Bottleneck of Data over Cable

David M. Fellows
Continental Cablevision

Abstract

Advanced modulation techniques, combined with protocols such as the MPEG 2 transport layer, have the ability to turn cable systems into broadband digital pipes to the home. However, a growing issue will be the bottleneck of data in the reverse direction, especially as the number of services supported over cable networks grows beyond Impulse Pay Per View and traditional status monitoring. Not only does the reverse path offer at best one-twentieth the bandwidth of the forward direction, but the noise and other impairments limit the aggressiveness of the modulation possible. Even though most applications still will use more bandwidth to the home than from it, the reverse path represents the most severe bottleneck in future systems. Only by careful utilization of this resource, and agreement on common protocols across services, will a cable network support all the services that will be required of it.

CABLE ARCHITECTURES

Fiber-to-the Serving Area

For several years, cable systems have been using fiber to reduce amplifier cascades and increase bandwidth. The use of fiber to small pockets of homes has the added benefit of increasing reliability, improving the reverse path, and creating a star architecture out of the headend, so bandwidth can be reused from pocket to pocket. This is essential for different voice and data calls to go to different pockets of homes. These pockets are at most 2000 homes-passed, and more often are 500 homes.

Forward Path

Most cable systems are being rebuild to either 550 MHz or 750 MHz bandwidths, with roughly 500 MHz or 700 MHz dedicated to the forward direction and 25 to 35 MHz dedicated to the reverse direction. These systems have carrier-to-noise figures in the high 40's, and tend to have diplex filters (which contribute group delay) only at the very bottom of the frequency range (where an analog channel 2 sits). The MPEG 2 digital video systems discussed in this session have concentrated on 64 QAM or 256 QAM modulation. Taking 30 Mb/s in every 6 MHz, a system with 700 MHz of forward downstream capacity could, in theory, carry 3.5 Gb/s of data on the cable! The major impairment to digital transmission is micro-reflections due to impedance mismatch and unterminated connections.

Historically, multiple services in the forward direction have been handled primarily by Frequency Division Multiplexing (FDM) - every channel is given a different frequency. Within one MPEG frequency slot, multiple channels are handled by Time Division Multiplexing (TDM). Because all services originate from the same place (e.g. the headend), FDM or TDM is possible, and results in efficient packing of data.

Reverse Path

The reverse direction, however, is everything the forward path is not. It has at most 35 MHz of bandwidth, and suffers from the noise funnel effect, group delay from aggressive diplex filters (in 40 MHz split systems), and lots of high-power interferers (Ham, International AM, and CB radio). Most of the reverse systems being proposed achieve about a 1 bit/second/Hertz throughput (the modulation is higher, but overhead and other inefficiencies discussed below reduce the usable bit rate), meaning that 35 MHz yields 35 Mb/s - one one hundredth of the forward amount.

Different services in the reverse direction start out using FDM; for example, IPPV uses a different frequency than status monitoring. For a given service, within a single frequency, TDM can also be used. But in the reverse direction, data is originated from different sources, and unpredictably so for many services, so a multiple access protocol must be used, further reducing efficiency. In any event, guard bands or guard times must be inserted between channels to separate them from each other (more in the next section).

DIFFERING SERVICE REQUIREMENTS

Services

Cable systems will be called upon to carry many differing types of services in the near future. Going from the existing to the very near future, the list for the reverse direction includes Impulse Pay-Per-View (IPPV), status monitoring, high speed data return, telephony return, interactive set-top real-time return, energy management/UCS/telemetry services, PCS return (rads/rasp), and so forth. Even though many of these applications do not require much bandwidth, the fact that they "talk" different languages means that they need different frequency slots, with the waste of guard bands between the channel frequencies.

Multiple Access

To make matters worse, within each service type, there will be multiple people trying to simultaneously access or use the service. If there were enough channels to go around, then the multiple access is set-up at installation time - each user is assigned their own channel. But this is too inefficient for long - must use concentration. that is, there will be more users than channels or bandwidth, and a channel or bandwidth must be assigned upon demand

Multiple Access Protocols

Many customers vying for and sharing a limited number of channels is a problem attacked for satellite service between Hawaii and the mainland. In a protocol called "Aloha", anyone wanting service just transmitted. A variant of this was slotted Aloha, where the beginning point of customers was synchronized (and resulted in a factor of two increase in loading efficiency). To use ethernet as an example, the transmitter first looks at the channel to make sure no one else is using it (carrier-sense multiple access - CSMA), then transmits its data, making sure that no one else transmits on top of it (because of delays in most channels, the fact that a channel is clear at the start of transmission does not mean that another transmitter has not also seen a clear channel and started transmitting - but that transmission signal has not reached this location yet - called collision detection - CD) Put together, this is called CSMA-CD, and if a collision is detected, both transmitters back off a random amount of time, then try again. Further refinements include central reservation or distributed reservation via signals called tokens. Today, multiple access protocols fall into three categories: Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA). These protocols have been further enhanced by reservation or assignment techniques, where channels are assigned centrally after contention on a reservation channel.

With FDMA, channels are assigned different carriers, and users contend for these channels. In TDMA, a single frequency carries a data stream that is logically broken into sub-channels or timeslots, and users vie for these timeslots. CDMA uses the spread spectrum technique of orthogonal codes, and each code represents a different channel, for which users contend. In all of these, a separate reservation channel may be used to centrally assign channels (whether frequencies, time slots, or codes).

Between many services and many users of each service, there is the real possibility that there is not enough reverse bandwidth for every subscriber and every application.

SYSTEM LEVEL SOLUTIONS

More Reverse Bandwidth

Standard systems in the USA are built with sub-split reverse, which used to be 5 MHz to 30 MHz and now typically is 5 MHz to 40 MHz, a 40 percent increase. Since the bandwidth below 10 MHz is tough to use, this results in an even greater increase. Many other splits are available, and are used in foreign countries. In the USA, the must-carry provisions of the 1992 Cable Act makes it very difficult to carry Channel 2 anywhere other than 54 MHz, so that wider bandwidth at the low end is not available. In Orlando, amplifiers were build that allowed more reverse above the forward spectrum. This proved that more reverse bandwidth is technically available, but this is not thought to be an easy answer.

Asymmetric Services

Another answer is not to waste what bandwidth is available. If a service is asymmetric, then the channels in the downstream and upstream direction should be different, and sized for the service. This is especially true if the demand is for more downstream than upstream bandwidth. The high speed data service is the most obvious example where a smaller (although adequate) upstream channel can save spectrum.

Common Protocols

In the vein of not wasting bandwidth is the concept of having multiple services use the same protocol. In Australia, Optus Vision is using the overhead channel in their telephony product to carry the telemetry information for the utility communication service (load shedding, meter reading, etc.). In the future, use of Asynchronous Transfer Mode (ATM) or other cell-based protocol may allow constant and variable bit rate services, connection and connectionless services, and different bit rates to all use a common language.

A simple first step toward this goal is a MIB developed by Time Warner which allows a management system to move services around in frequency. This means that a system can evolve to new protocols over time by shifting existing services around.

Smaller Nodes

When the problem is too many users (subscribers) of a service, and more bandwidth is not available, then fiber nodes can be split into smaller nodes. This splits the number of users into smaller groups, and frees up capacity. Most systems have installed extra fibers to allow node splitting.

Since the bottlenecks in the reverse and forward direction are different, some approaches treat the two paths differently. For example, a fiber node could have one forward path and four bridger outputs. Each output port could have a different reverse path - either four return lasers, or the four reverse paths could be stacked in frequency and sent back on one fiber.

Cheating

It should be noted that not all services that look interactive in fact are. and many do not use any return bandwidth. Examples include the SEGA channel or Electronic Program Guides, both of which have an interactive feel to the customer, but do not require return channels. Another example is the launch of Enhanced Pay-Per-View in place of a Video-On-Demand - not the same look and feel, but much less capacity-hungry. Obviously, interactive services demanded by subscribers must be delivered, but there are fall-back services that may achieve 80 percent of the goal.

Conclusion

While downstream data capacity looks very promising, there are issues with the upstream direction, which could result in a data bottleneck. Multiple access protocols have been developed which allow many users to share limited capacity and nodes can be split to free up capacity. But, for all the services envisioned on future cable systems, protocols that address multiple services must be developed.