AN OPTIMAL 'FULL-SERVICE' HFC NETWORK

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Abstract:

Dual-cable (one cable upstream, one downstream) is recommended as the best solution to the upstream bandwidth problem. Separate power conductors provide flexibility and adequate capacity for powering the network and user interfaces.

The fiber component is *`fiber as far as we can afford'*.

Optical power is expensive

- *'Linear'* optical power is much more expensive than *`digital'*.
- HFC networks will use `linear' (analog) optical transmitters. A transmitter/receiver pair costs about $15,000. This can be reduced to about $11,000 if fiber runs are shorter than maximum.
- A $15,000 optical TX/RX has a power budget of only 8 dB. This means that even if there were only short lengths of fiber between headed and viewer only 7 TV sets could be served -- about $2,000 per TV set! Under similar conditions a broadband RF amplifier has a power budget of about 40 dB. It could `light up' 10,000 TV sets.

RF power is cheap.

- Broadband RF amplifiers are in the $500 - $1,000 range and serve, on average, several dozen homes (taking into account cable losses in addition to power-division).

Fiber network component of HFC must therefore be amortized over a large number of customers.

- Co-ax network component of HFC is affordable down to level of individual customers

Fiber network is scalable - infinitely expandable in capacity:

Higher bit rates

- Wavelength-division multiplexing
- Additional fibers
- Spare fibers at installation
- Relatively easy replacement or reinforcement of optical fiber cables after initial installation.

The co-ax network is a serious bottleneck - not easily upgraded.

Additional (reinforcing) coaxial cables are expensive and difficult to install, mostly because of their bulk compared to fiber.

- Bandwidth is severely limited. Modem technologies face the *`Shannon information-theory'* limit. We are already packing almost as many `bits/Hz' as information theory allows. Co-ax doesn't have nearly as many useable *`Hz'* as fiber.

What is the practical bandwidth of a co-ax network?

Co-ax cable attenuation is approximately proportional to square root of frequency.

- This favors use of wider bandwidths.

Limitation is the repeater amplifier(s).

- Amplifier bandwidth is not a problem
- Amplifier distortion characteristic is the problem.
  - Distortion characteristics of amplifiers handling `digital signals are different and more favorable than for all-analog signals.
- It is much easier to build a wider-bandwidth repeater amplifier for a network that is *`all-digital'* or *`mostly-digital'* than for an *`all-analog'* or *`mostly-analog'* network.
- Present *`catalog'* bandwidth is 750 MHz.
- 1000 MHz is readily available if a more realistic `mostly digital' distortion spec' is applied.
- Even higher bandwidth (1500 MHz or even 2000 MHz) would be available within one or two years.
- Most repeater amplifier *`platforms'* are already spec'd to 1000 MHz.
- Many *`passives'* -- splitters, couplers, taps, etc. -- are already spec'd to 1000 MHz.
- 1000 MHz co-ax network will be `easy' -- if the loading is *`mostly digital'*.

The coaxial cable bandwidth should be extended to 1,000 MHz. Paraphrasing the late Duchess of Windsor, ***"You can't be too rich, too thin or have too much bandwidth."*** Most *`legacy'* cable-TV systems are being rebuilt to 550 MHz bandwidth, a few to 750 MHz. 750 MHz is the highest *`catalog'* bandwidth from American manufacturers. New `full-service' networks should be have bigger `numbers' than the present `heritage' systems -- more useful bandwidth and more electrical power.

Two-way (bi-directional) transmission in the co-ax network.

Alternative techniques:

- Frequency division
- Space-division (dual cables)

- Frequency division -- spectrum allocation -- *`upstream'*
  - `High end' vs `low end'.
    - *`Cable-TV'* systems are obliged to maintain FCC channels 2-13 (54-216 MHz) for analog TV (VSB-AM) channels (downstream).
    - This leaves practical options of:
      - 5-40 MHz (35 MHz) *(sub-low)*
      - 900-1000 MHz (100 MHz) *(high end)*

`Low-end'* or *`high-end' reverse path?

`Low End'!!

- `High end' reverse path caps the forward path bandwidth.
- Once set it will be practically impossible to expand bandwidth in future.
- It is easier to predict reverse path bandwidth requirement than forward path.

    - If one of these paths has to be `capped' let it be the reverse path.
    - Filters in 900 MHz region waste a lot of spectrum (100 MHz) compared to filters at lower frequencies.
- 5-40 MHz isn't much bandwidth
  - Reducing node size helps, but is expensive - increases number of expensive optical TX/RX's
  - Improved access technologies (DAMA, etc.) increase utility of restricted bandwidth

The more reverse-path bandwidth per customer the larger our nodes can be:

- Major cost reduction - trades off expensive fiber network for cheaper coaxial cable.

A better solution! -- <u>Dual-cable!</u>

- A dedicated second co-ax cable for reverse path -- 0.625".

Co-ax cable attenuation (P-III) (dB/100')

Size	450 MHz	550 MHz	750 MHz	1000 MHz
0.625"	1.30	1.45	1.72	2.03

- Trunk repeater spacing (22 dB) in 0.625" co-ax at 1,000 MHz would be 1,080'
  - Signal launch levels from subscribers' premises would not have to be excessively high because much of the attenuation in the reverse-path is due to *`passives'* which have *`flat'* loss characteristics.

Dual co-ax trunk-feeder-drop - to interface at customer `entrance'

- Various cable/wire options inside.

Unrestrained reverse-path bandwidth allocation!

Unrestrained forward-path bandwidth allocation!

Dual-co-ax networks are not uncommon.

- I built several large dual-coax networks in the early '80s.
  - Suburban Chicago - now owned by TCI and recently used for very successful NVOD/PPV trial.
  - Fairfax County (Virginia suburbs of Washington, DC) - now serves 240,000 subscribers.
  - 50 miles of dual-coax -- one forward and one reverse -- as adjunct to Fairfax County system

New `full-service' networks should be *`dual-cable'* -- two 1,000 MHz co-axial cables -- one for the `forward' path and one for *`reverse'* path. **The present 5-40 MHz *`sub-low'* reverse path allocation in a single cable is grossly inadequate. It is like building a super-highway with eight lanes in one direction and a dirt track in the other.** The ideal network has equal bandwidth in each direction. Who can reliably predict the degree of unsymmetry (if any) of traffic in these new networks? The best way is to provide symmetrical, adequate two-way capacity is with two cables - one for each service direction ..... 1000 MHz in each direction!

Alternatively, the second cable could be split to provide both forward and reverse bandwidth - `1-1/2' cables forward and `1/2' cable reverse.

Reverse path bandwidth examples:

Sub-low - 35 MHz - bandwidth per feeder:

Com' Channels per feeder	BW per channel
50	700 KHz
100	350 KHz
200	175KHz
500	70 KHz
1000	35 KHz

High-end - 100 MHz - bandwidth per feeder:

Com' Channels per feeder	BW per channel
50	2000 KHz
100	1000 KHz
200	500 KHz
500	200 KHz
1000	100 KHz

Second cable - 950 MHz - bandwidth per feeder:

Com' Channels per feeder	BW per channel
50	19 MHz
100	9.5 MHz
200	4.8 MHz
500	1.9 MHz
1000	1.0 MHz

We could provide a dedicate 950 KHz channel full-time to each of 1,000 users! Multiple-access technologies, e.g. DAMA, allow even more users per node.

MAXIMIZE DIGITAL TRANSMISSION

Digital transmission is better than analog in every respect. Digital picture quality is much better than with conventional `NTSC-analog' TV transmission. Minimize analog-TV services to minimum permitted by regulation. All `premium' TV services, i.e. those needing conditional access (addressable scrambling) should be digital. Hughes DirecTv has shown the practicability and viewer-appeal of digital TV transmission (my emphasis):

> *TELEVISION DIGEST via NewsNet*
> *Monday December 26, 1994*
>
> *DBS's 150-channel service "is a hoot," Washington Post TV critic Tom Shales said in ecstatic Dec. 21 report. Shales, who said he subscribes to both $29.95-per-month DirecTv and $34.95 USSB, called DBS "greatest new toy since the VCR, with* ***pictures so sharp and rich that it's as if a veil were lifted from in front of the screen. Cable cannot compare.*** *" He praised on-screen program guide, but noted that service can be subject to rain fade and doesn't include local channels.*

Electric Power In Co-Ax Networks

`Cable-powering' (60V AC on the center-conductor) is customary

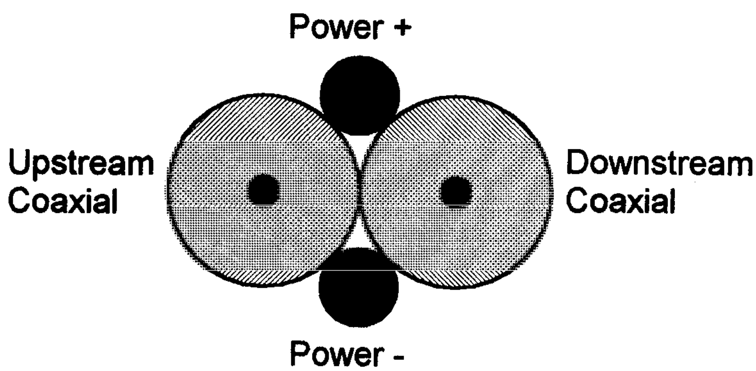
- Problems:
    - Requires RF `chokes' in electronic equipment to separate power and RF. Difficult to provide good RF spec's when RF/power bypass is required.
- Power handling limitations because of relatively high resistance of co-ax cable center-conductor.
    - .625" cable - center conductor 0.136" diameter

- Al center -- 0.86 Ω / M'
- Cu center -- 0.55 Ω / M'

- High loop resistance limits ability to power supplemental network equipment, such as interfaces at customer premises entrance.
- Aluminum cable material creates electrogalvanic corrosion problems - necessitating use of AC.
- DC would be much more efficient.
- Low cost standby power provisioning

Separate (copper) power conductor would solve these problems.

- DC operation is feasible.
- Easy standby power provision.
- No electric power in RF carrying cables and components.
- Very low ohmic resistance. Conductor to at least #2 (AWG) size is practical (0.156 Ω / 1000').
- Moderately expensive - but worth it. A #2 copper wire (200 lbs of copper / 1000') costs almost as much as a .625" coax cable.
- Would allow network powering of user-interface equipment.



CABLE BUNDLE