated Ethernet link to make a

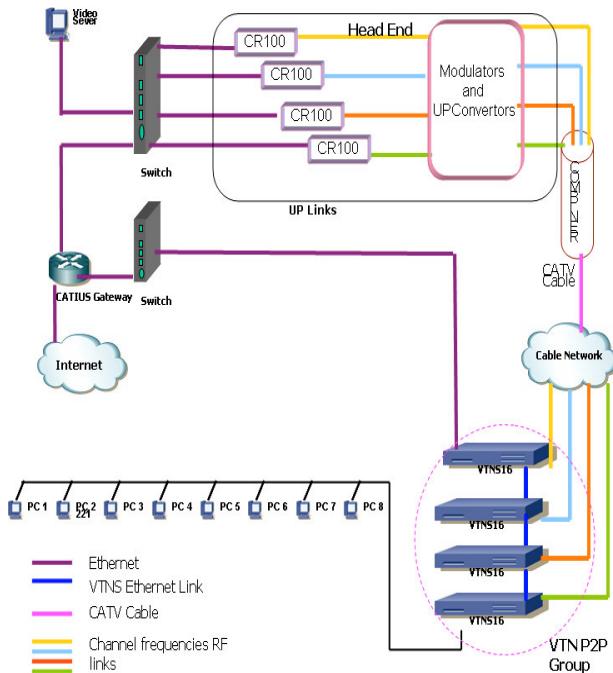


Fig. 4 Virtual Tuner Network All VTNSwitches are interconnected with each other. This link is either a single port trunk or multiple. Multiple ports can be used as trunk ports between two switches for increased bandwidth.

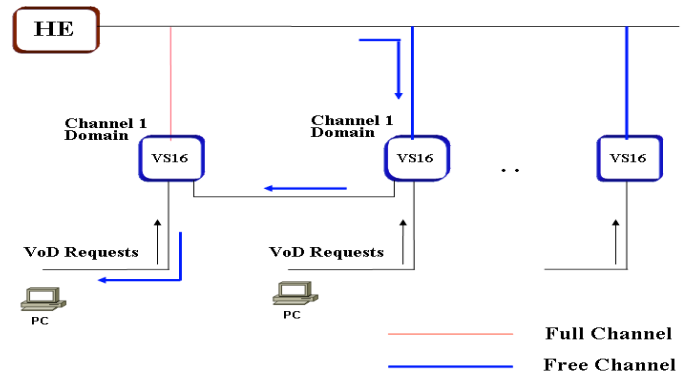


Fig 5 Virtual Tuner Network can relay the video traffic of a user from one frequency domain to another frequency domain. Channel domain 1 in the figure is fully used and relaying is done through channel domain 2.

VTNGroup. This Ethernet link can also act as uplink for the VTNSwitch. There can be port aggregation between VTNSwitches to support high bandwidth for relaying of video.

B. Functionality

Virtual Tuner Network operates similar to CATIUS in addition it has the capability to relay the video traffic of any subscriber through relay VTNSwitch.

The decision whether to relay a particular video stream depends on the effective bandwidth utilization of the frequency segment of the VoD request under process. The video stream traffic can be multicast or unicast. The operation of relaying of video stream traffic from one VTNSwitch to other is shown in Fig 5.

We can observe that the channel in red color (shown as thin red color line) is fully occupied. The video requests from this segment are serviced using free channel (shown in blue color thick line) using relaying. The relayed video is received by the subscriber in the channel domain 1.

C. Design and Implementation of VTN

Design of Virtual Tuner Network requires the following features to be incorporated into the VTNSwitch.

- Implement P2P functionality in VTNSwitch software.
- Establish loop free Dedicated Ethernet link between VTNSwitches.
- Develop protocols for communicating the relay decision among VTNSwitch network.
- Relay the video traffic and isolate the video traffic from normal uplink traffic using VLANs at gateway end [8].
- Port aggregation between VTNSwitches for supporting high bandwidth trunk..

In VTN, we consider two ways of video streaming in the network. Unicast streaming also called Video on Demand can be serviced based on the user request. Multicast services are provided by the network operator on specific time schedules. These are viewed by subscribers by sending multicast IGMP request from their PCs. VTNSwitch recognizes these IGMP requests and filters the multicast video traffic for the subscriber.

For multicast services, VTNSwitch will decide whether a multicast request has to be relayed or not as it processes the

user IGMP request. Native VTNSwitch finds the requested multicast stream is available in its VTNGroup members. If native frequency channel bandwidth is fully utilized or multicast stream is already available in other frequency channel then video request can be relayed. If relaying is needed the P2P message *relay request* is sent to the relay VTNSwitch. If relay VTNSwitch is ready and available, it sends *relay reply* P2P message as acknowledgement. The video stream is filtered by the relay VTNSwitch.

For unicast services, the VoD requests are directly handled by the video server itself at ISP network. Video server has to determine the frequency segment of the request received and find whether its channel bandwidth is available for that request or not available in that frequency segment. If fully loaded (bandwidth is fully occupied) then request is relayed to less loaded frequency segment and this relay decision is informed to Gateway server. The gateway forwards this relay decision towards VTNSwitch network segment using custom protocol messages. Thus the relaying decision for unicast services is done at video server end. Video server has one utility, called VideoTraf, which can monitor all the available frequency channels using polling mechanism. This utility gives the bandwidth utilization information for the relay decision at Video server.

1) Structure of P2P messages

P2P message used in establishing the peer network among VTNSwitches are given below.

- Search message (broadcasted to subnet).
- Search reply message (unicast).
- Join message (broadcast).
- Query Request and Reply messages.
- Relay Request and Reply messages.

Figure 6 explains the structures of P2P messages exchanged by VTNSwitches. Peer groups are formed by connecting the VTNSwitches that are tuned to different frequencies channels.

2) Loop free dedicated Ethernet link for VTNSwitch.

The figure 7 explains the vlans that is configured in VTNSwitch to establish the loop free and dedicated Ethernet link. It can be configured only in a VTNSwitch which is near the Gateway end. The VTNSwitch that has this VLAN configuration is called *Active VTNSwitch* as it isolates the multicast video traffic towards uplink. All other VTNSwitches in the group are *Passive VTNSwitches*.

P2P message packet format:

Ethernet Header	IP header	P2P Header	P2P Payload
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P2P header format:

VTN Version	Message Type	Sub Message Type	Connect String
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P2P message payload information General structure

VTN Switch address	Group Number	Frequency Connected / Tuned	QAM Type	No of users Configured	Bandwidth Used	Bandwidth Free	Multicast streams
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VTNSwitch information structure

Fig 6 Peer to peer message formats in VTN.

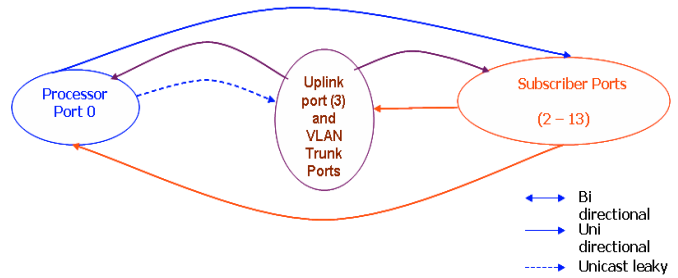


Fig 7 VLAN configuration in Active VTNSwitch for isolating the relay video traffic from normal uplink traffic. The direction of arrows shows the reachability of ports from/to other ports. Avoids loops among the Ethernet network.

3) Custom protocols developed for VTN

Custom protocols are used for communication between video servers and Gateway and between Gateway and VTNSwitch subnetwork. These protocols help in maintaining the VTN network. CSTP protocol is used for adding route entries for the newly configured users in the VTNSwitches. This helps in dynamically changing the routes from Ethernet path to cable path whenever there is a cable link failure. Seamless switchover takes place from Ethernet path to cable path without user intervention thus providing reliability of the system. Gateway to Video server protocol is used for exchanging the relay decision information to VTNSwitch network to elect the relay VTNSwitch.

Gateway sends relay decision information towards VTNSwitch subnetwork. This message is broadcast over the VTNSwitch subnetwork. After receiving these messages, native VTNSwitch performs relay VTNSwitch election algorithm for selecting available relay VTNSwitch. The algorithm is given in below.

Once the relay VTNSwitch is elected the native VTNSwitch sends confirmation of relaying to the Gateway server which in turn forwards it to video server to stream the requested video.

4) Relay VTNSwitch Election Algorithm

This algorithm elects the relay VTNSwitch that is less loaded and has free bandwidth available in its frequency segment. It is triggered when Relay_Route_Add message is received from the Gateway server while relay decision is taken place at video server. A VTNSwitch is eligible to act as relay VTNSwitch if and only if it is tuned to relay segment frequency and is in the same VTN group of native VTNSwitch.

Two cases for selection of relay VTNSwitch.

- When VTN group of native VTNSwitch contains more than one VTNSwitch that is tuned to the relay frequency.
- When VTN group of native VTNSwitch contains exactly one relay VTNSwitch that is tuned to the relay frequency.

We provide the algorithm for the above first case to elect most eligible relay VTNSwitch. The second one reduces when number is exactly one.

If there are no VTNSwitches present that tuned to relay frequency, the error message is sent to Gateway.

Algorithm

Relay_VTNS_Election (Input: Messages, Output: Relay VTNSwitch)

1. Receive the Relay_Route_Add / Relay_Route_Delete message.
2. If message is Relay_Route_Add message and freq is as same as its frequency tuned

Begin

(i). Send the Relay_VTNS_ElectMe message to all the VTNS switches. This is a subnet directed broadcast.

(ii). Process the Relay_VTNS_ElectMe message received from other VTNS Switches.

(iii). If this VTNS Switch is least loaded compared to other VTNS switches, that is no other VTNS is better for relaying, send the Relay_VTNS_Me message to all.

(iv). for all Relay_VTNS_Me message senders

Begin

If Sender's VTNS Id is < its own VTNS Id

Stop and do not act as Relay VTNS Switch

Exit;

End

Act as relay VTNS Switch;

Send the Relay_VTNS_OK message to Gateway;

End

After receiving the VTNS_OK message the video server stream the requested video to relay frequency channel. Subscriber receives the video from relay VTNSwitch using relaying.

IV. ANALYSIS AND RESULTS

The Virtual Tuner Network is implemented and tested. We tested VTN with 4 digital channels with bandwidth threshold of 5Mbps. VTN effectively utilizes the Idle channels for serving other channel subscribers. There is about one second delay for establishing the relay path and this is traded off with increase in channel utilization. The channel utilization graph in Fig 8 and Table 1 shows that VTN improves over CATIUS many fold especially when there are idle digital channels. The Requests are discarded more in CATIUS while VTN continues to serve requests.. VTN also tend to discard requests when all channels are fully occupied (> 20Mbps) as shown in the Fig 8. Increase in the channel utilization enables more no of subscribers supported.

V. CONCLUSION

In this paper we present the Virtual Tuner Network as an efficient means of providing video services over cable TV networks. VTN uses peer to peer communication for utilizing idle digital channels. This software solution is shown by experiment to perform very well. It is scalable and robust.

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Bandwidth vs Requests Received

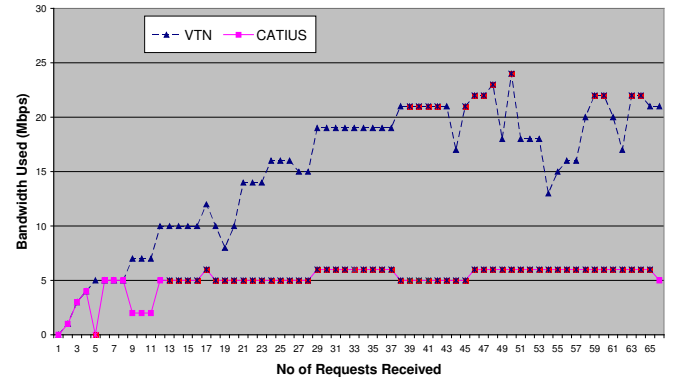


Fig 8. Channel utilization comparison. VTN effectively utilizes the other channels. Bandwidth in Mbps.

TABLE 1
COMPARISON OF CATIUS vs VTN.

Serial. No	No of Requests Received	Channel Load	Requests Served		Requests Discarded		Serviceability in %	
			CATIUS	VTN	CATIUS	VTN	CATIUS	VTN
1	23	< 100%	4	23	19	0	39.2%	100%
2	33	< 100%	16	28	17	5	15.3%	84.8%
3	42	~ 100%	4	24	38	18	9.5%	57.1%
4	62	~ 100%	40	56	22	6	64.5%	90.3%
5	65	< 100%	10	47	55	18	15.3%	72.3%
6	102	<< 100%	40	102	62	0	39.2%	100%

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