

Part IV – Wireline Multiuser Examples

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Parts 3 and 4: Outline/Schedule

- 2:00-2:45 MU Theory
- 2:45-3:30 channels for wireline
- 3:30-4:00 Coffee
- 4:00-4:30 DSL and Ethernet arch
- 4:30-5:15 Multiuser improvements

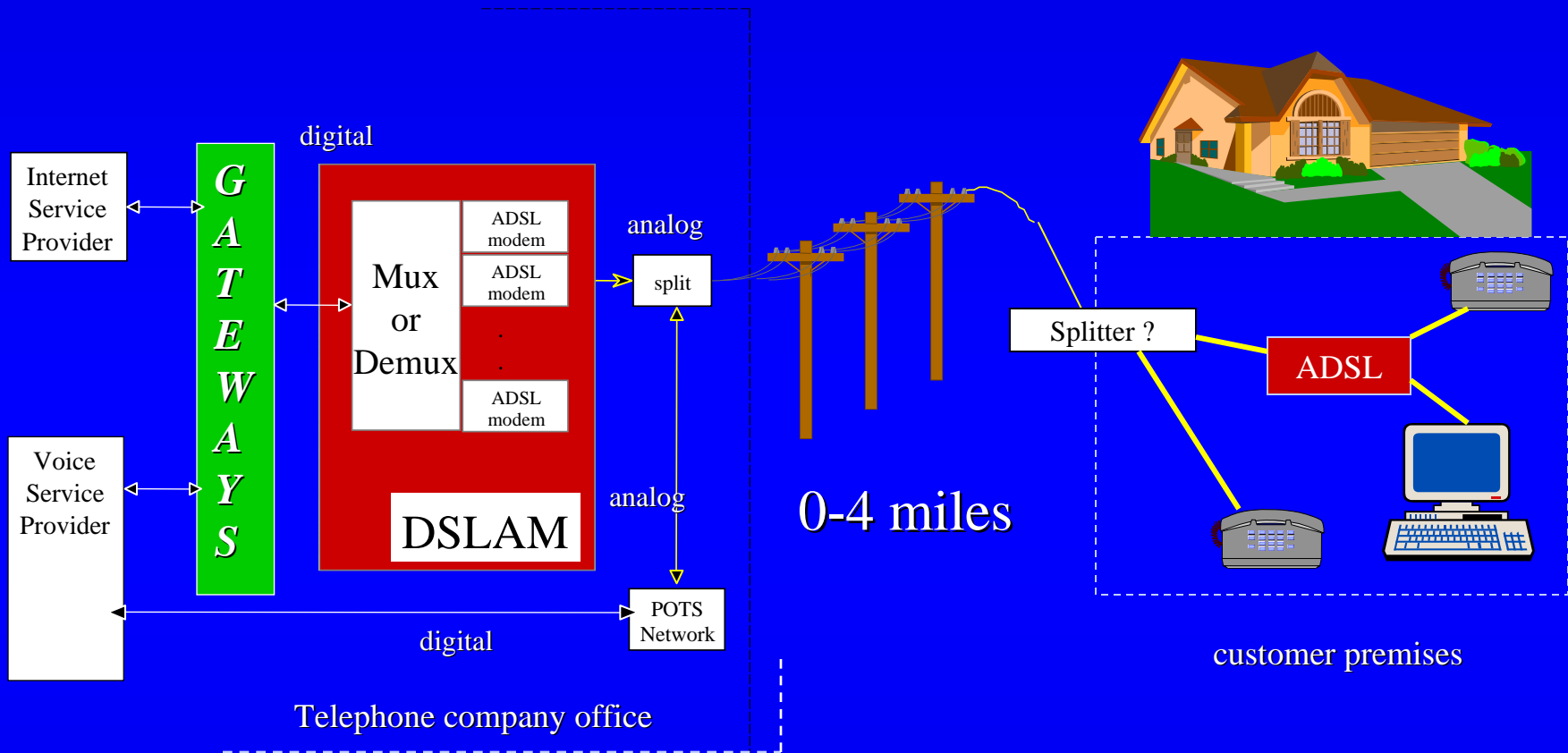


Outline – Part 4

- DSL and Ethernet Applications
- Evolution of DSL and DSM vs SM
 - ◆ Unbundling
 - ◆ Towards ethernet
- Multiuser Spectrum Balancing
- Vectored VDSL
- Vectored Ethernet



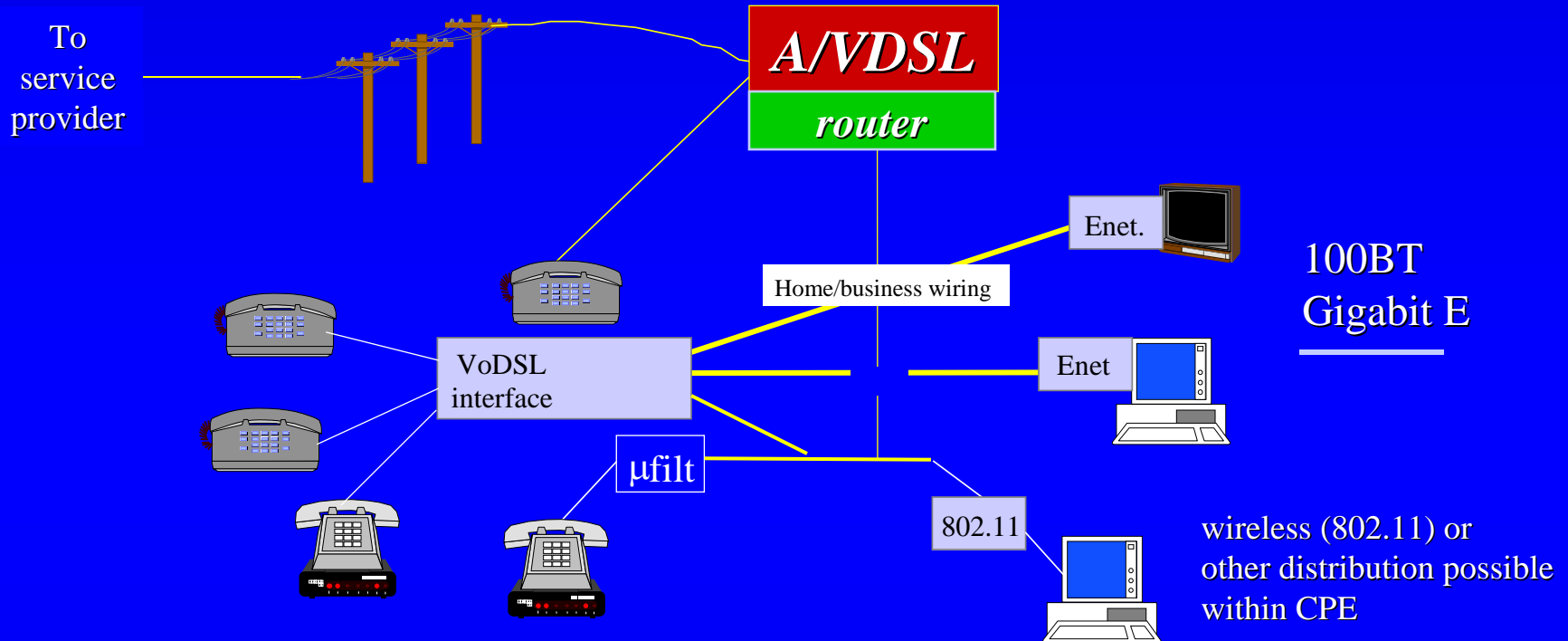
DSL in 2001



- Data, some voice beginning, to 1.5/5 Mbps
- Conservative deployments (9 Million lines)



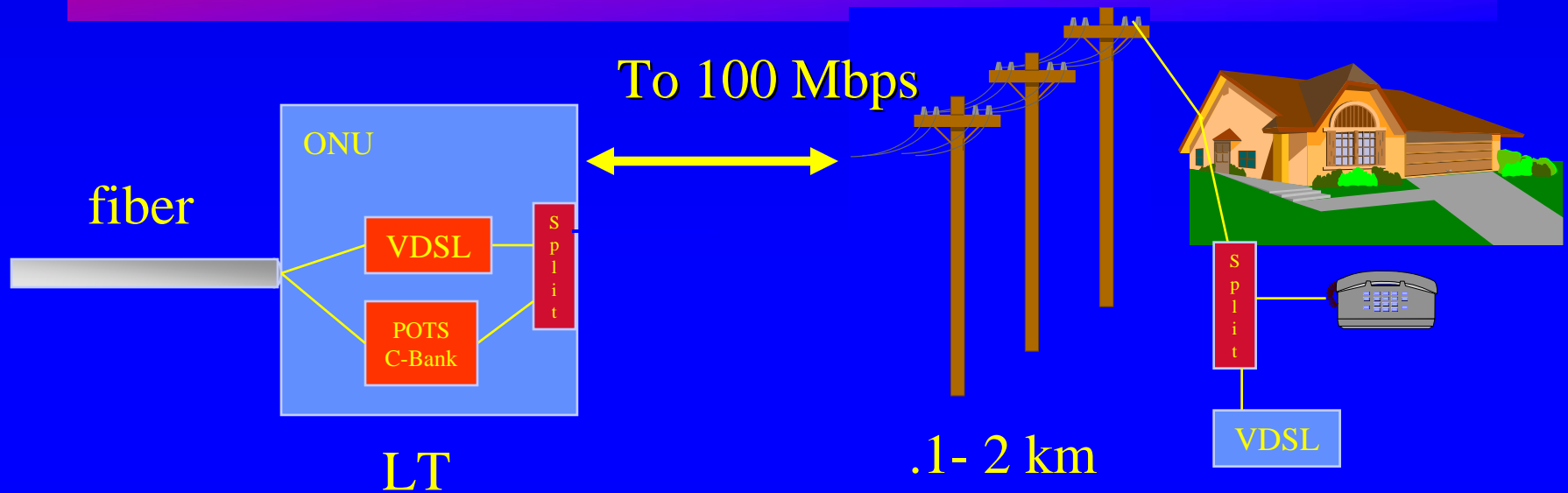
DSL Future Applications



- Multiline voice (VoDSL)
- Video (internet, packet based)
 - ◆ Not likely “traditional” TV
- Small Businesses – less asymmetric



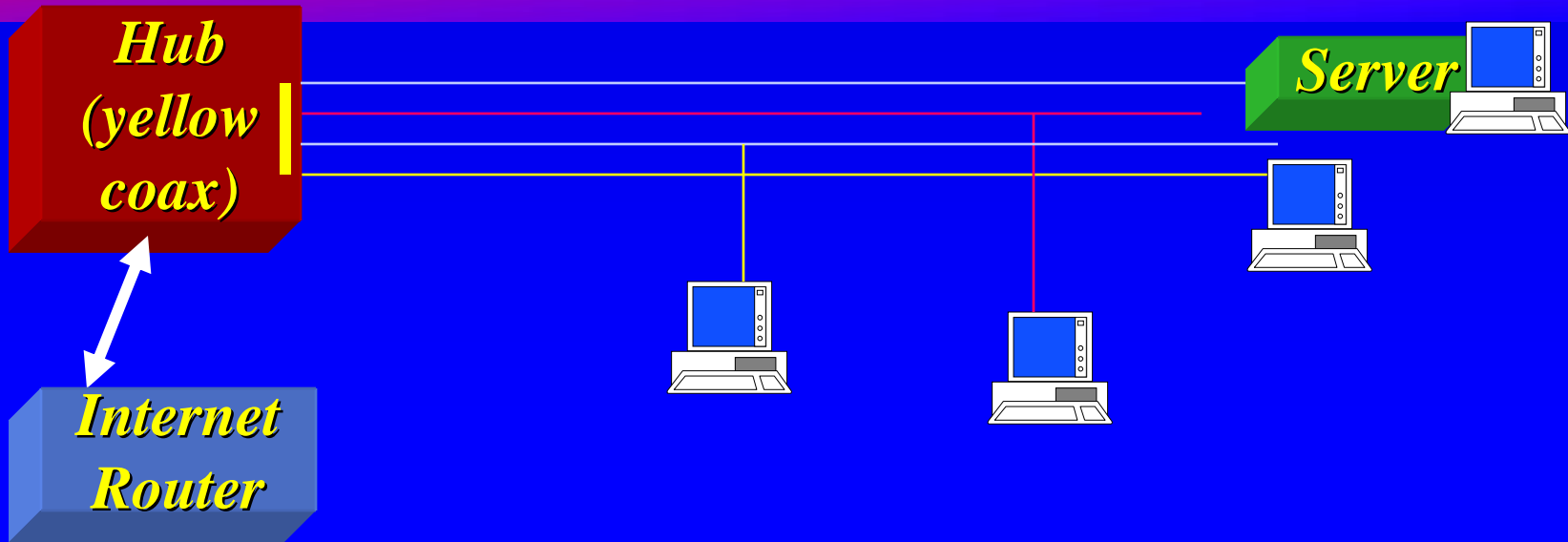
Part Fiber, Part DSL = VDSL



- Only 12,000 of 10^7 businesses connected by fiber all the way – essentially 0 residences
 - ◆ Rather ONU's/remote terminals, incrementally with time
- How long is fiber? Twisted-Pair?
 - ◆ Incremental trade-off with time/demand



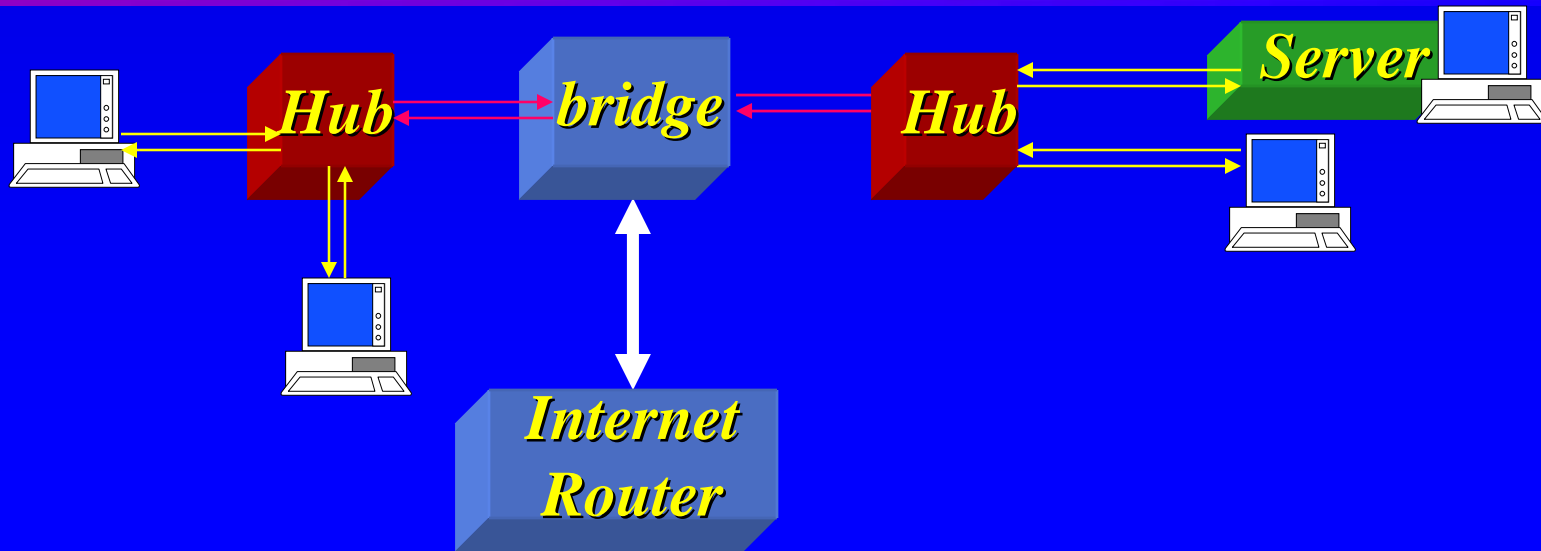
Ethernet – 10BT



- STAR wiring – collision detection not really used
 - ◆ Hub is electronic version of a “coax-wired” connection
 - ◆ All lines on Hub share the 10 Mbps
- 100’s millions deployed on copper
 - ◆ Manchester coding
 - ◆ Category 5 tp (20 dB less xtalk than phone lines- cat 3, 24 gauge)
 - ◆ Each line is 2 pairs (so 2 of 4 in cat 5)
- 100 meters (systems run longer)
 - ◆ Result of delay specification related to days in which HUB was a coax.



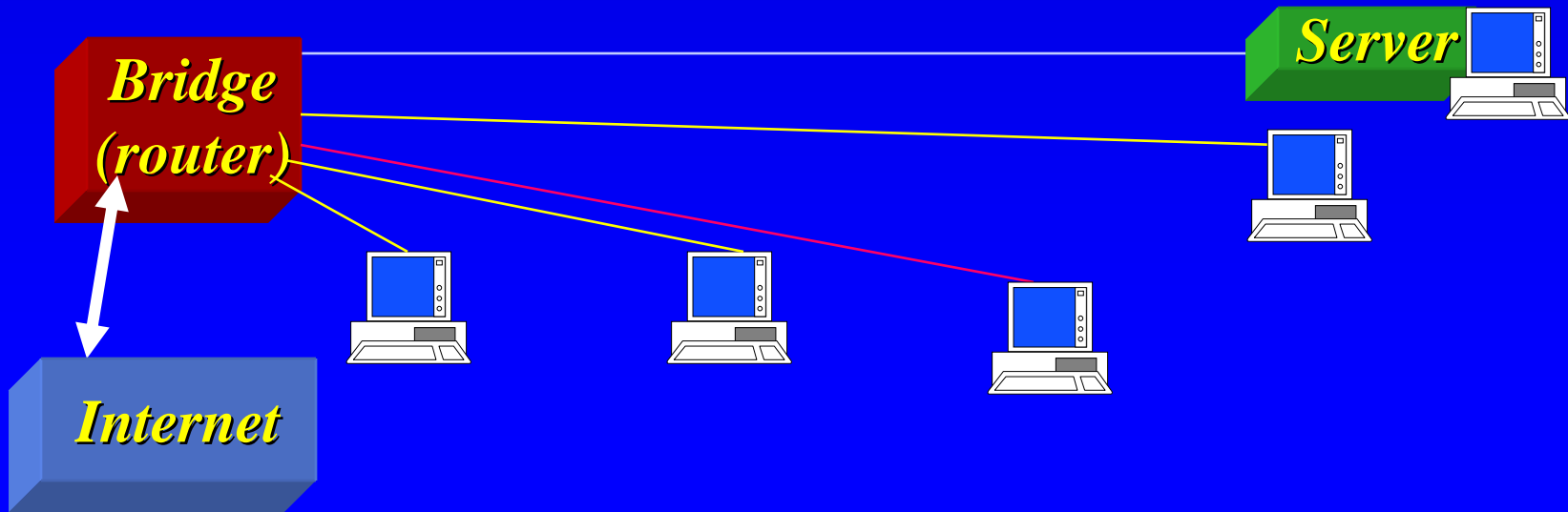
Introduction of Bridges



- Little higher level than Hub, which is an electronic version of a “yellow coax”
- Allows each line’s 10 Mbps to be different
- Dedicated connection to each user



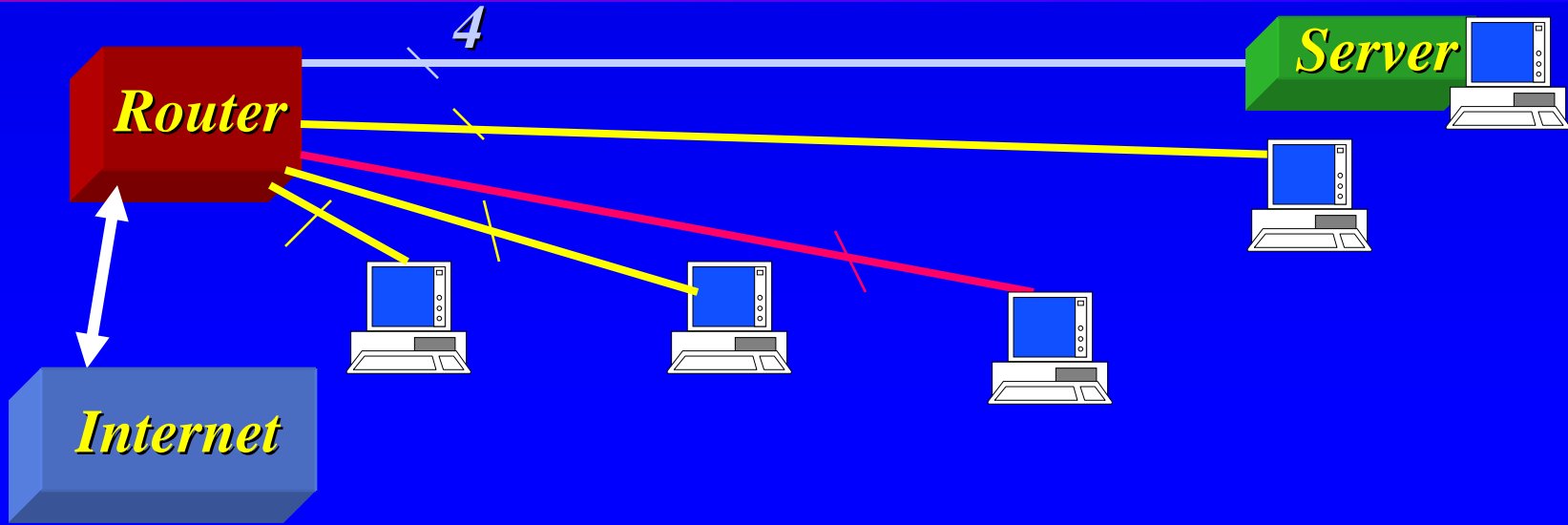
Ethernet – 100BT



- Each user gets 100 Mbps, dedicated link
- MLT3 code (4B5B to ternary) – 125 MHz
- 100 meter range – back compatible with 10BT
 - ◆ Data sent when packets available
 - ◆ Delay spec really not needed on link anymore
 - ◆ Remains a 2-wire duplex situation
 - ◆ Lead suppliers do 170m range



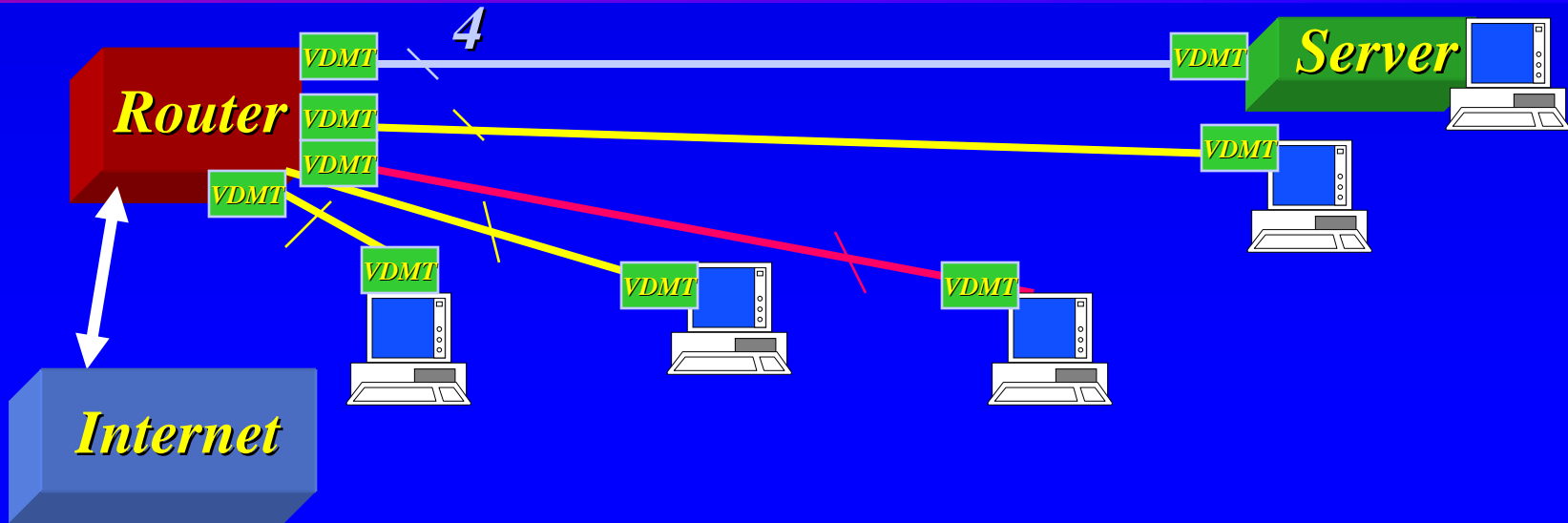
Ethernet – 1000BT



- Continuous, 250 Mbps on each of 4 lines for 1 Gbps total
 - ◆ Continuous only
 - ◆ All 4 wires in cat 5 used by a single user in duplex, echo-cancelled fashion
 - ◆ 125 MHz 5-level (effective 4, or 2 bits) PAM on each line
- 100 meters – physical layer constraint (lead suppliers do 160 m)



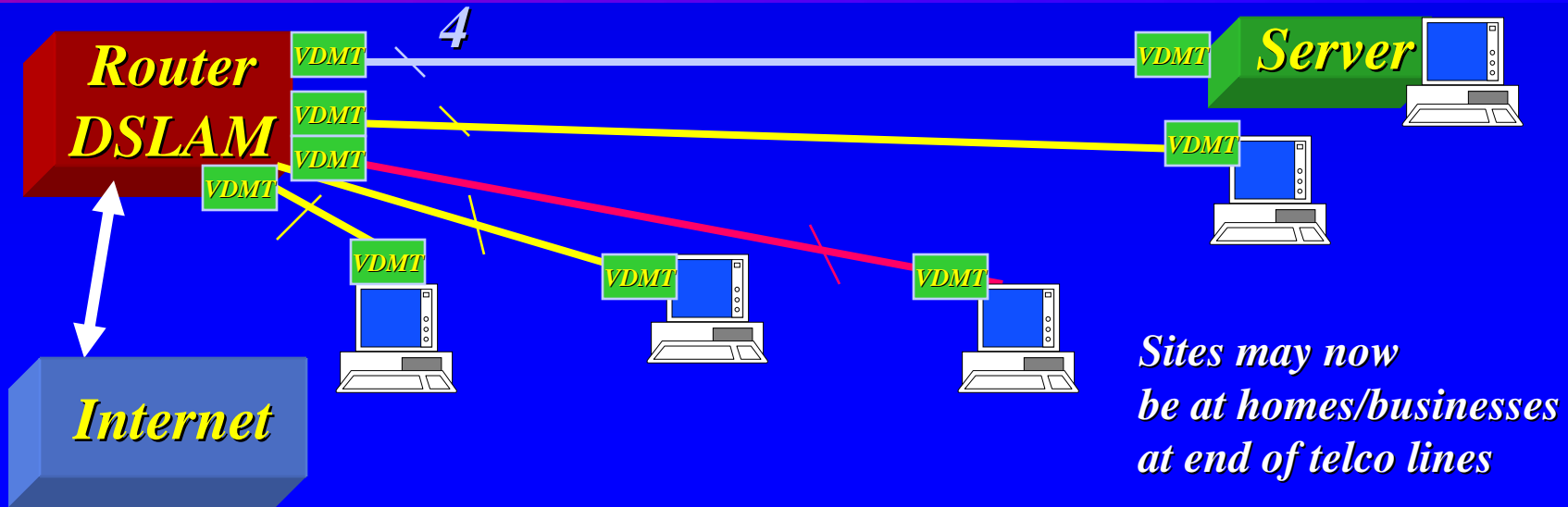
Ethernet Faster?



- 10,000BT – vectored multiuser, 100 meters



Ethernet – longer (EFM)



- VDSL=VDMT
- 100BT (4 wires) > 1 km
- Single wire – very high speeds,
 - ◆ Distance/rate tradeoff
- Vectored/spectrally balanced – number of pairs allocated, etc.

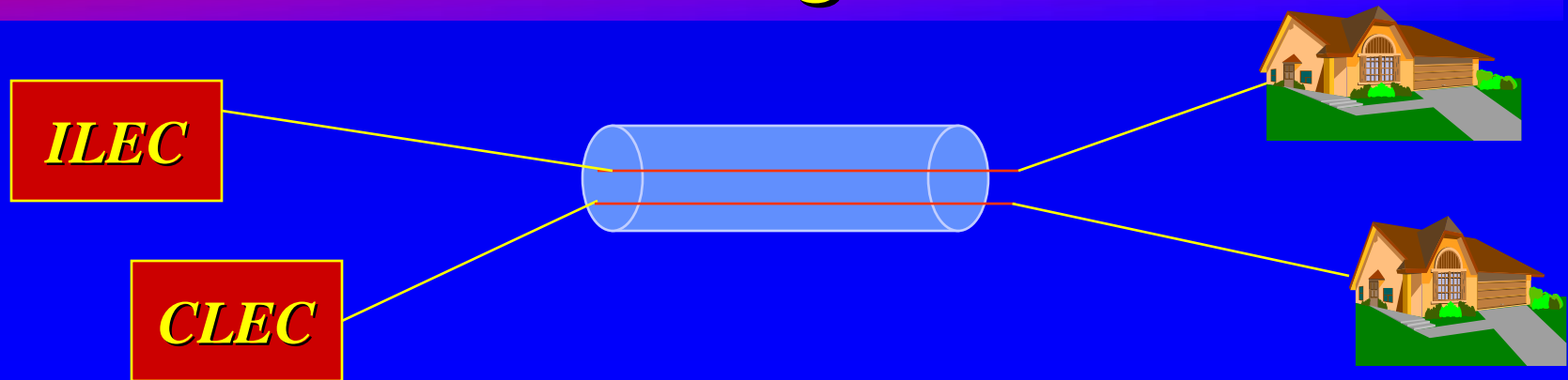


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Unbundling in DSL



- Different service providers can “rent” lines to customers
 - ◆ Consequent emissions between lines (crosstalk)
 - ☞ Gets worse with wider bandwidths (shorter lines)
 - ◆ Can be reduced with asymmetric transmission
- ILEC – often wants asymmetric
- CLEC – often wants symmetric

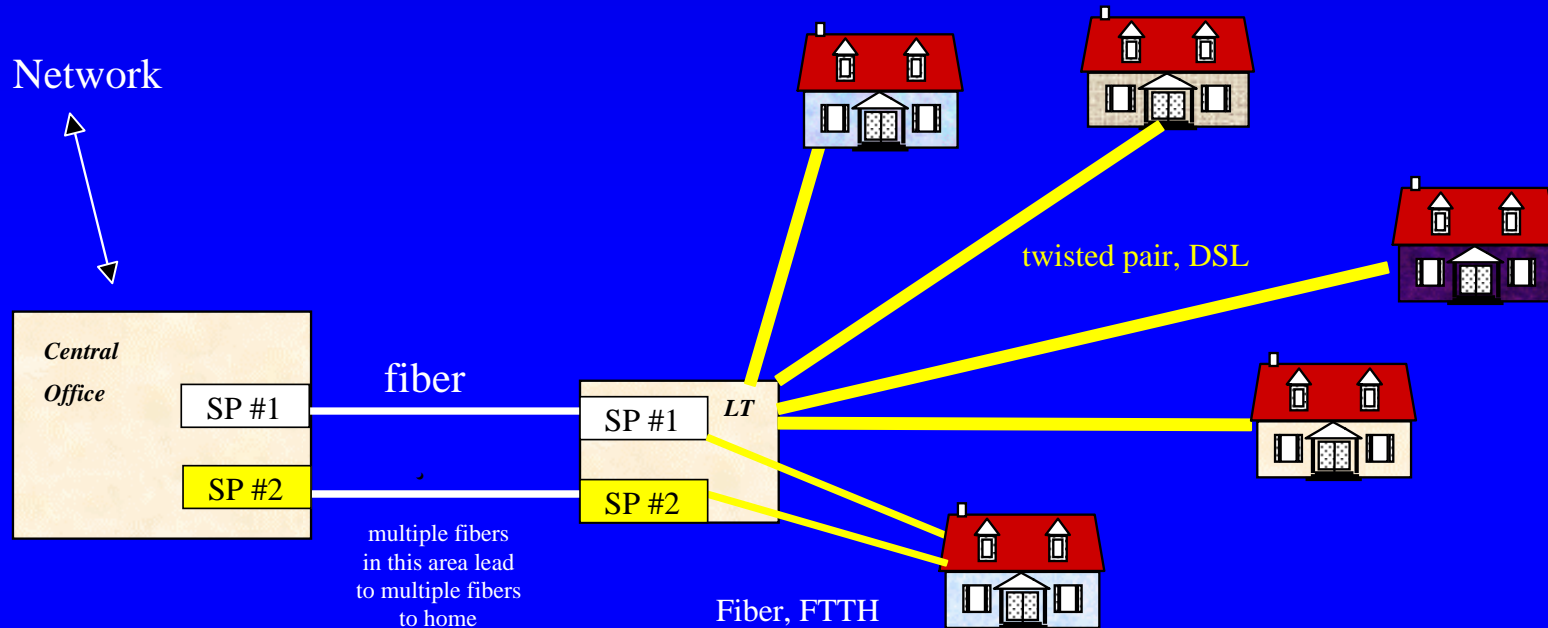


Spectrum Management

- Regulate the spectra of the different service providers within the cable
 - ◆ Minimize radiation between cables
 - ◆ Balance interest of symmetric/asymmetric (CLEC/ILEC)
- Fixed spectra defined for each type of DSL service, no matter where it is used in the world
 - ◆ **STATIC** spectrum management
- CO-based SM before FCC for approval
- ONU/fiber-feed case still under study



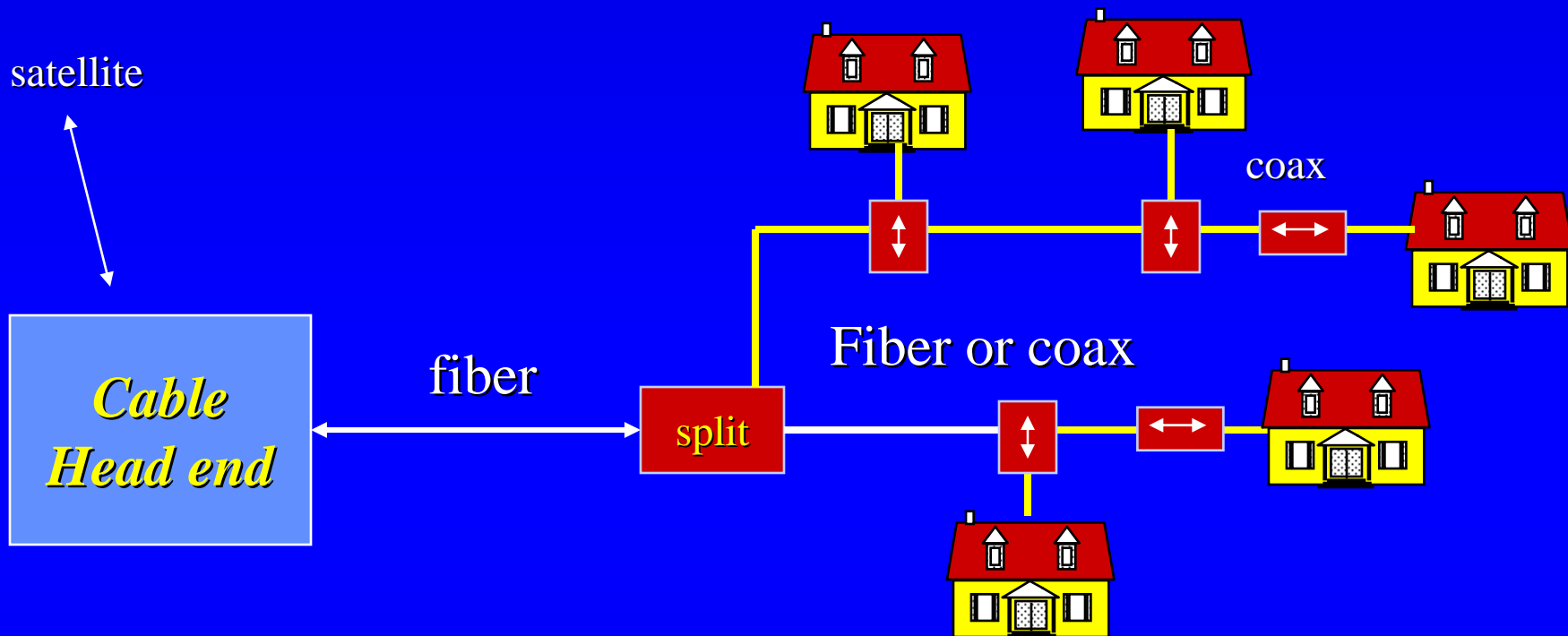
DSL Line-Unbundled Evolution?



- Fiber for each service provider?
- Space at LT for each service provider?



HFC – Hybrid Fiber Coax

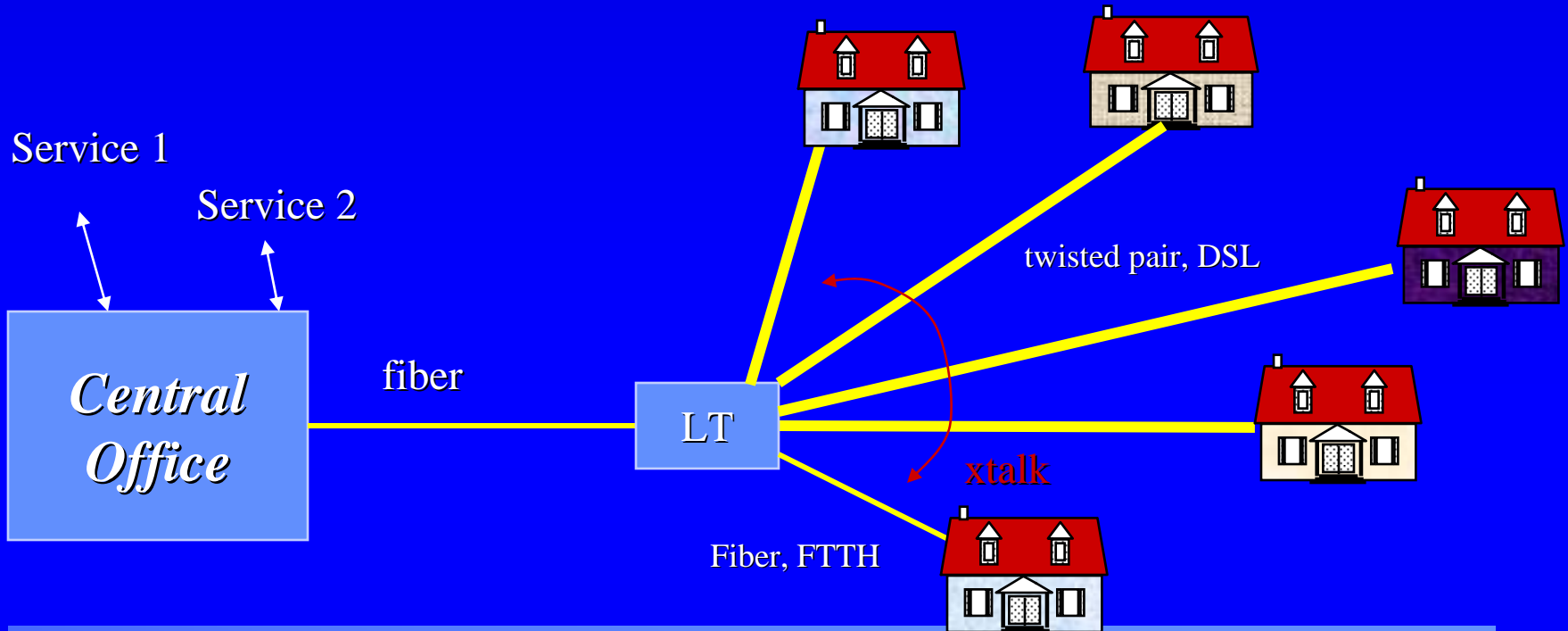


- **Fiber from head end to first split**

- ◆ More bandwidth, easier bidirectionally
- ◆ Coax still shared among 100's of users (500)
- ◆ Multiple content providers, unbundling?



Packet Unbundling

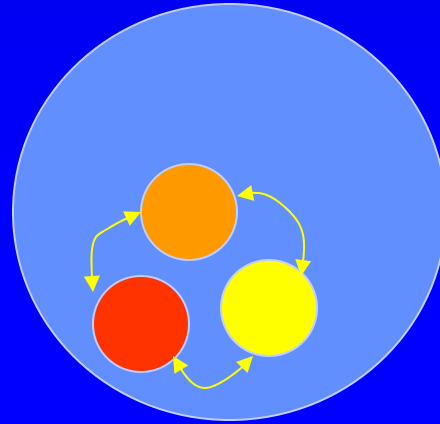


- Single fiber/LT controlled by one service provider
 - ◆ SBC example: FCC allowed in Sept 2000 at LT only
- Services unbundled at packet level
- MAC in LT to control crosstalk problems
 - ◆ Dynamic spectrum management



The Main Technology Issue

(a prime app for MU)

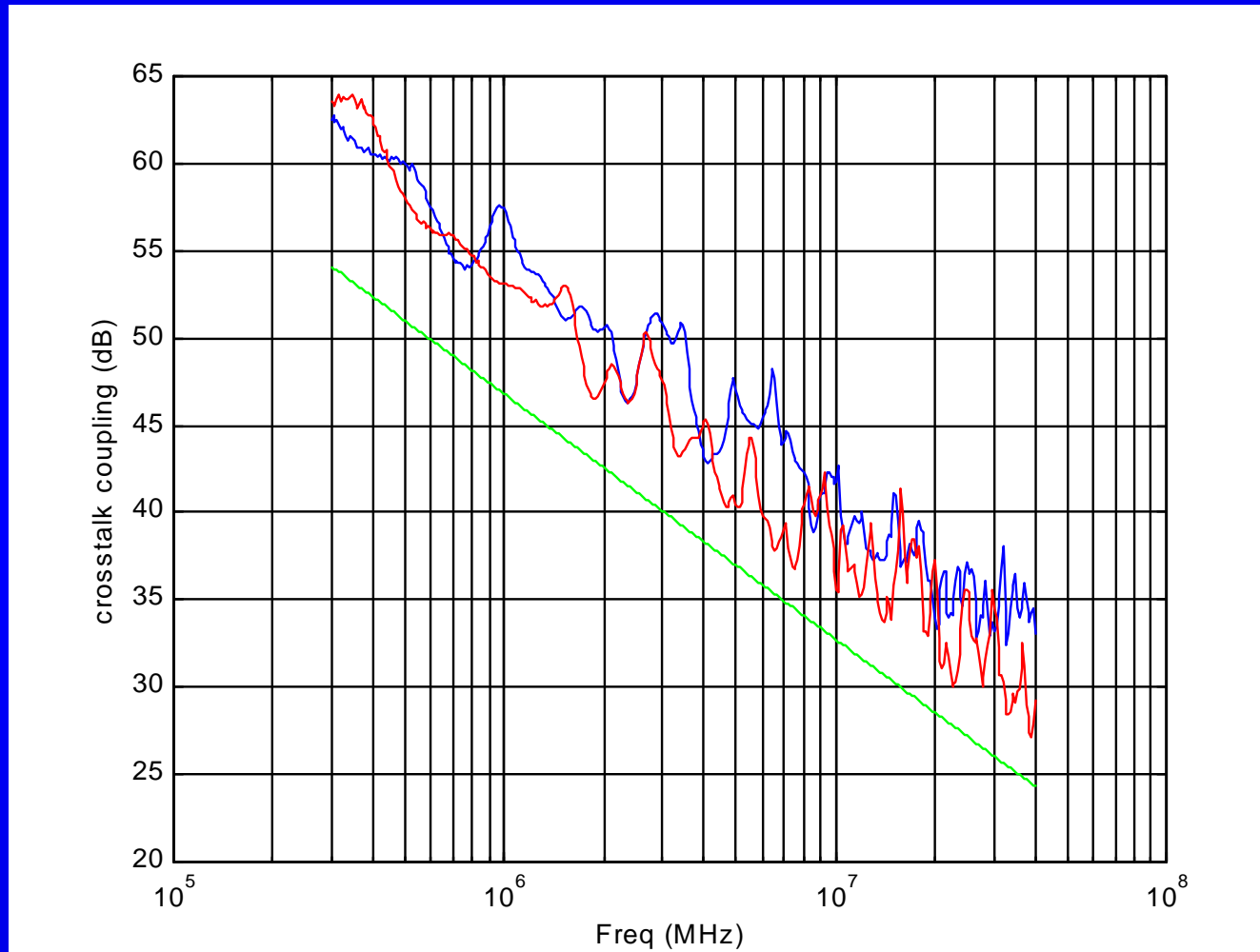


Cross-section of cable
Also, space

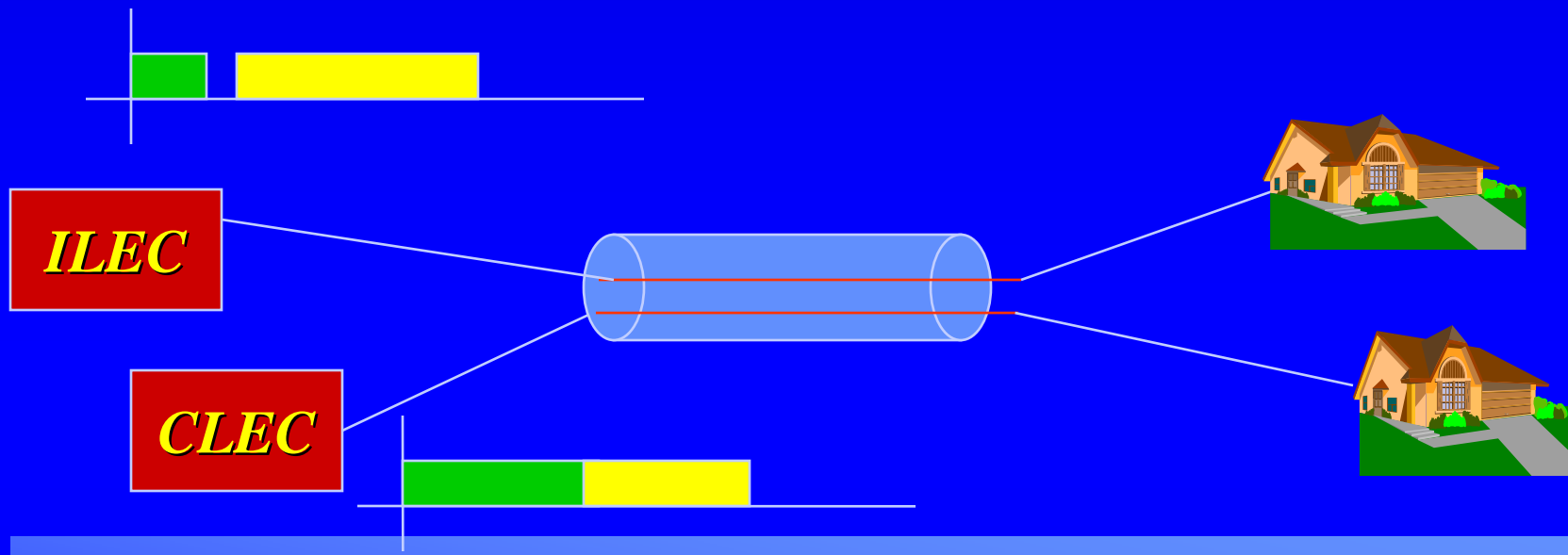
- Crosstalk – interference between lines
 - ◆ Increases with frequency (data rate)
 - ◆ Largest source of noise and performance loss
 - ◆ Requires spectrum management



xtalk coupling “resistance”



Static Spectrum Management



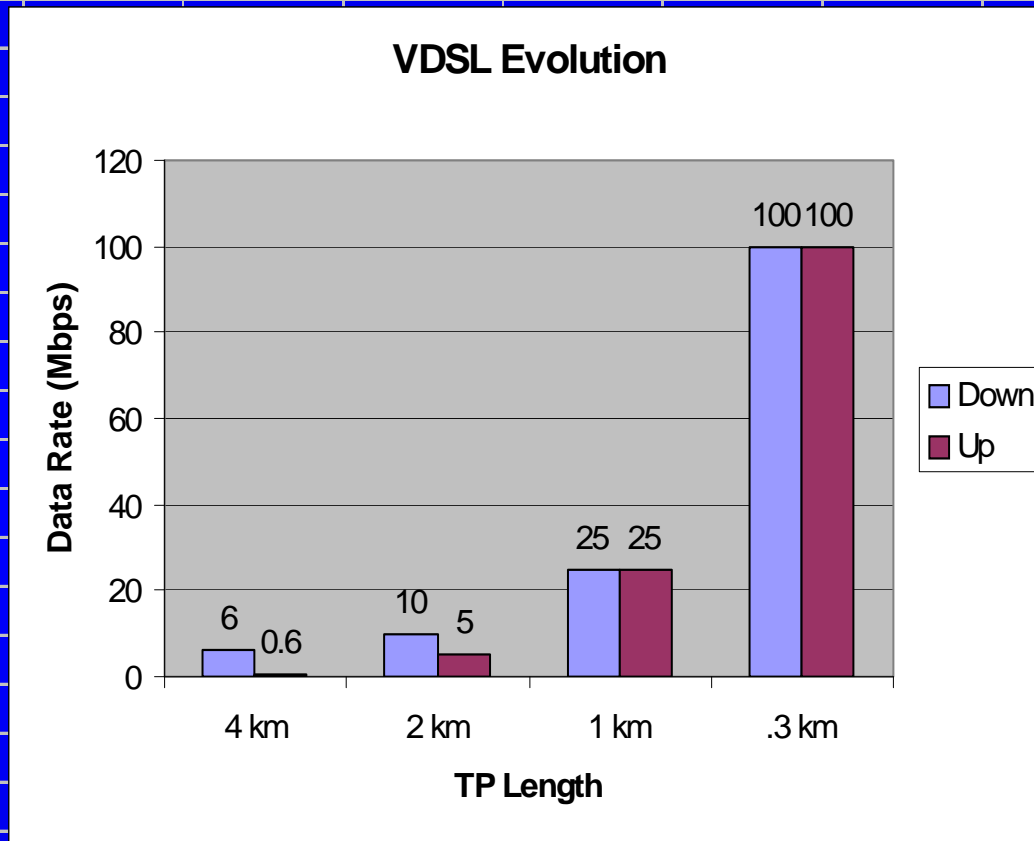
- Up (green) does not like down (yellow)
 - ◆ Avoid overlap of yellow with green = static SM
- Fix allocations to compromise ILEC/CLEC
 - ◆ but xtalk/lines are different as are customers in each location

DYNAMIC SM = MU Methods

- Line spectra/signals varied according to situation
 - ◆ Data rates/symmetries of customers
 - ◆ Relative line lengths
 - ◆ Topology of cable loops
- Large Improvements Possible
- Migration Strategy to DSL/DSM of future necessary
 - ◆ Line to packet unbundling
 - ◆ Static to dynamic spectrum management



DSL Evolution Goal



ADSL

VDSL

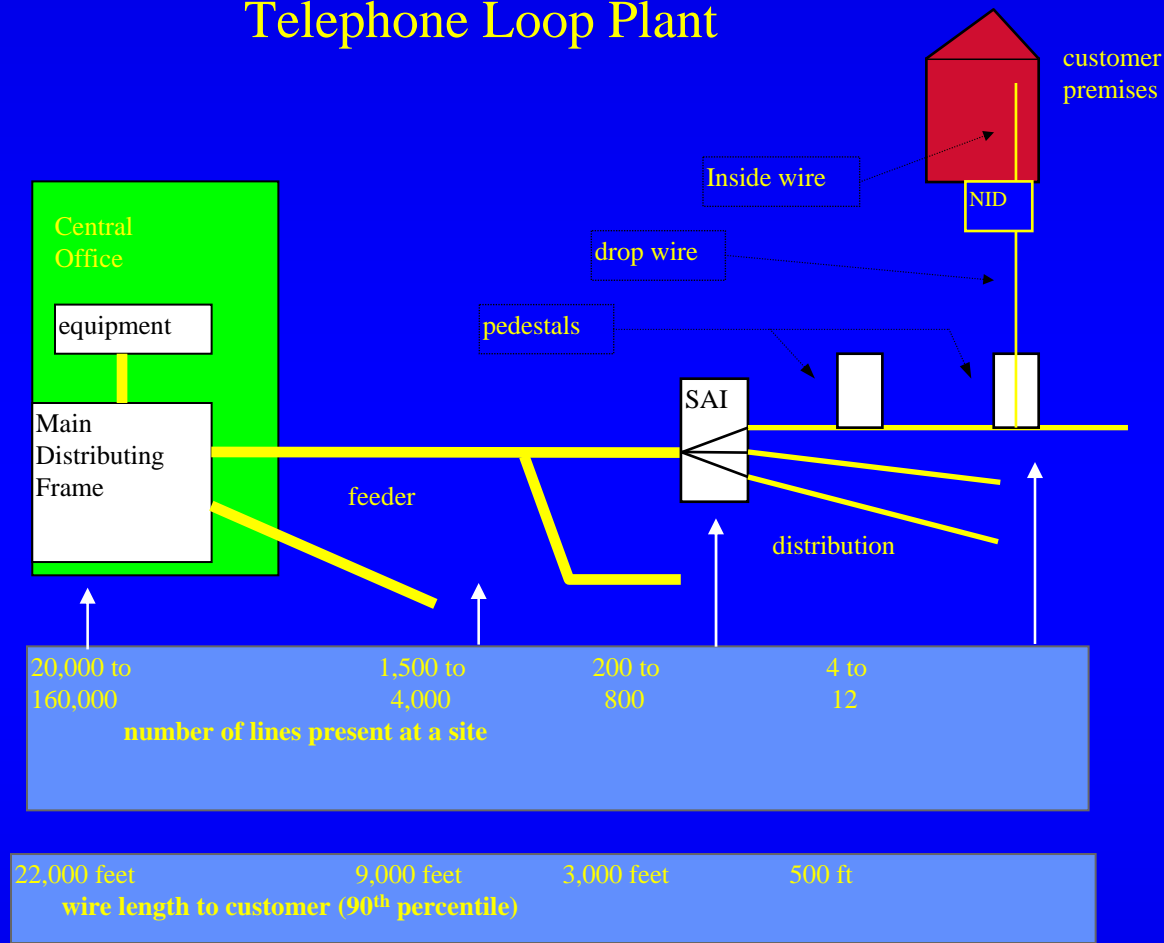
VDSL-EFM

VEFM



Loop Plant of a Service Provider

Telephone Loop Plant



- Convenient points

- ◆ RT, SAI (distribution node), pedestal



Dynamic Spectrum Management Steps

- Spectrum balancing – line unbundling
 - ◆ For existing “line unbundling” situation where 3rd party can make recommendations to individual lines, all or some
 - ◆ Evolution to packet unbundling where situations are mixed pac/line
 - ◆ Implementation possible with current ADSL, VDSL systems
- Vectoring – packet unbundling
 - ◆ Lines coordinated at ONU side (or CO side) in terms of signals placed on the line (packet unbundling)
 - ◆ Highest possible performance levels, shortest lines
 - ◆ Add-on (backward compatible) with ADSL, VDSL



Towards Ethernet

- DSLAMs
 - ◆ Move toward customer
 - ◆ Speeds go up and DSM used
 - ◆ Ethernet reused on top of DSL
- Multiuser methods
 - ◆ Spectrum balancing
 - ◆ Vectoring
 - ◆ Combination of pairs to get 10, 100, or 1000



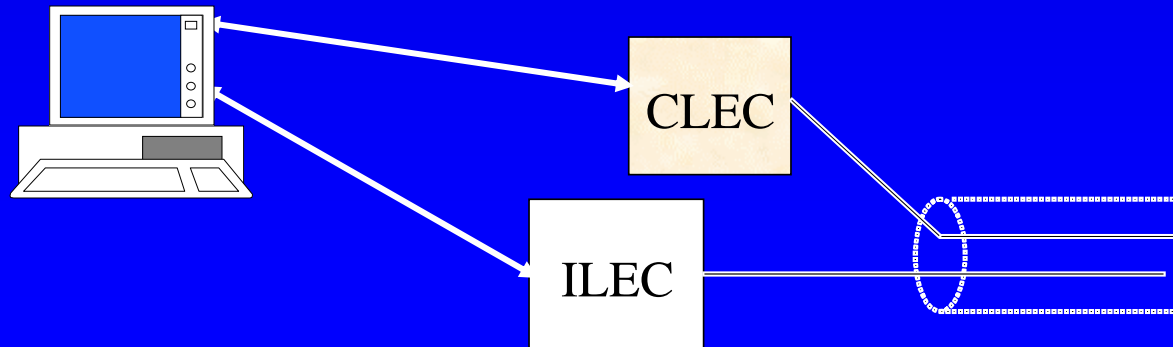
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Spectrum Balancing

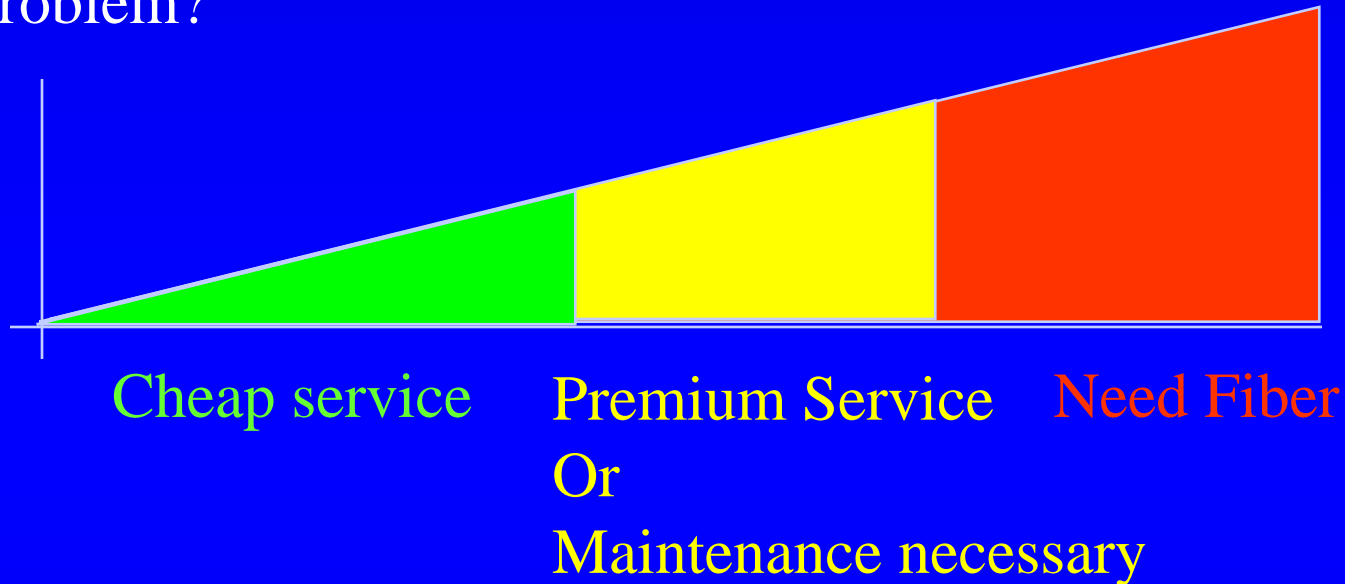
Central DSM/DSL Maintenance



- Lines report information
 - ◆ Helps with deployment, problem isolation
 - ◆ Can be used for DSM
 - ☞ Cent main recommends line spectra

Translation to Telco Terms

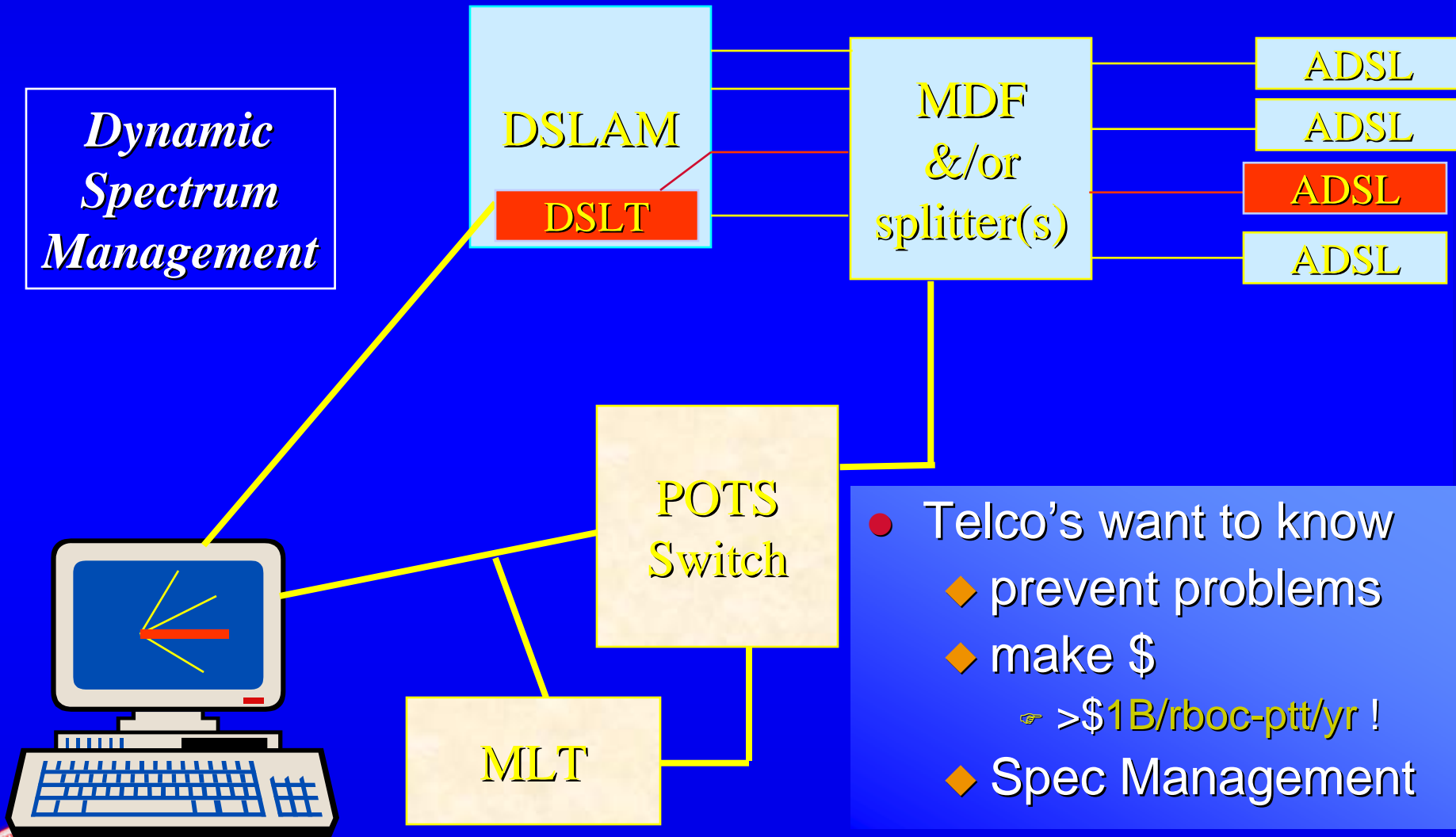
Problem?



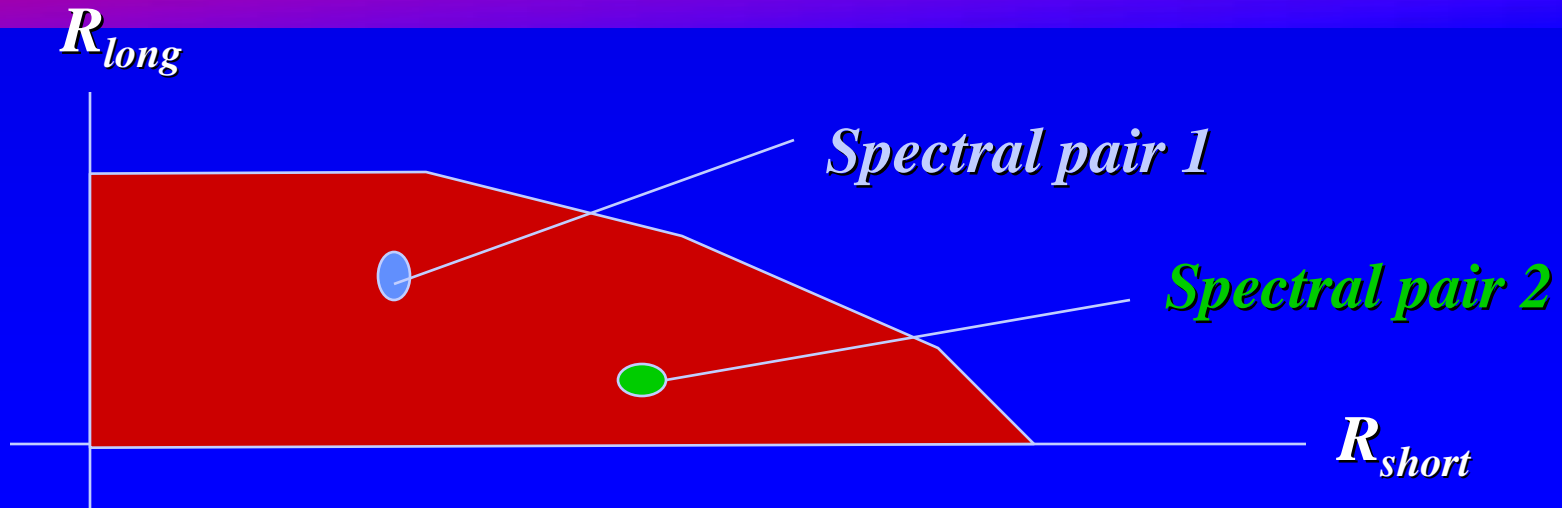
- time of day
- as available
- guaranteed



Network Maintenance



Rate REGIONS



- Plot of all possible rates of lines
 - ◆ Upstream
 - ◆ Downstream
- Any point in region is possible, but each with different spectra
 - ◆ Varies for each cable and loop topology
 - ◆ Varies for each combination of desired (allowed) rates



Simple Example –PBO

- 4 lines at 3000' (7.8 Mbps upstream)
- Line at 500, 1000, 1500, 2000, 2500'
- Compare against best SSM
 - ◆ Very little coordination (power of line, rate)

	<i>Ref length(SSM)</i>	<i>iterwater.</i>
<i>500</i>	<i>14.0</i>	<i>28.5</i>
<i>1000</i>	<i>11.5</i>	<i>24.0</i>
<i>1500</i>	<i>10.0</i>	<i>19.5</i>
<i>2000</i>	<i>9.0</i>	<i>15.5</i>
<i>2500</i>	<i>8.5</i>	<i>11.0</i>



So far, Static SM

- Plans

- ◆ 998 (USA) – more asymmetric



- ◆ 997 (Europe) – more symmetric



- ◆ Flex plan

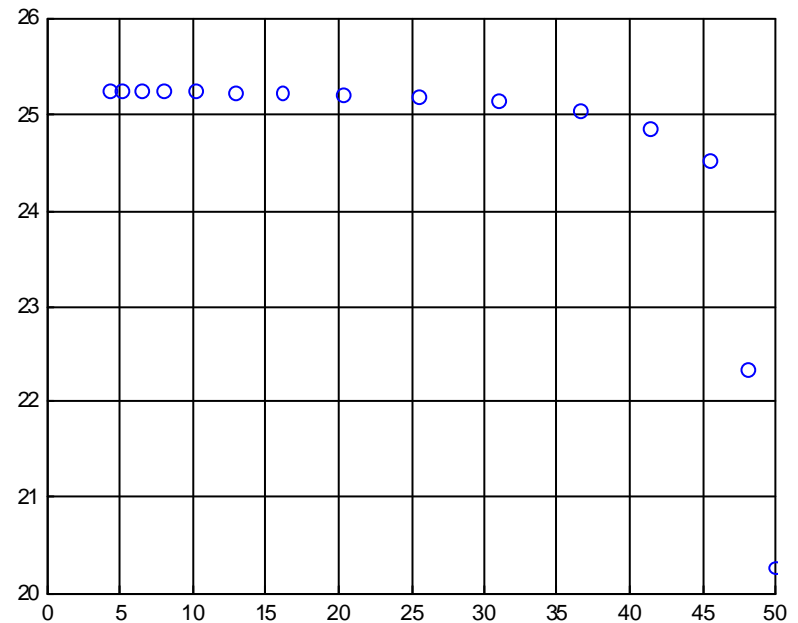
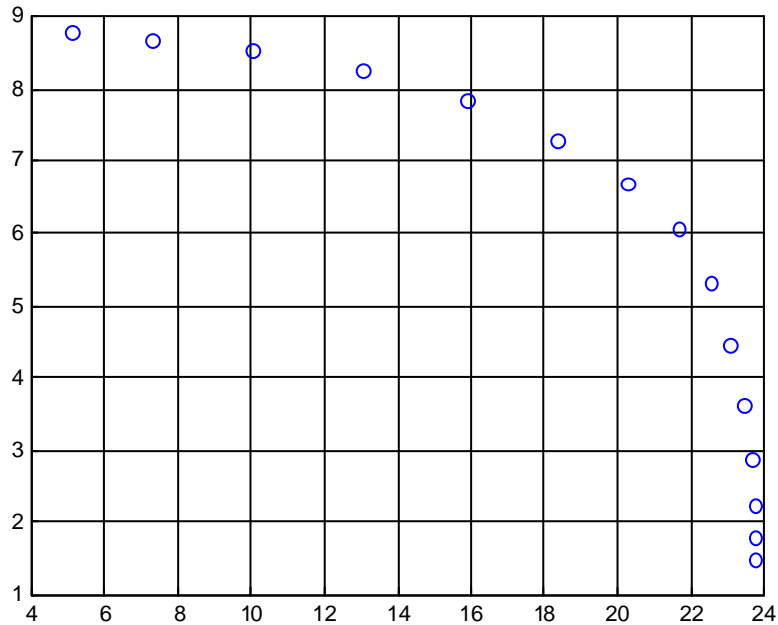
- ☞ Number of bands programmable
- ☞ Start/stop frequencies programmable
- ☞ USA VDSL Standard – part 3 (allows DSM)



998 with spectrum balancing

Up

Down

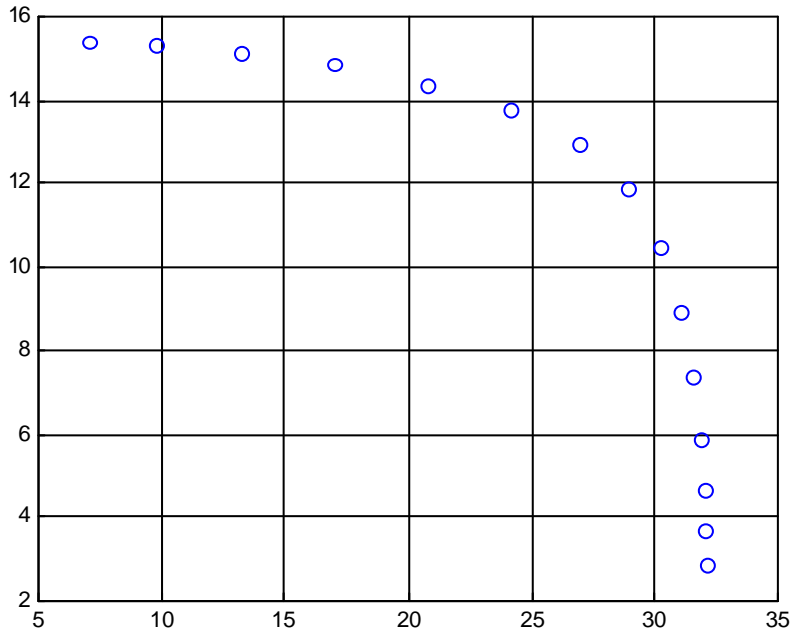


- Line 1500 ft versus 3000 ft
- 26/6 on 3000' while 30/22 on 1500'
- Static SM only 18/1.5 and 6/6

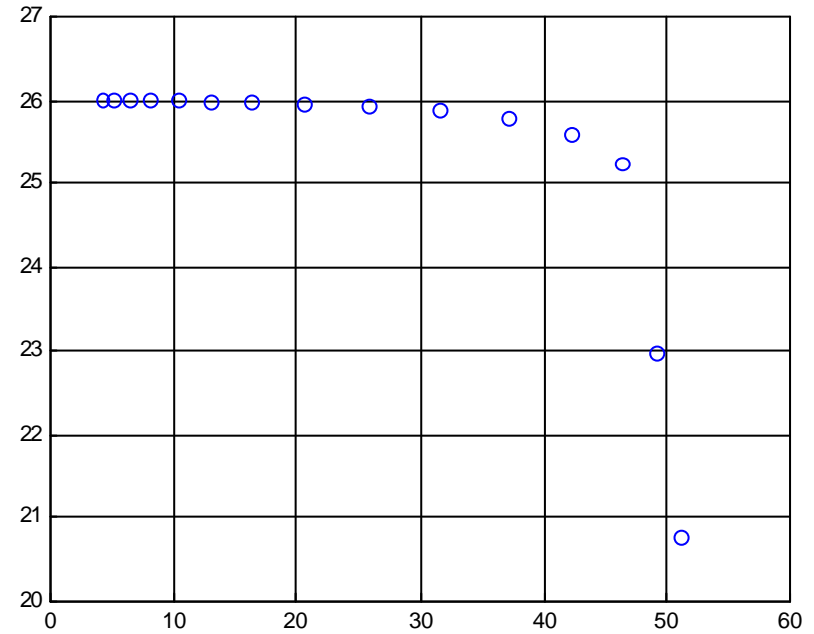


flex with spectrum balancing

Up



Down

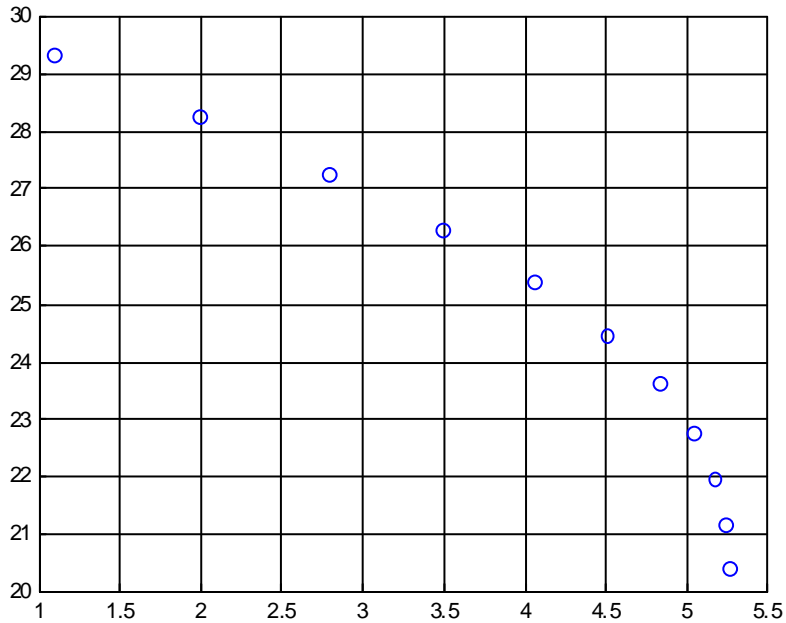


- Line 1500 ft versus 3000 ft.
- 26/13 Mbps on 3000', 52/26 Mbps on 1500'

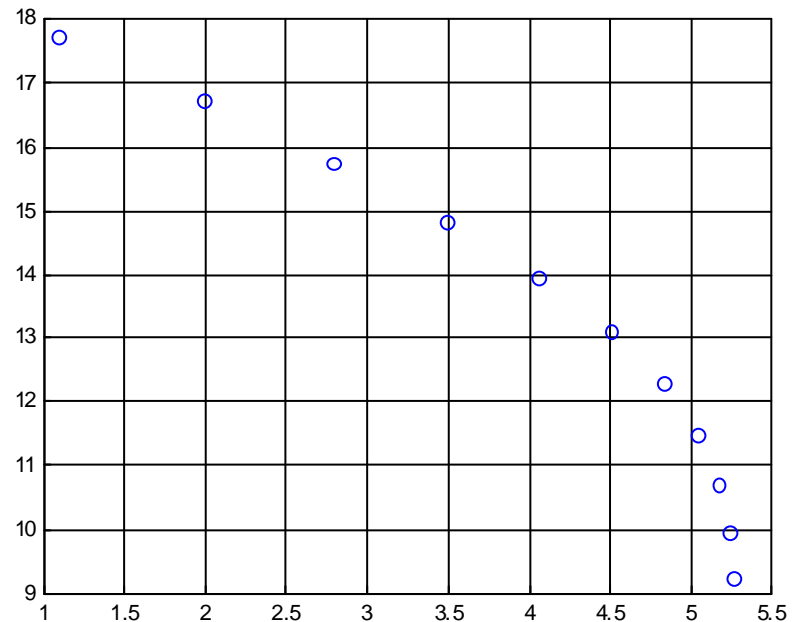


VDSL and ADSL

Down 3000'



Down 4500'

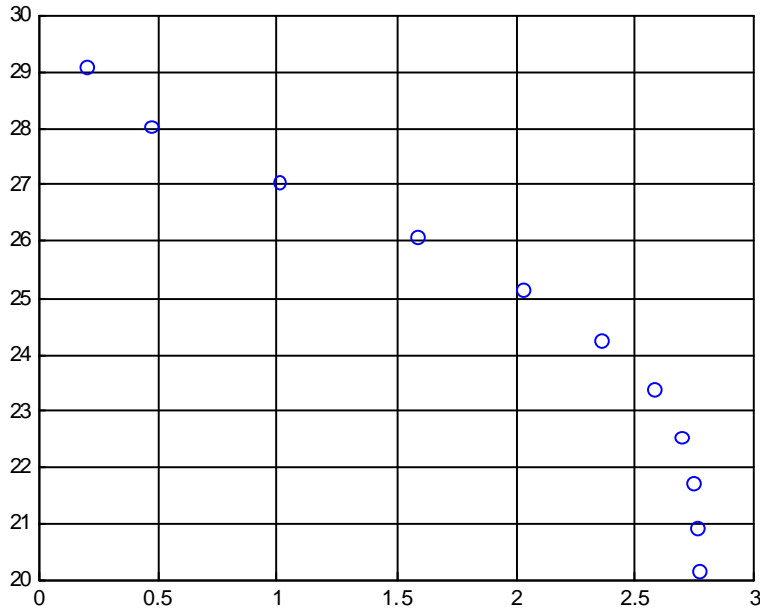


- Yellow on short line acts like green
- 9000' ADSL (fig 6)
- 26/3 possible on 3000' VDSL while ADSL runs 5/.5.

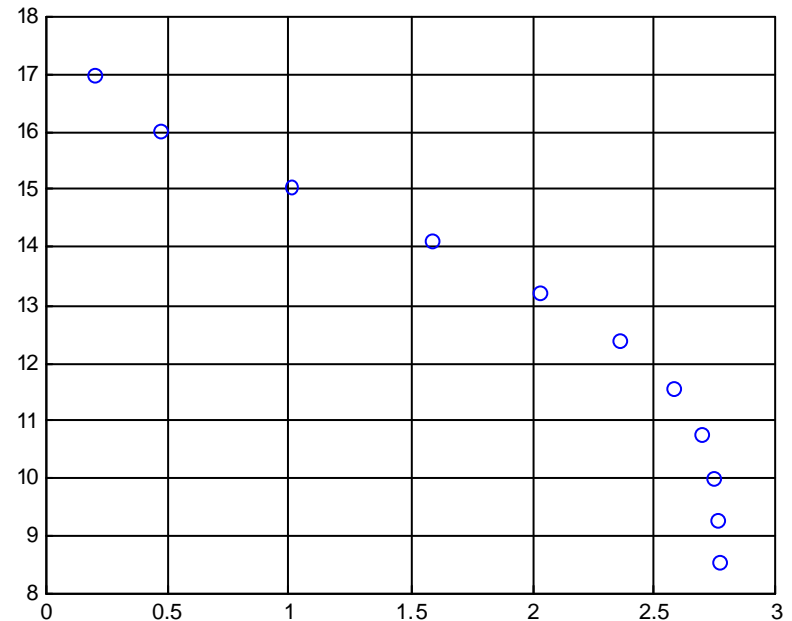


VDSL and ADSL with Hdsl/Idsn

Down 3000'



Down 4500'



● 9000' ADSL

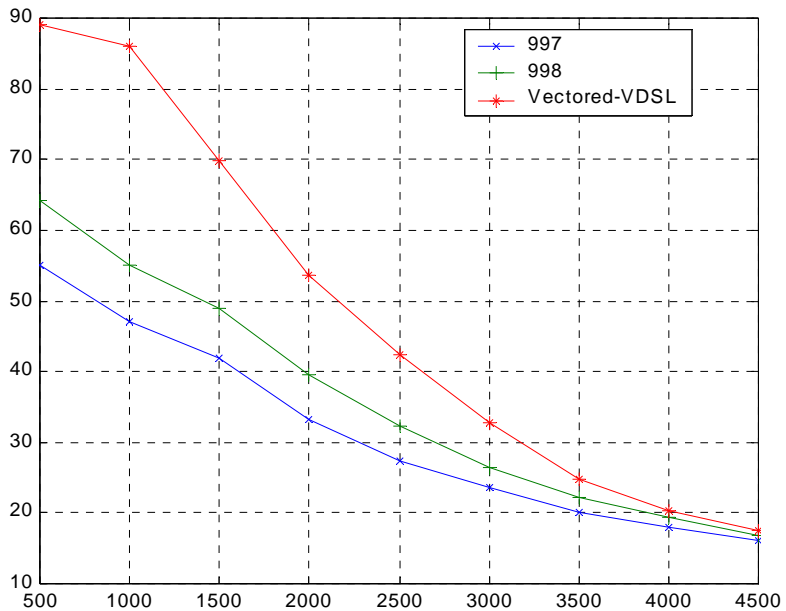


Outline – Part 4

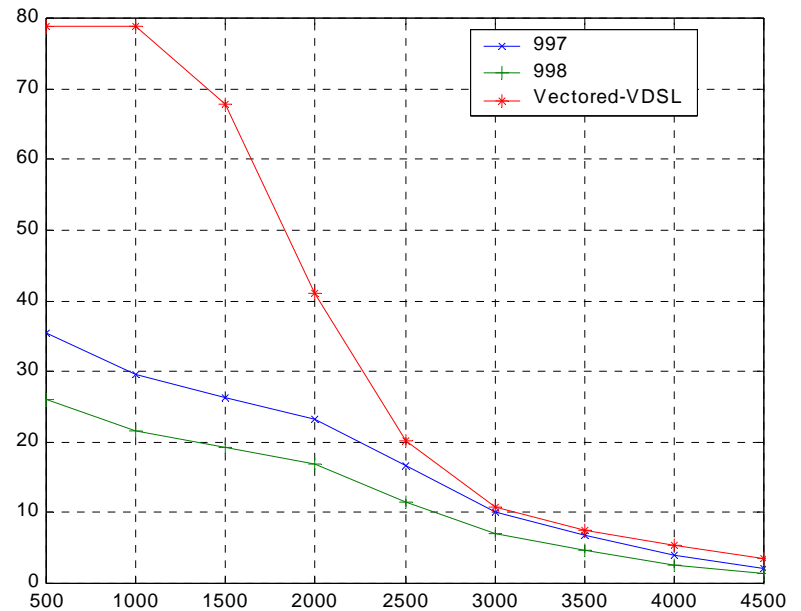
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Vectoring Results



Down

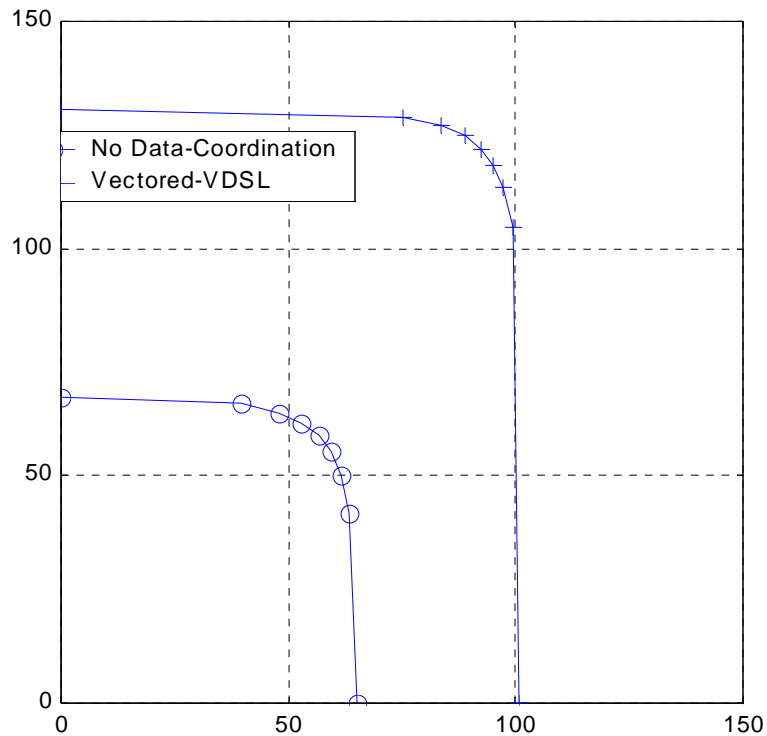


Up (see correction)

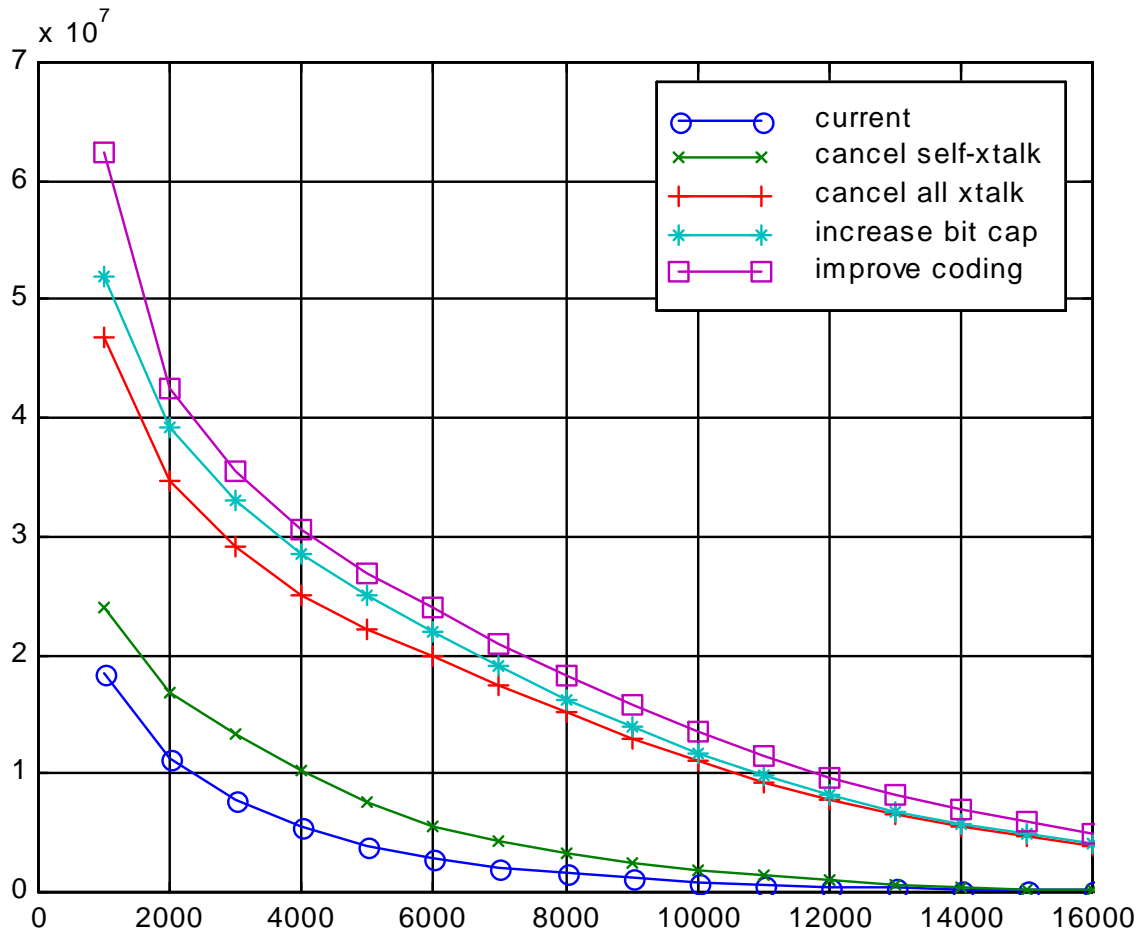


Rate Regions

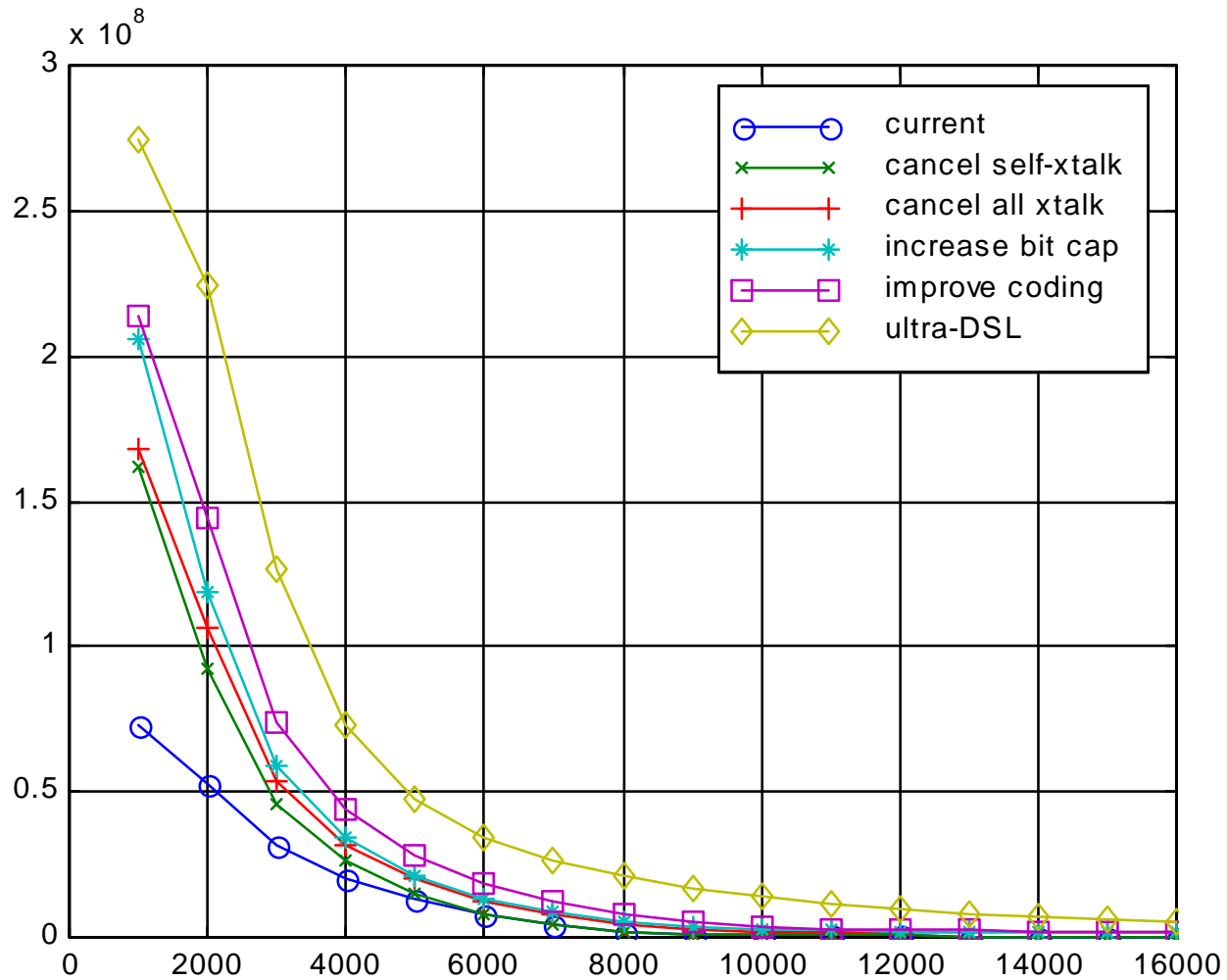
- Last slide had all lines same length
- Rate Region allows tradeoffs between lines (1500, 1000)



How much better can we do? (ADSL)



Ultimate VDSL

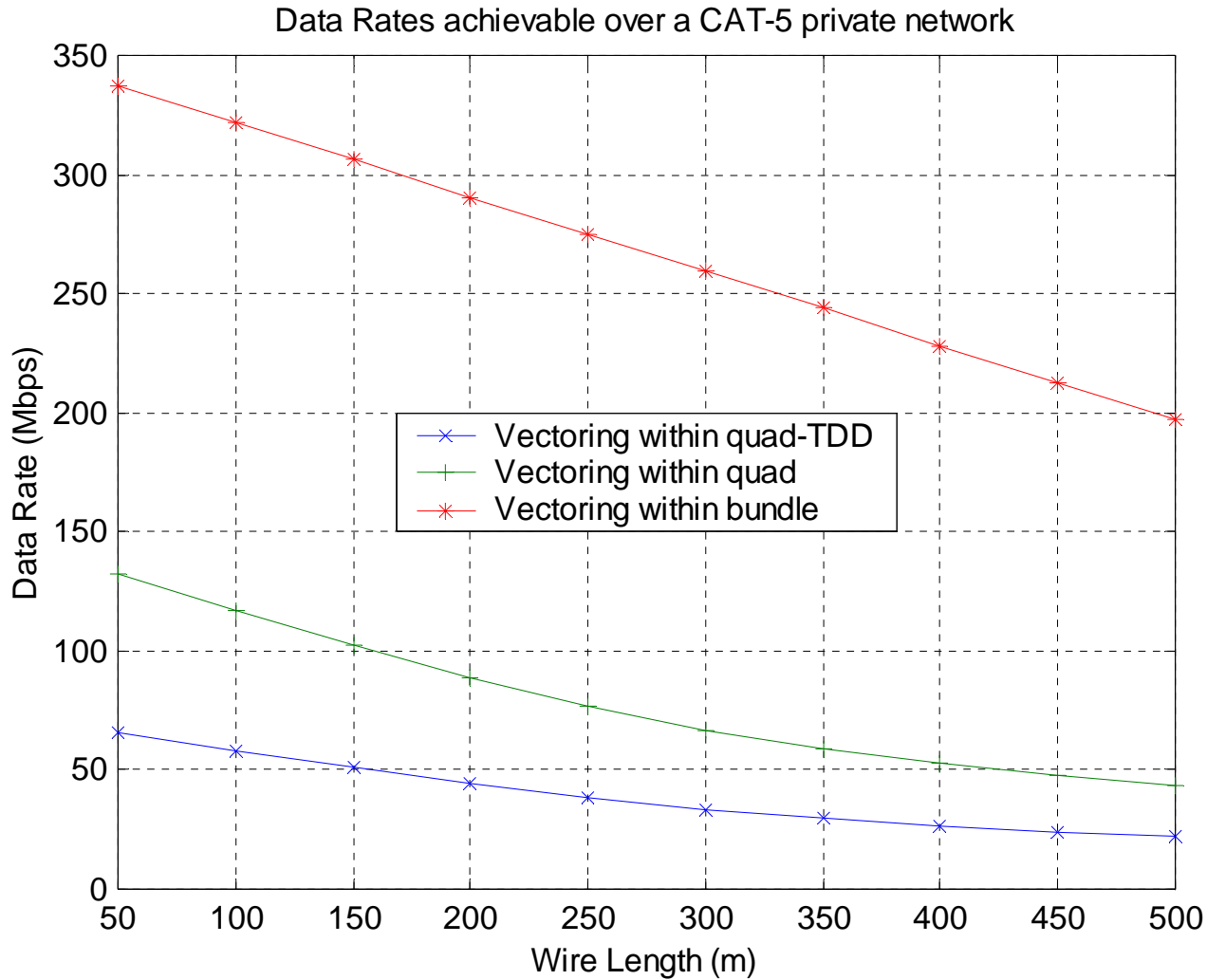


Outline – Part 4

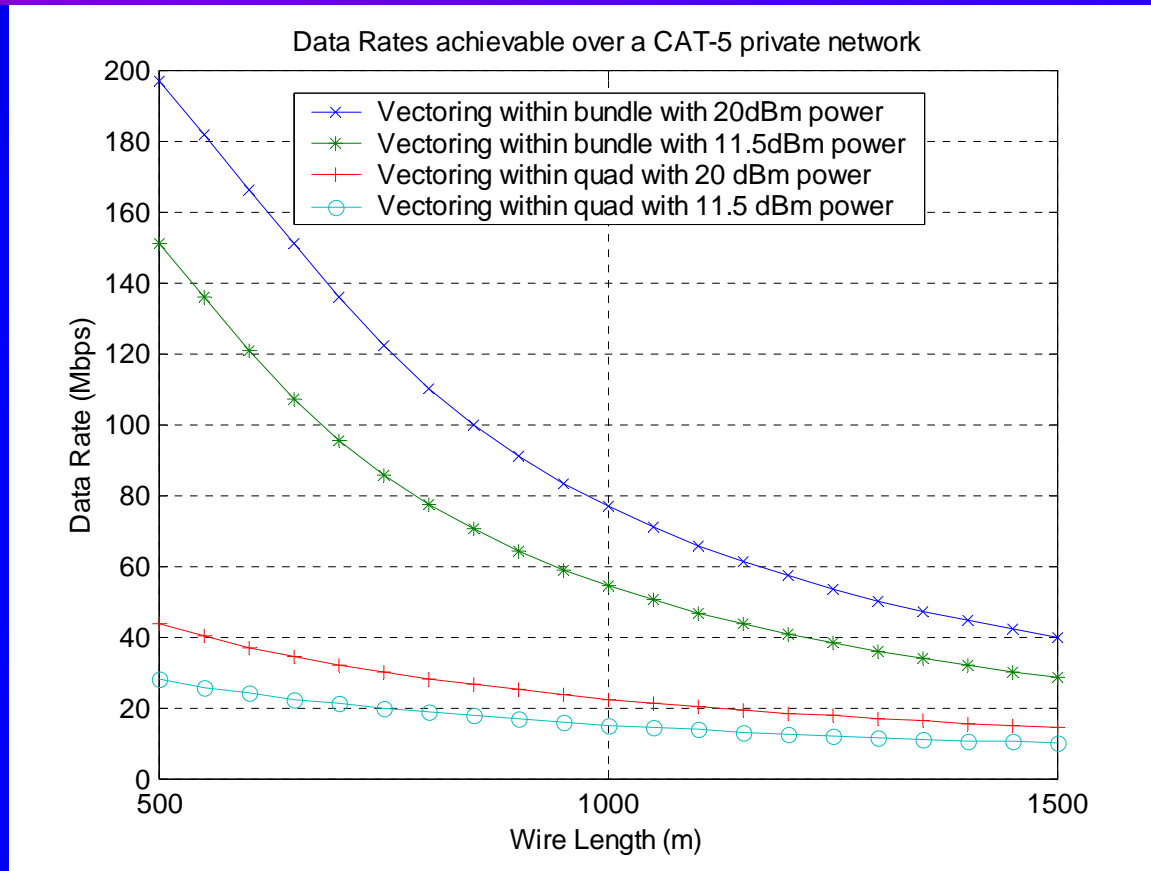
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EFM Examples



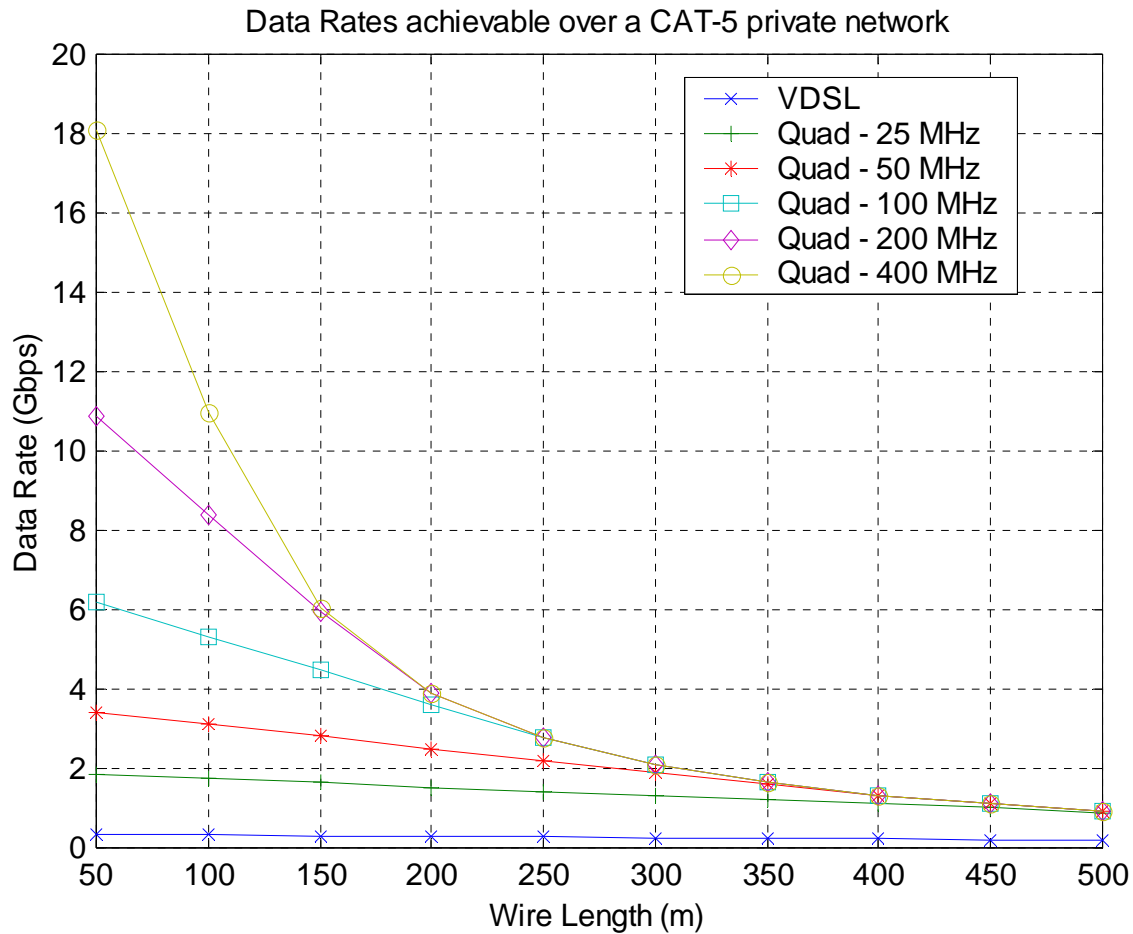
EFM Range



- 2 lines, 100BT at 1 km
- 10BT at 1 km on one line easily
- 4 lines, 100BT at 2 km



Ethernet Examples



Copper has more bw than fiber?

- 50 line bundle in last segment of phone network
 - ◆ 50 lines (200 Mbps/line) = 10 Gbps
 - ◆ FTTH shares 2.5 Gbps among several homes in PON architecture
- Get bandwidth up in fiber connections to and within network
 - ◆ Copper in last mile has more BW than system can handle
- 100BT/100 Mbps to everyone, everywhere a phone line goes, is possible in the next decade.



Conclusions

- Enormous wireline opportunity for multiuser
 - ◆ Gains may be even larger than for wireless
 - ◆ Relatively stationary environment
- The real broadband
 - ◆ At least 100 BT to everyone anywhere over a twisted pair
 - ☞ Data
 - ☞ Voice, voice, voice
 - ☞ Video
 - ◆ Welcome to the broadband age in this century



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References

- 1) T. Starr, J. Cioffi, and P. Silverman, Understanding Digital Subscriber Line Technology, Prentice-Hall, Upper Saddle River, NJ, 1999.
- 2) S. Verdu, Multiuser Detection, Cambridge Press, UK, 1998.
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- 7) A. Duel-Hallen, "Decorrelating Decision-Feedback Multiuser Detector for Synchronous Code-Division Multiple-Access Channel," IEEE Trans. Commun., vol. 41, no. 2, pp. 285-290, Feb. 1993. (Zero forcing DFE solution.)
- 8) J. Yang and S. Roy, "Joint Transmitter-Receiver Optimization for Multi-Input Multi-Output Systems with Decision Feedback," IEEE Transactions on Information Theory, vol. 40, no. 5, pp. 1334-1347, September 1994. (Showed that minimizing the decision feedback error is equivalent to achieving the mutual information.)
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More References

- 11) N. Al-Dhahir and A. H. Sayed, "The Finite-Length Multi-Input Multi-Output MMSE-DFE," IEEE Transactions on Signal Processing, vol. 48, no. 10, pp. 2921-2936, October 2000.
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- 13) A. Sendonaris, V. V. Veeravalli, "Joint Signaling Strategies for Approaching the Capacity of Twisted-Pair Channels," IEEE Tran. Commun., vol. 46, no. 5, May 1998, pp. 673-685.
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- 15) W. Yu, W. Rhee, S. Boyd, and J. Cioffi, "Iterative Water-filling for Vector Multiple Access Channel," IEEE International Symposium on Information Theory 2001.
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- 17) W. Yu, G. Ginis, J. Cioffi, "optimum solution of broadcast communications problem," in preparation, 2001, weiyu@dsl.stanford.edu.
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