Part IV – Wireline Multiuser Examples

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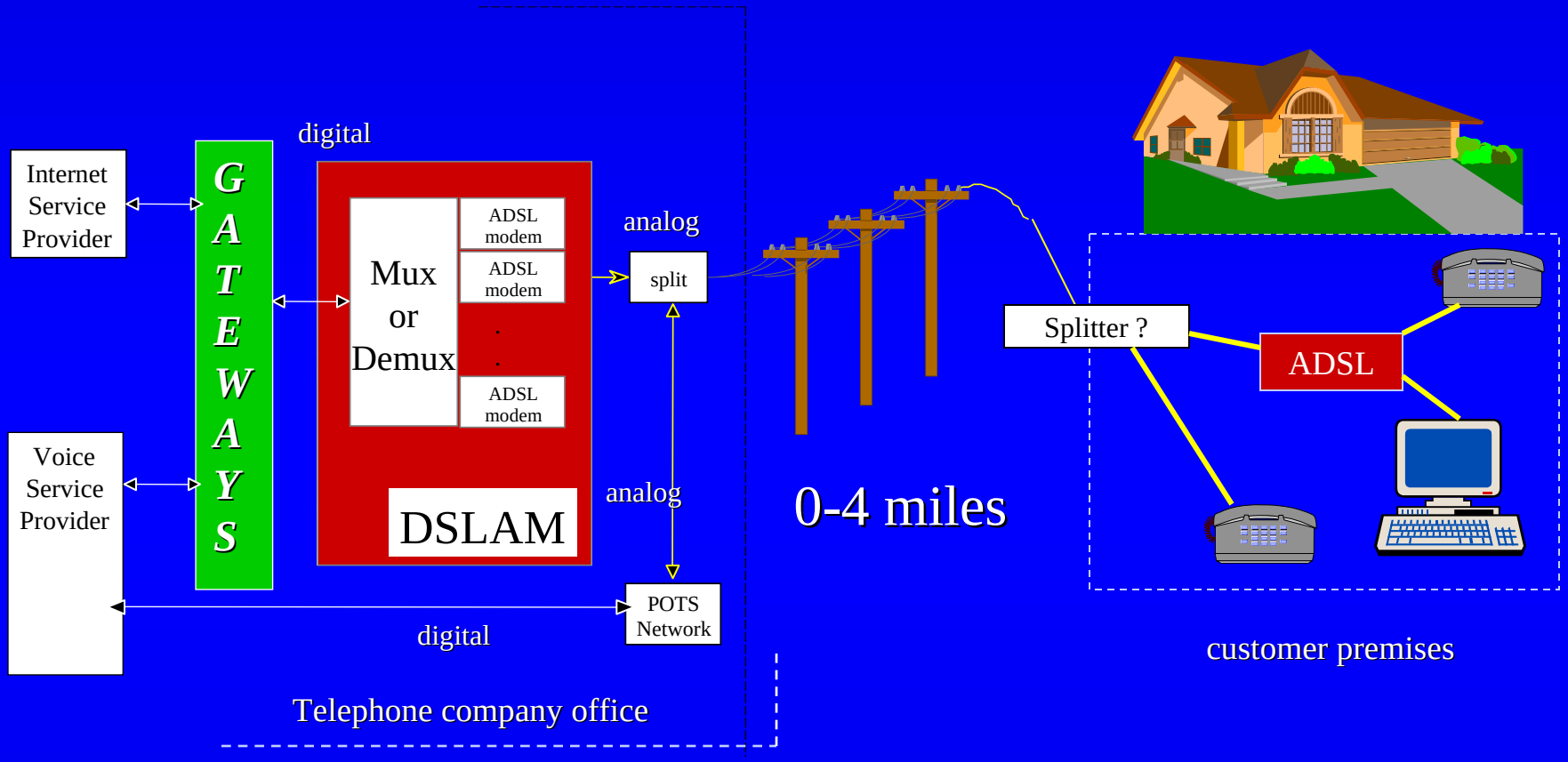
Parts 3 and 4: Outline/Schedule

- 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

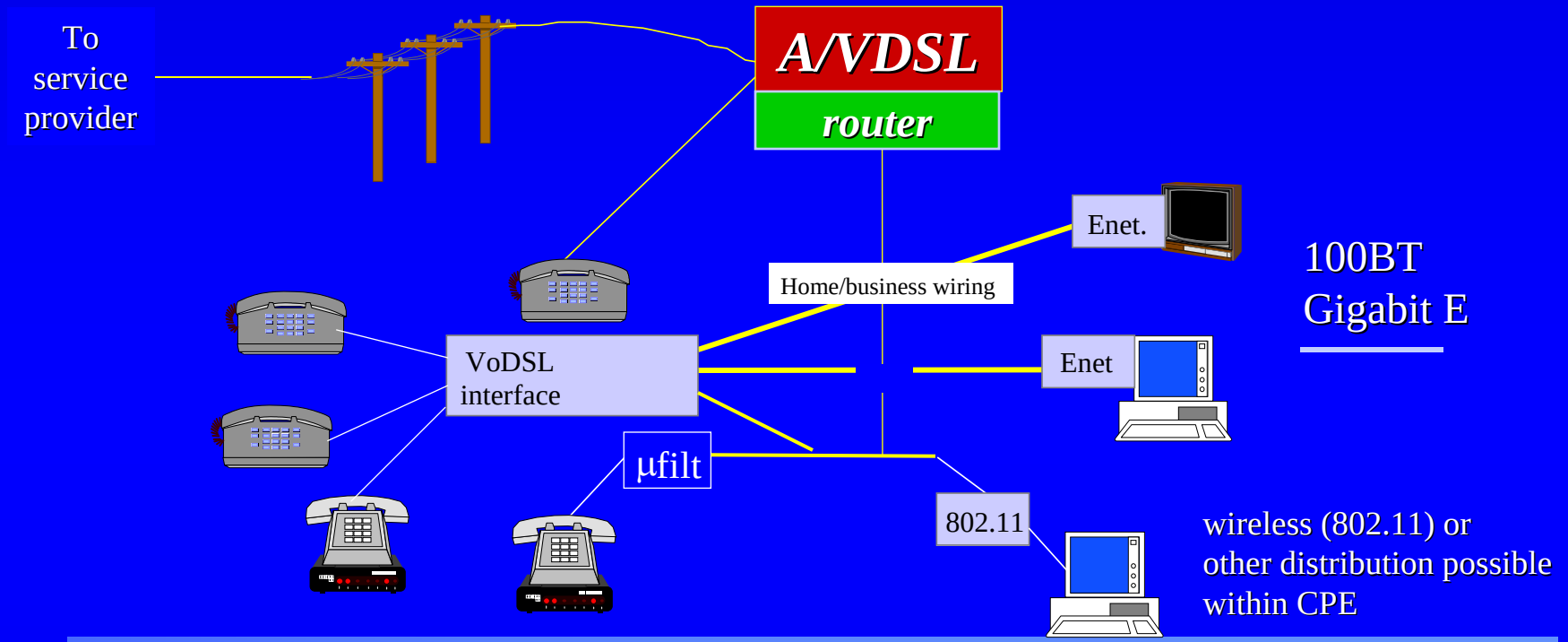
- DSL and Ethernet Applications
- Evolution of DSL and DSM vs SM
  - Unbundling
  - Towards ethernet
- Multiuser Spectrum Balancing
- Vectored VDSL
- Vectored Ethernet

DSL in 2001



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

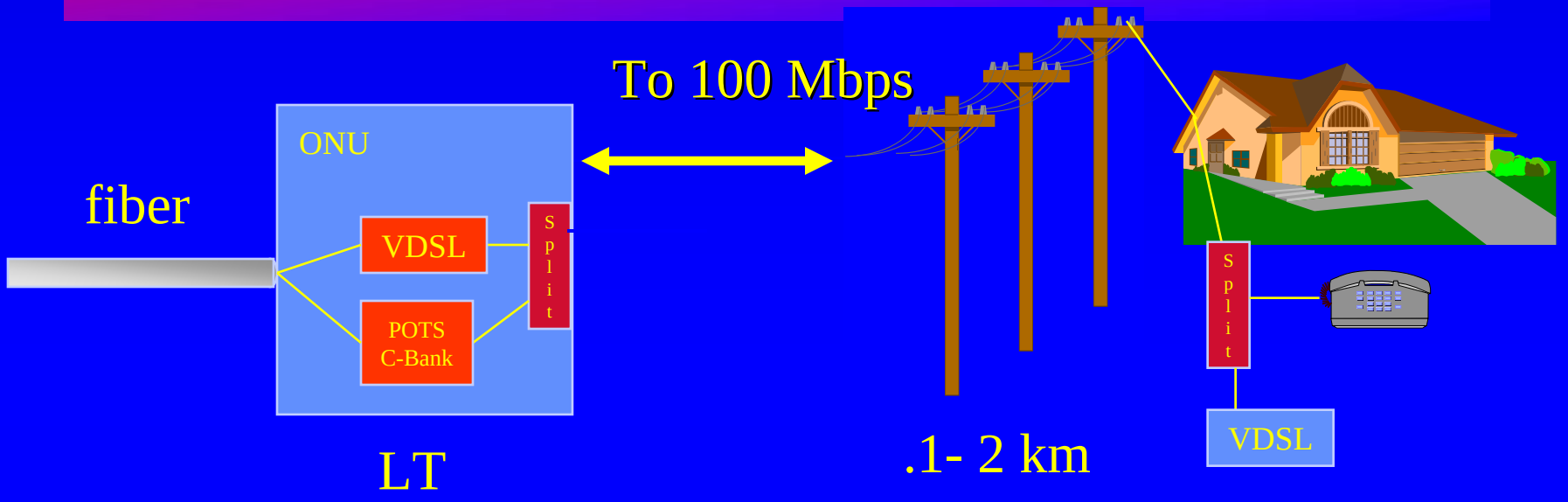
DSL Future Applications



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

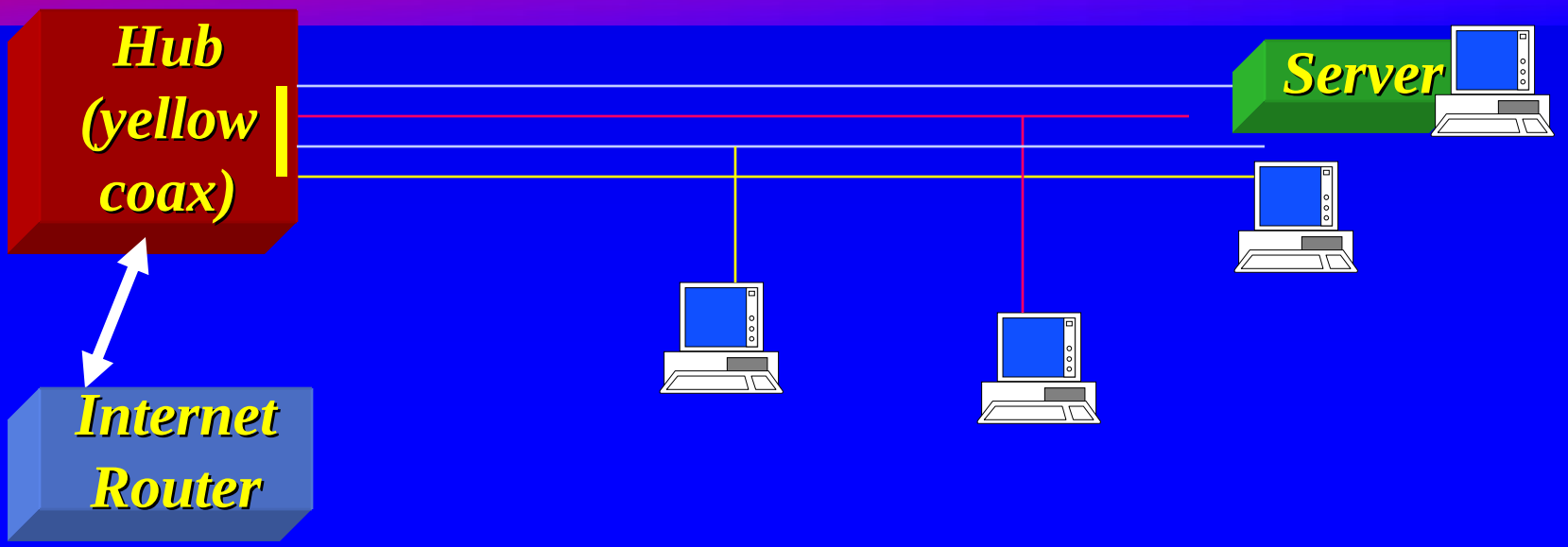
Multiuser Wonders

Part Fiber, Part DSL = VDSL



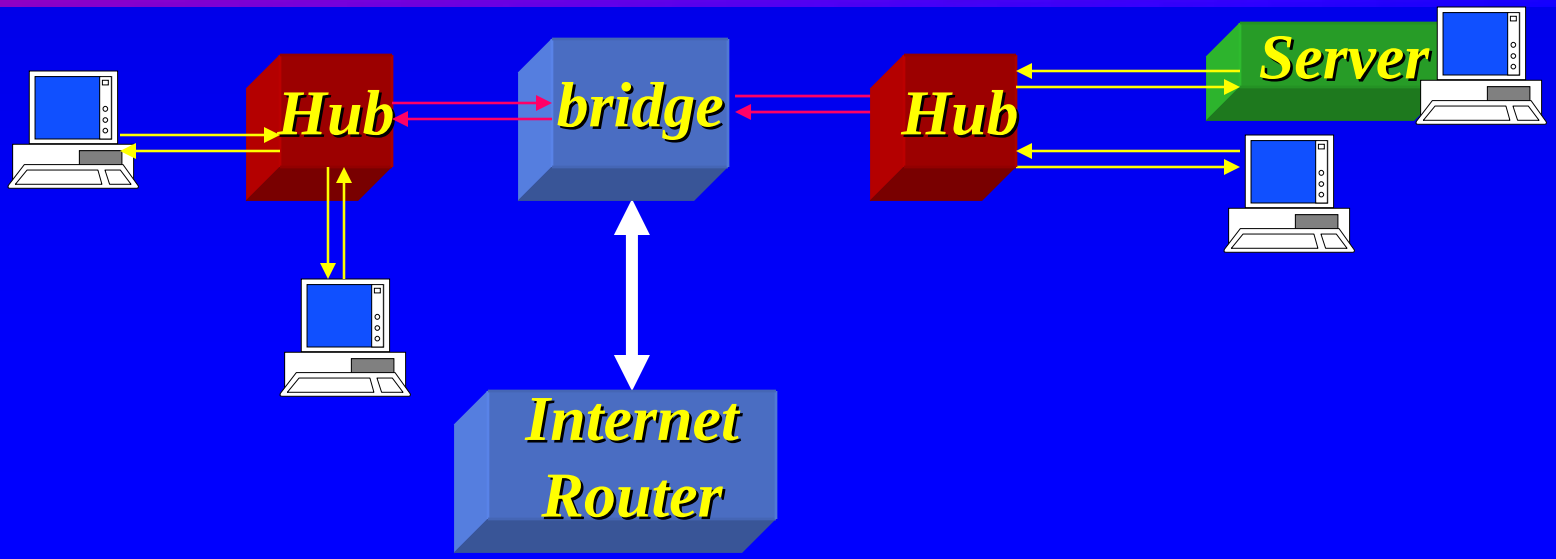
- Only 12,000 of 10^7 businesses connected by fiber all the way – essentially 0 residences
  - Rather ONU's/remote terminals, incrementally with time
- How long is fiber? Twisted-Pair?
  - Incremental trade-off with time/demand

Ethernet – 10BT



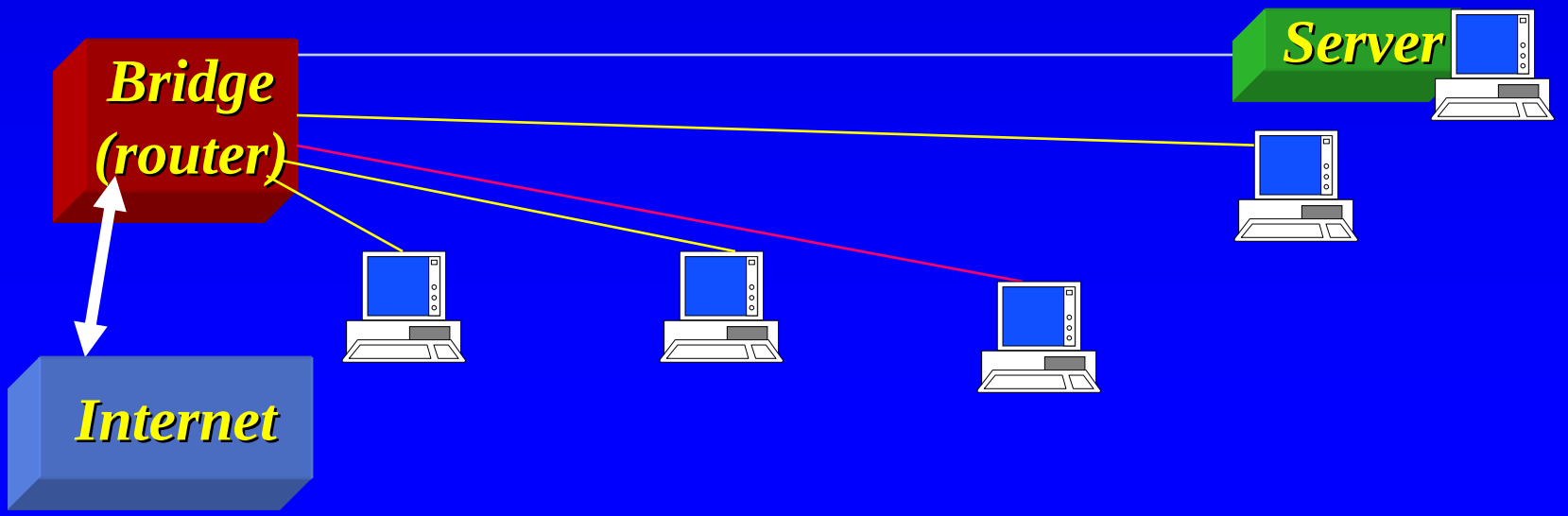
- STAR wiring – collision detection not really used
  - Hub is electronic version of a “coax-wired” connection
  - All lines on Hub share the 10 Mbps
- 100’s millions deployed on copper
  - Manchester coding
  - Category 5 tp (20 dB less xtalk than phone lines- cat 3, 24 gauge)
  - Each line is 2 pairs (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



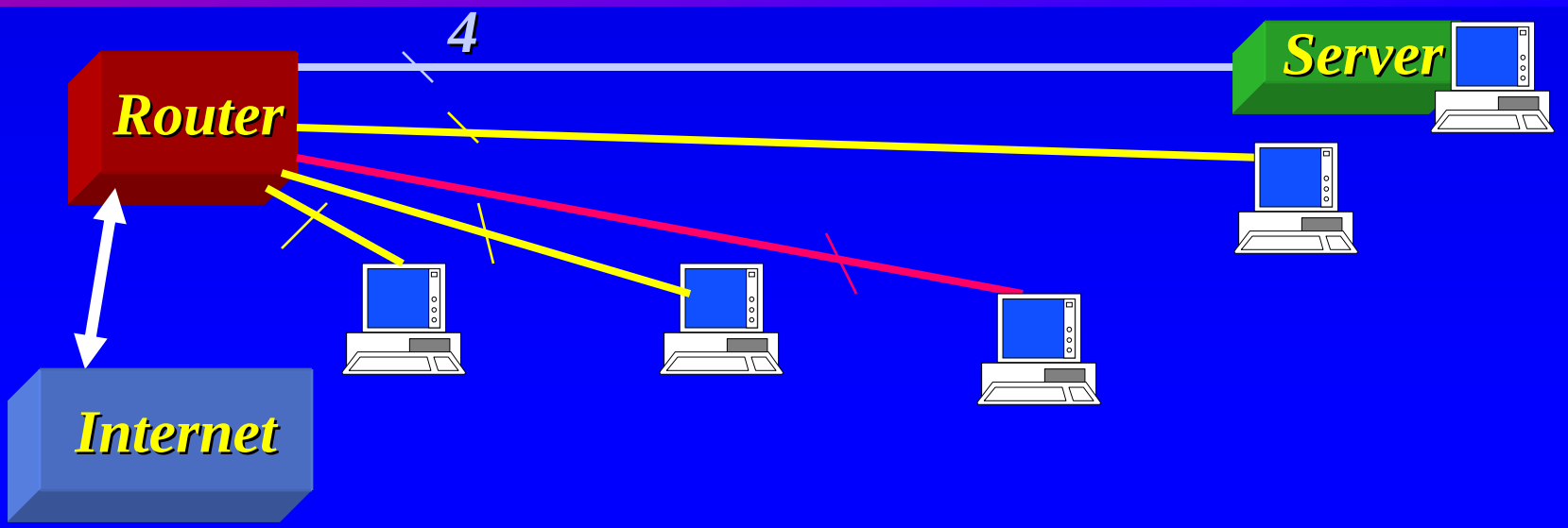
- Little higher level than Hub, which is an electronic version of a “yellow coax”
- Allows each line’s 10 Mbps to be different
- Dedicated connection to each user

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

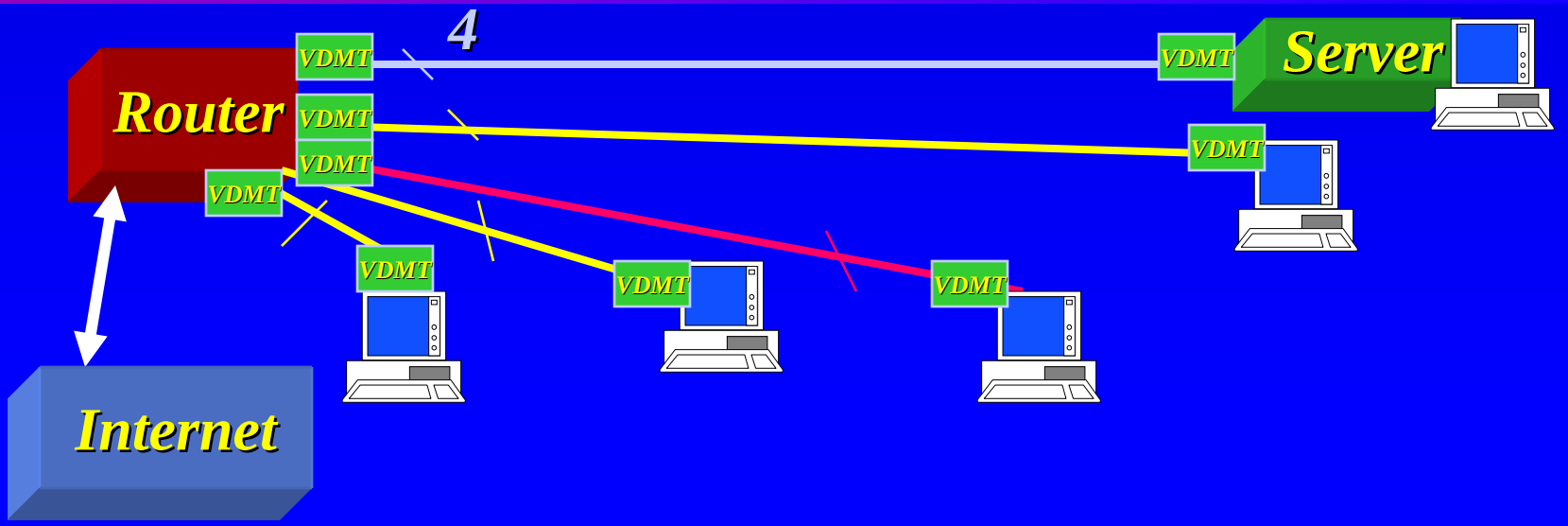
Ethernet – 1000BT



- 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)

Multiuser Wonders

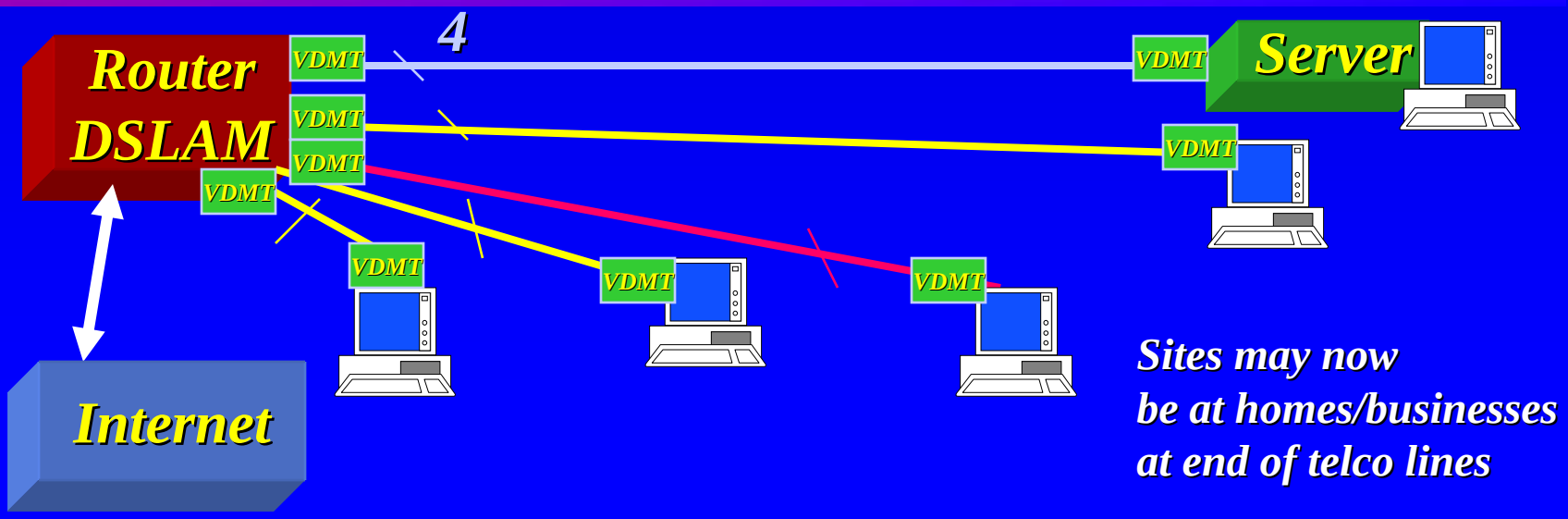
Ethernet Faster?



- 10,000BT – vectored multiuser, 100 meters

Multiuser Wonders

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.

Multiuser Wonders

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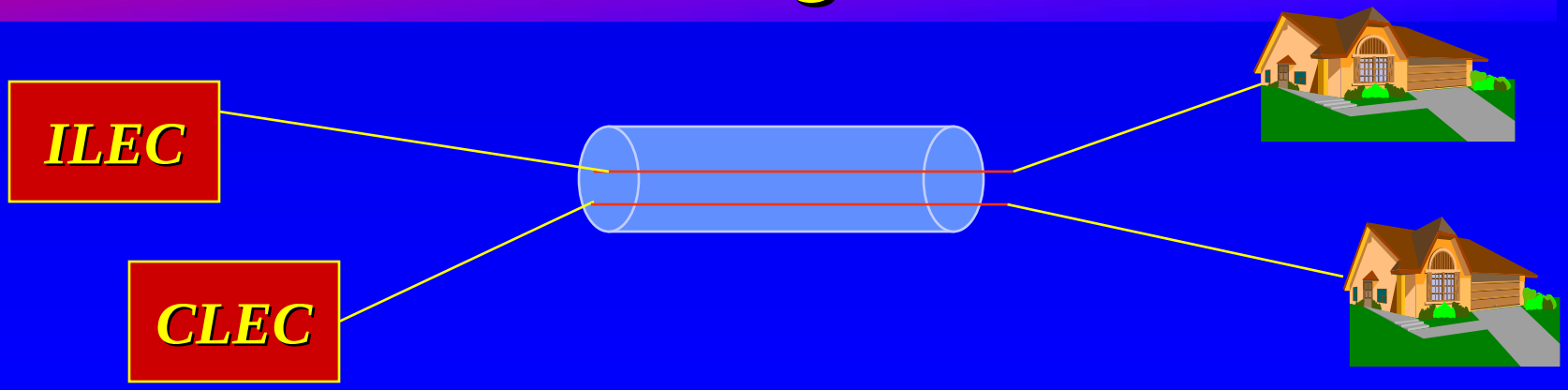
Unbundling in DSL

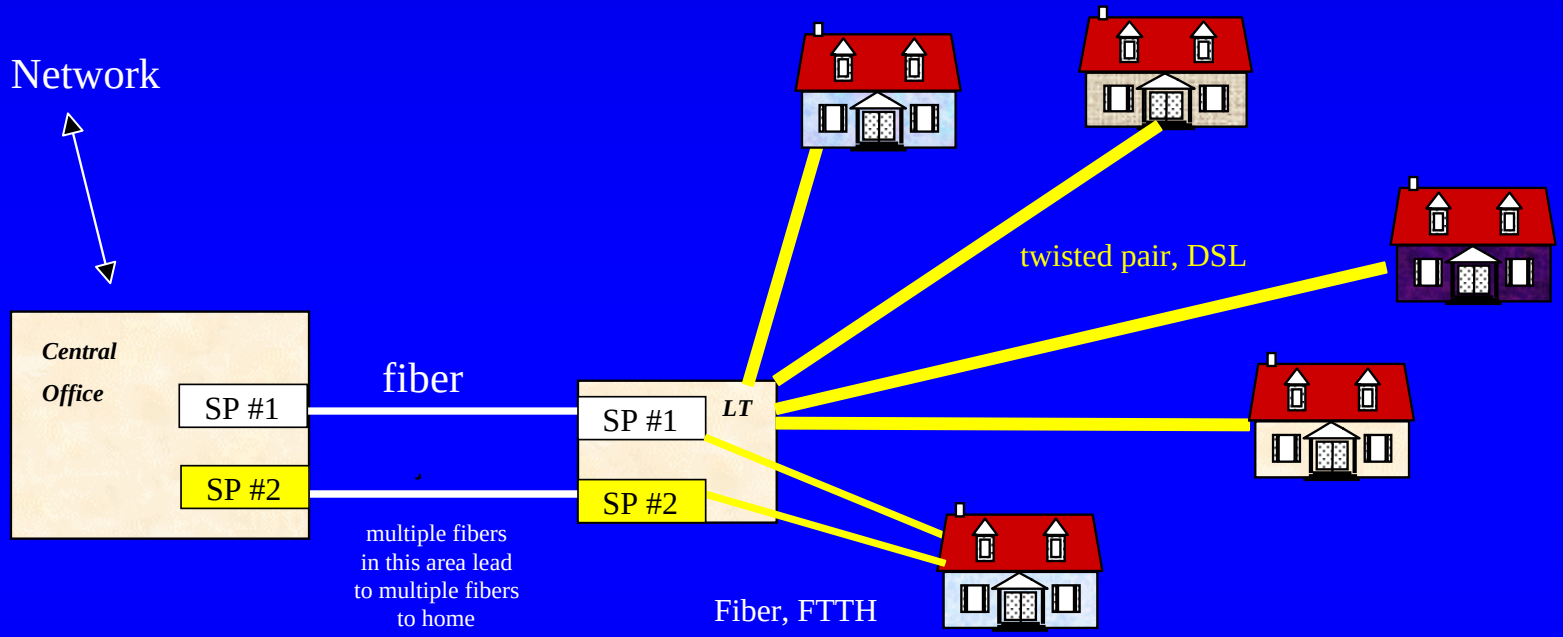


- Different service providers can “rent” lines to customers
  - Consequent emissions between lines (crosstalk)
    - Gets worse with wider bandwidths (shorter lines)
  - Can be reduced with asymmetric transmission
- ILEC – often wants asymmetric
- CLEC – often wants symmetric

Spectrum Management

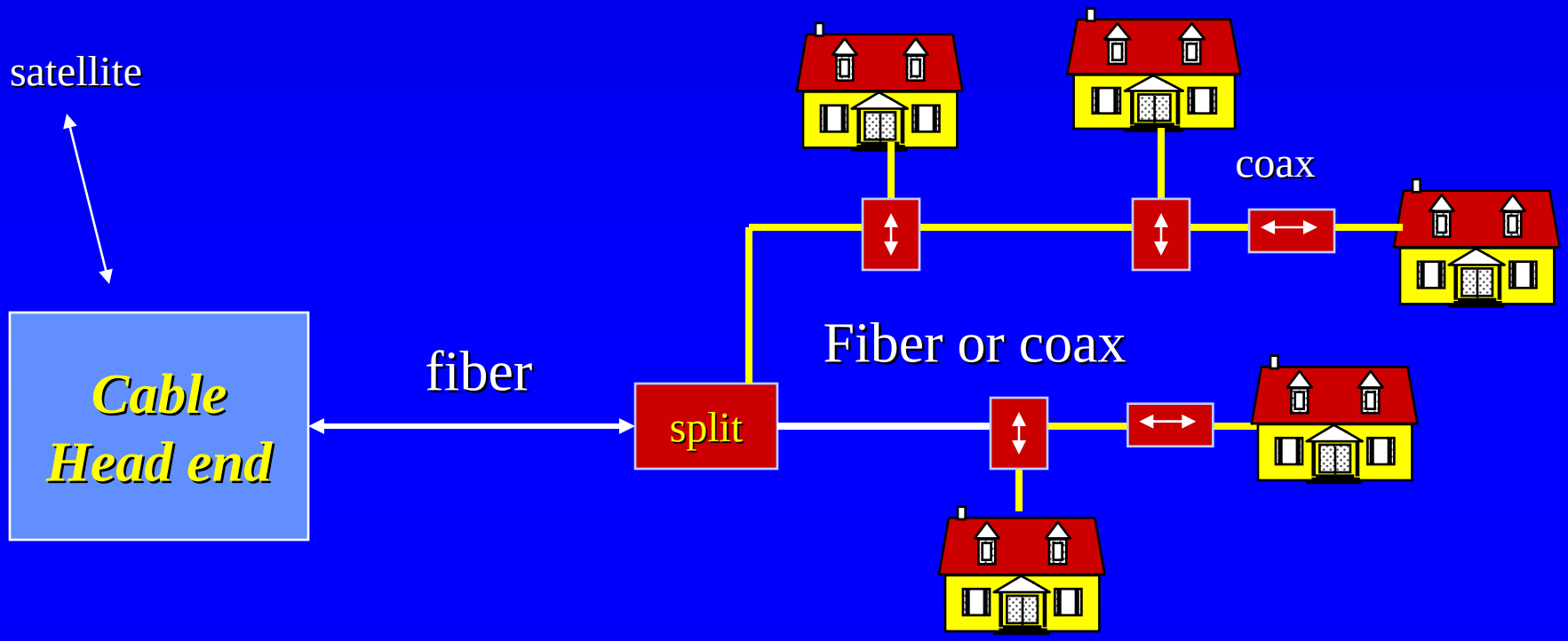
- Regulate the spectra of the different service providers within the cable
  - Minimize radiation between cables
  - Balance interest of symmetric/asymmetric (CLEC/ILEC)
- Fixed spectra defined for each type of DSL service, no matter where it is used in the world
  - **STATIC** spectrum management
-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

DSL Line-Unbundled Evolution?

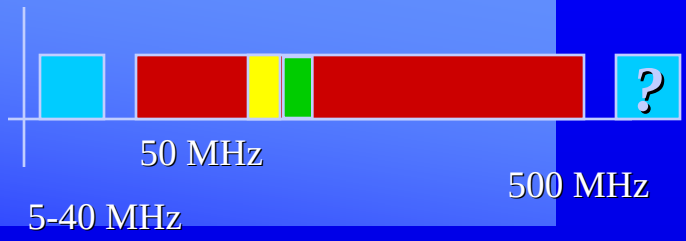


- Fiber for each service provider?
- Space at LT for each service provider?

HFC – Hybrid Fiber Coax

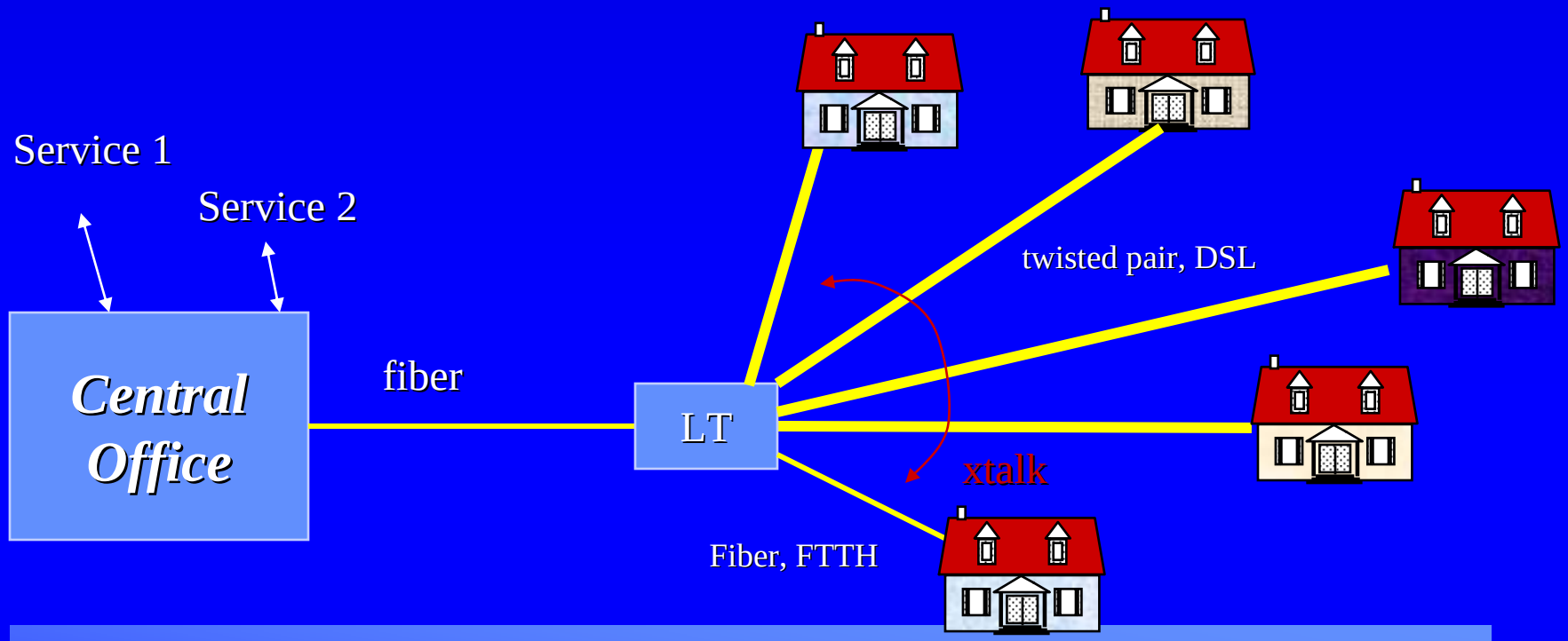


- Fiber from head end to first split
  - More bandwidth, easier bidirectionally
  - Coax still shared among 100's of users (500)
  - Multiple content providers, unbundling?



Multiuser Wonders

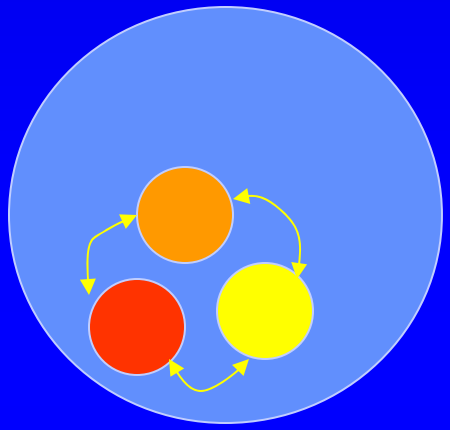
Packet Unbundling



- 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

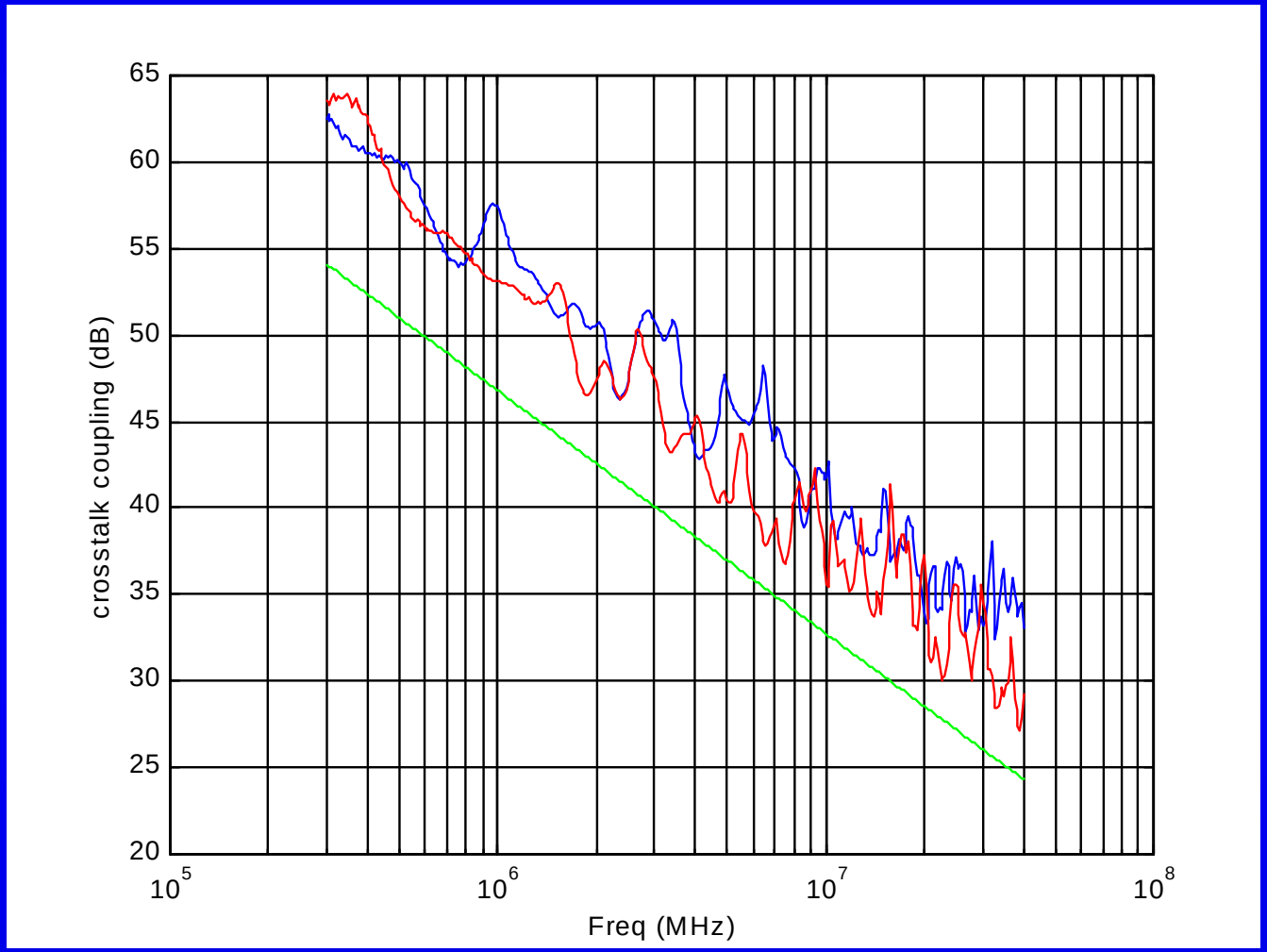
(a prime app for MU)



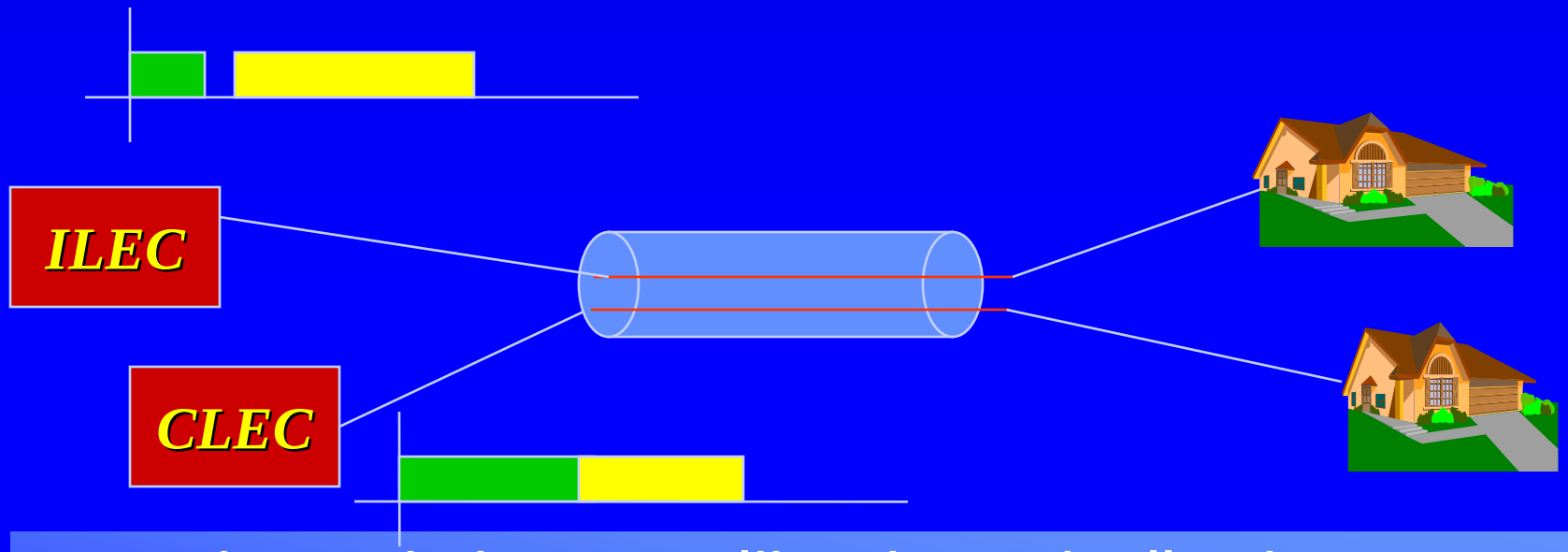
Cross-section of cable
Also, space

- 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

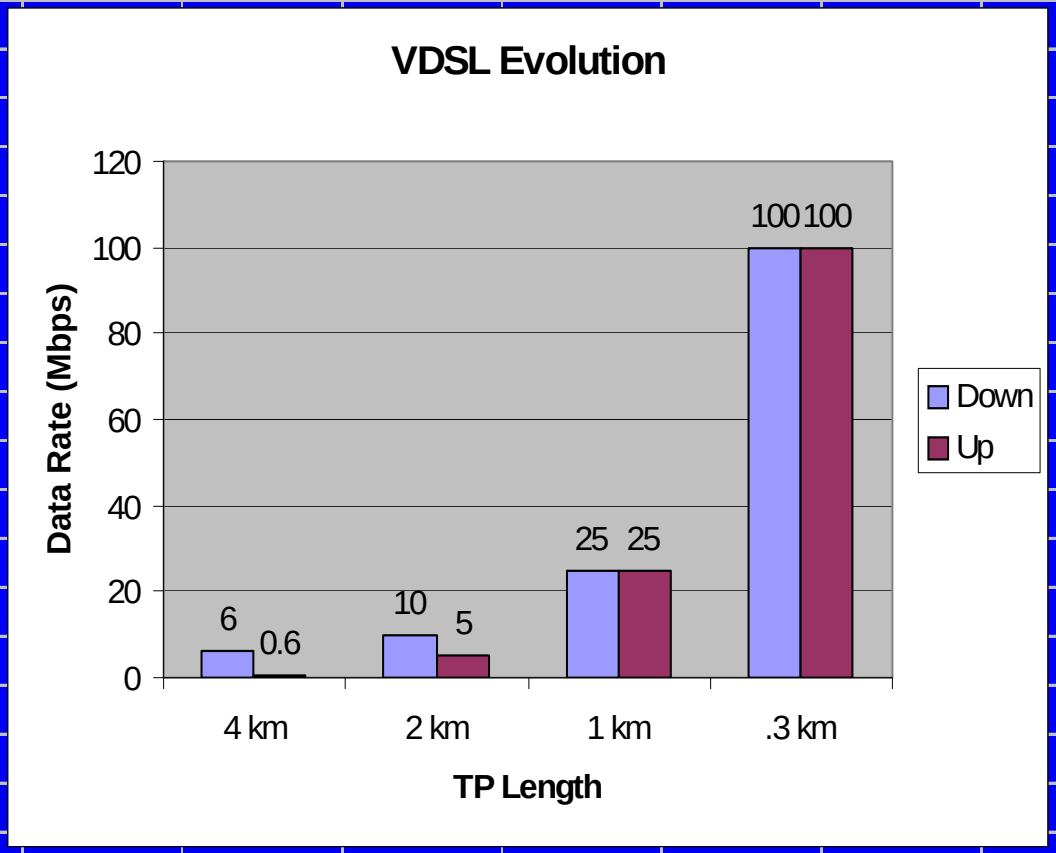


- Up (green) does not like down (yellow)
  - Avoid overlap of yellow with green = static SM
- Fix allocations to compromise ILEC/CLEC
  - but xtalk/lines are different as are customers in each location

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

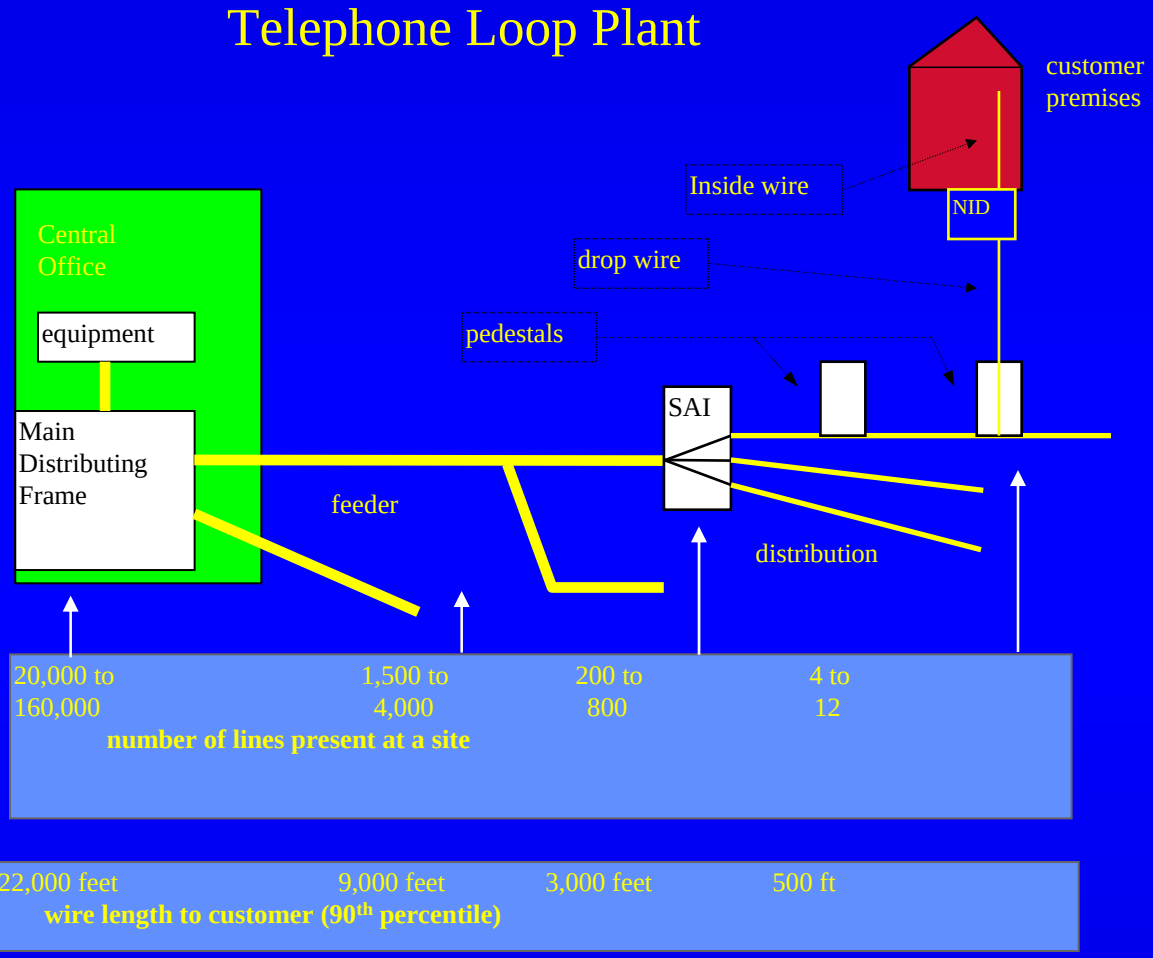
DSL Evolution Goal



ADSL **VDSL** **VDSL- EFM** **VEFM**

Multiuser Wonders

Loop Plant of a Service Provider



- 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 unbunding)
  - 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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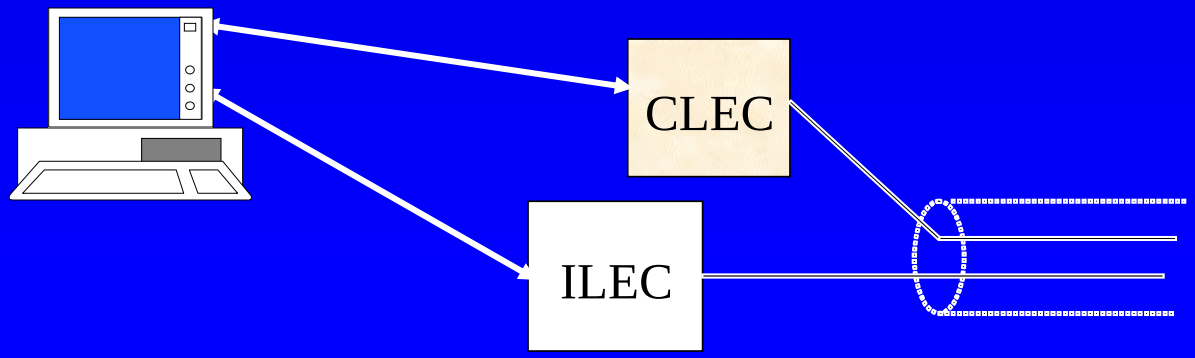
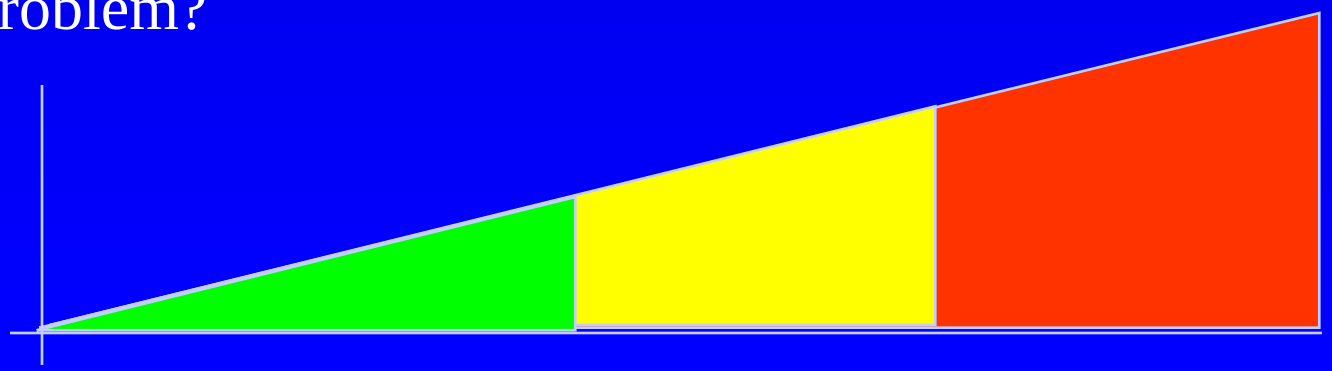
Spectrum Balancing

Central DSM/DSL Maintenance



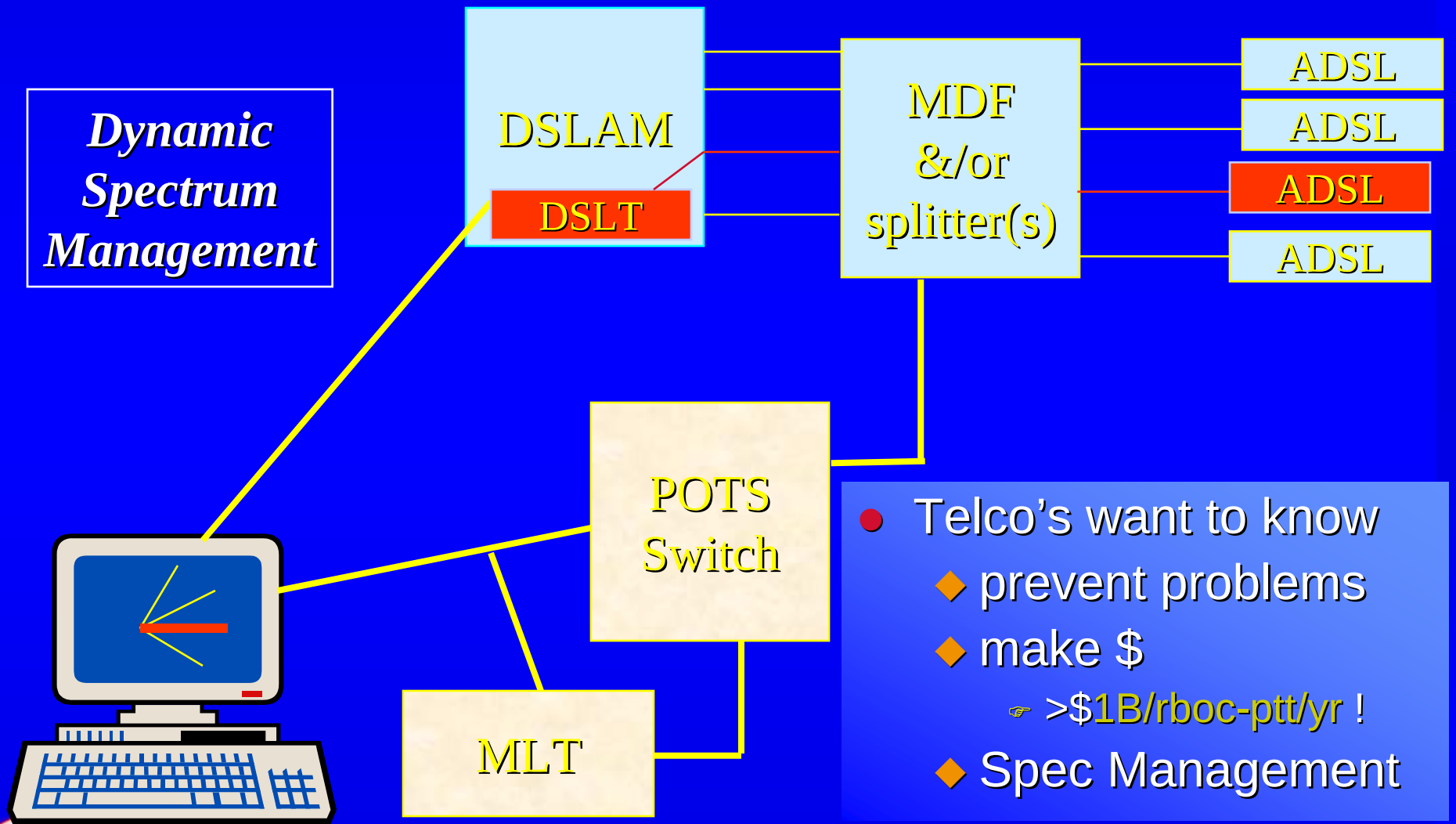
- Lines report information
  - Helps with deployment, problem isolation
  - Can be used for DSM
    - Cent main recommends line spectra

Translation to Telco Terms



- time of day
- as available
- guaranteed

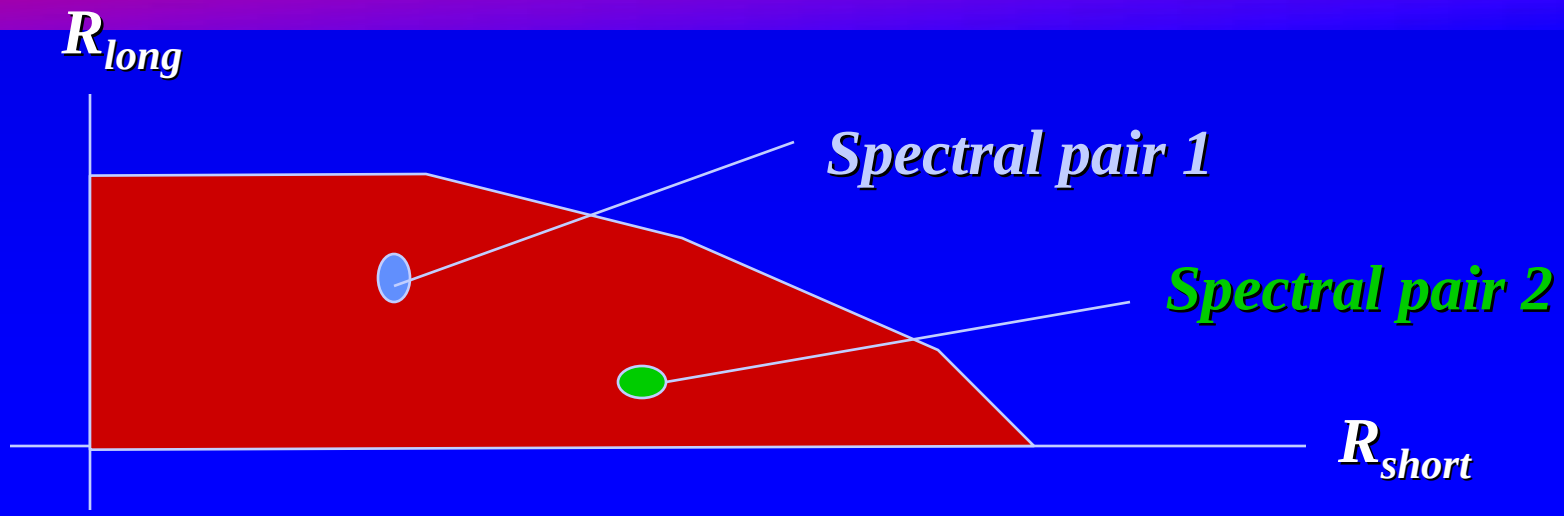
Network Maintenance



- Telco's want to know
  - prevent problems
  - make $
    - >$1B/rboc-ptt/yr !
  - Spec Management

Multiuser Wonders

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)

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

So far, Static SM

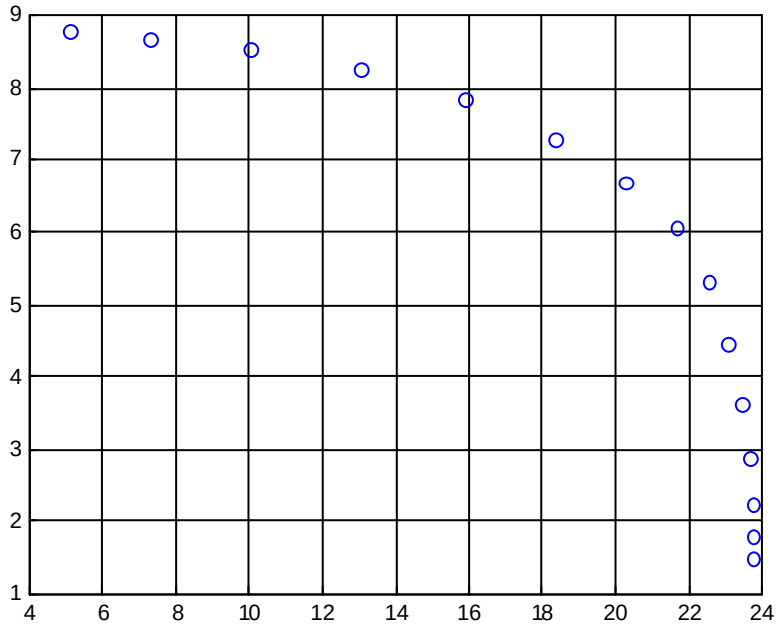
- Plans
  - 998 (USA) – more asymmetric

  - 997 (Europe) – more symmetric

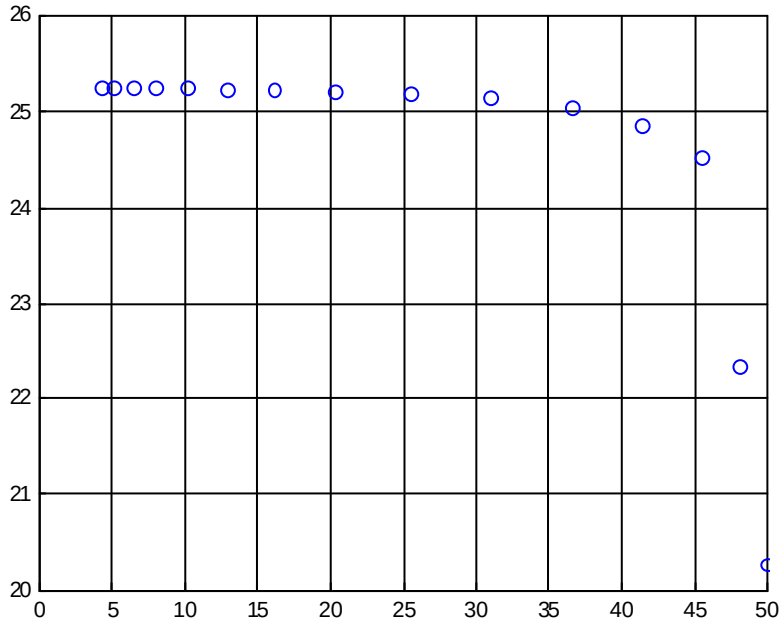
  - Flex plan
    - Number of bands programmable
    - Start/stop frequencies programmable
    - USA VDSL Standard – part 3 (allows DSM)

998 with spectrum balancing

Up



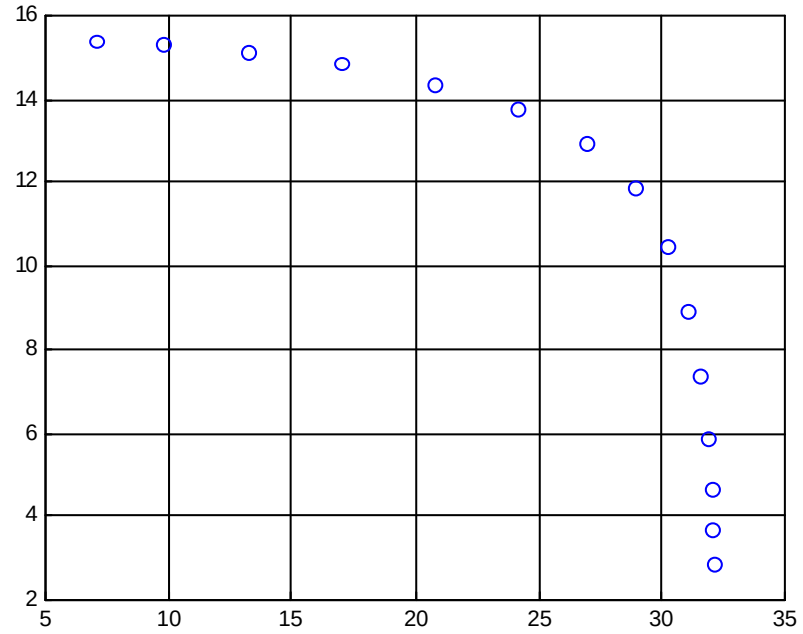
Down



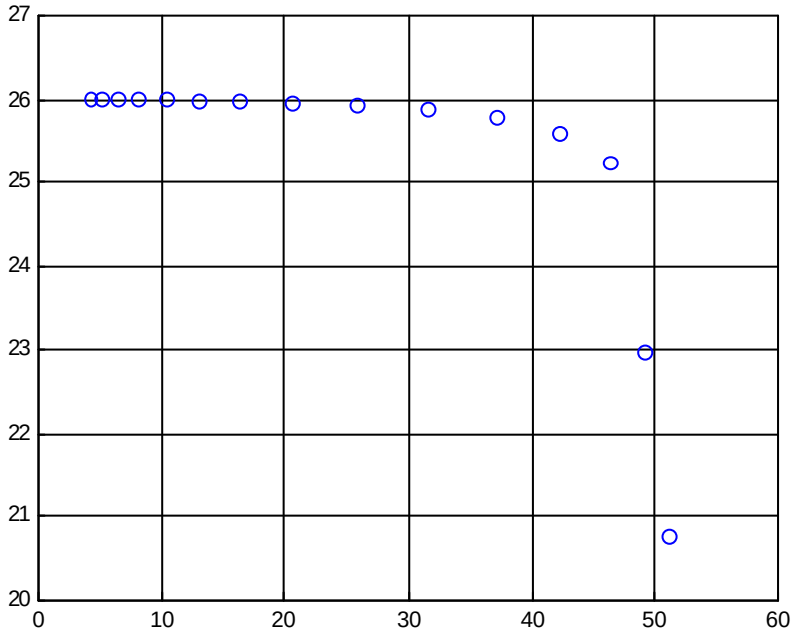
- Line1500 ft versus 3000 ft
- 26/6 on 3000’ while 30/22 on 1500’
- Static SM only 18/1.5 and 6/6

flex with spectrum balancing

Up



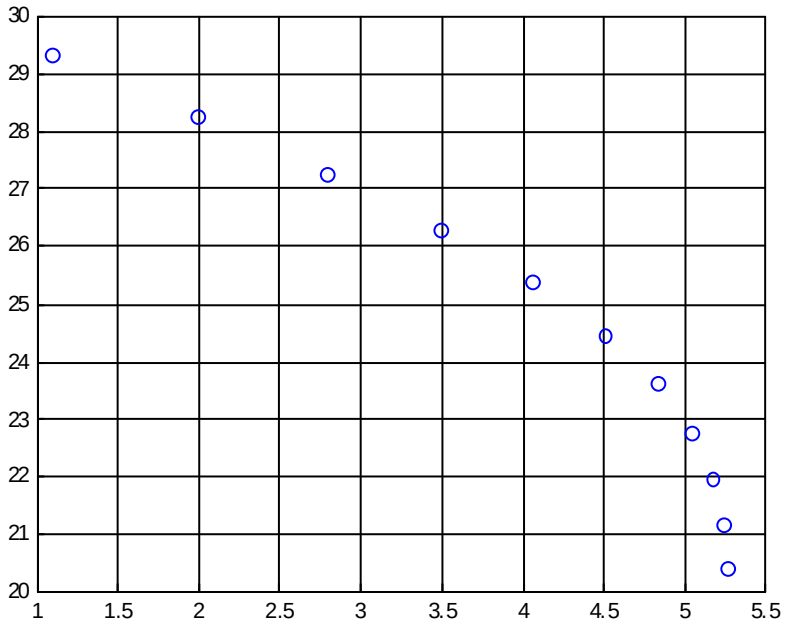
Down



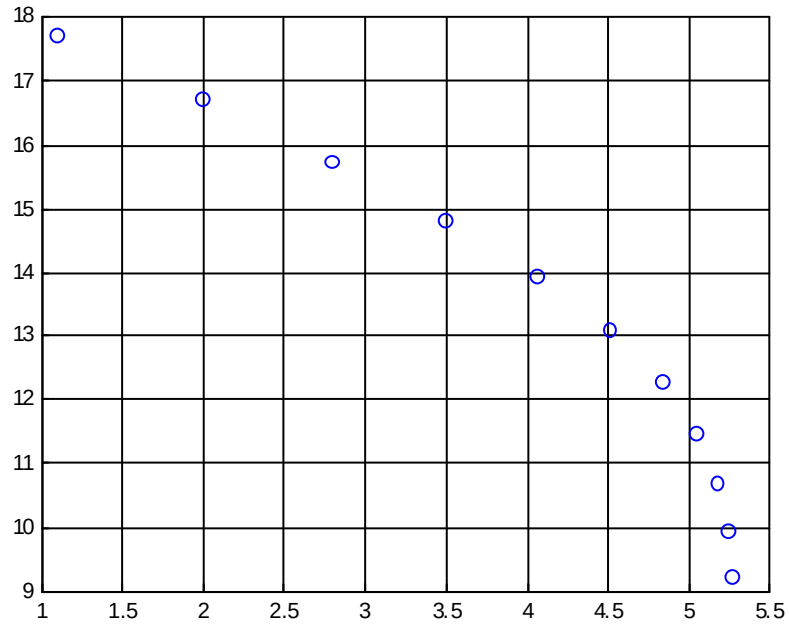
- Line1500 ft versus 3000 ft.
- 26/13 Mbps on 3000', 52/26 Mbps on 1500'

VDSL and ADSL

Down 3000’



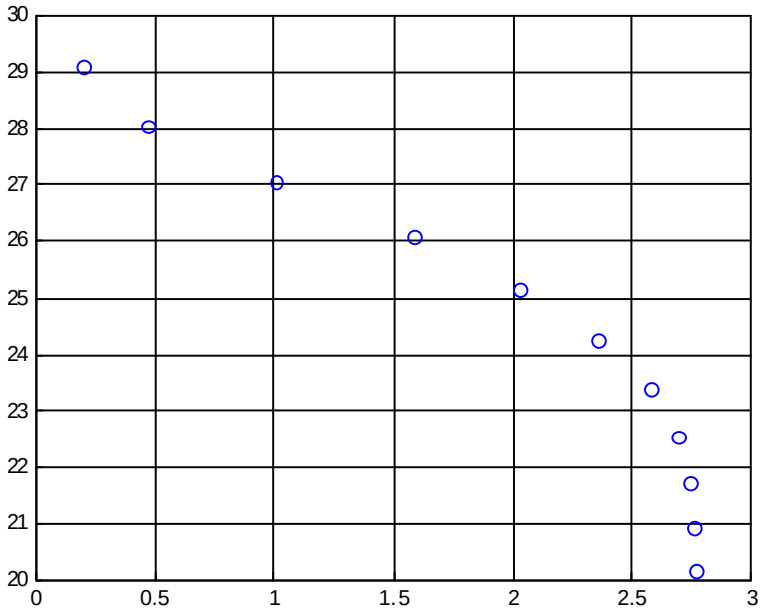
Down 4500’



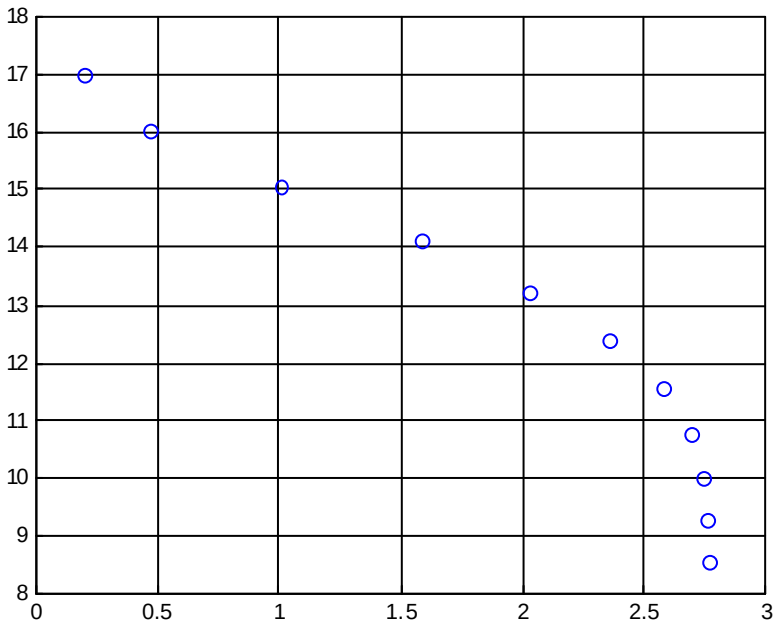
- Yellow on short line acts like green
- 9000’ ADSL (fig 6)
- 26/3 possible on 3000’ VDSL while ADSL runs 5/.5.

VDSL and ADSL with Hdsl/Idsn

Down 3000’



Down 4500’



- 9000’ ADSL

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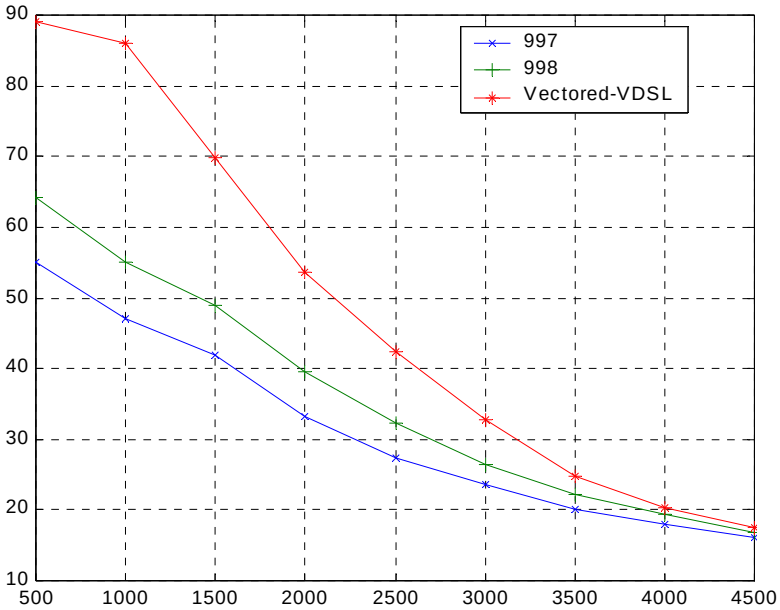
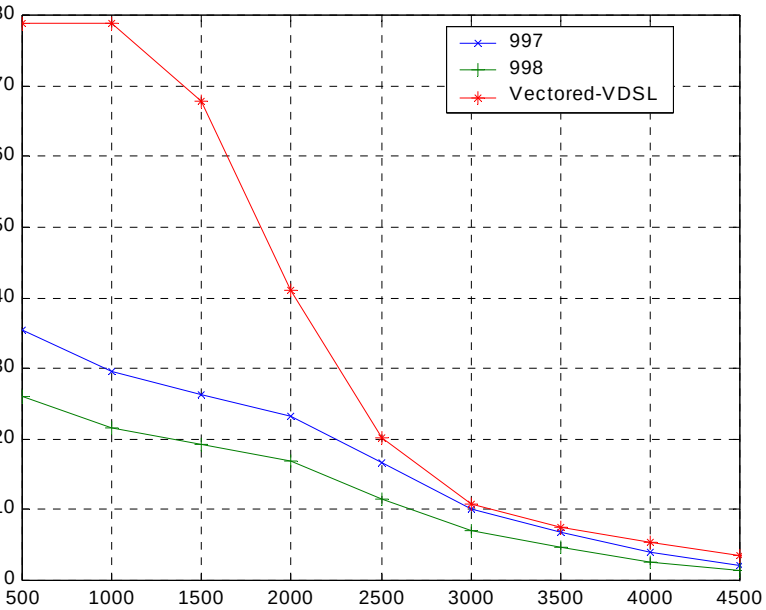
Vectoring Results



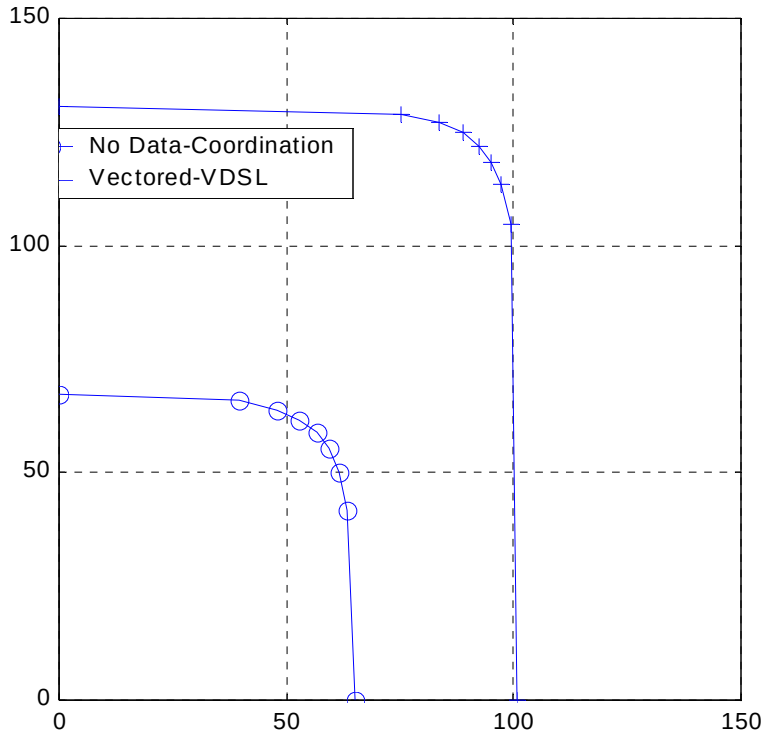
Down



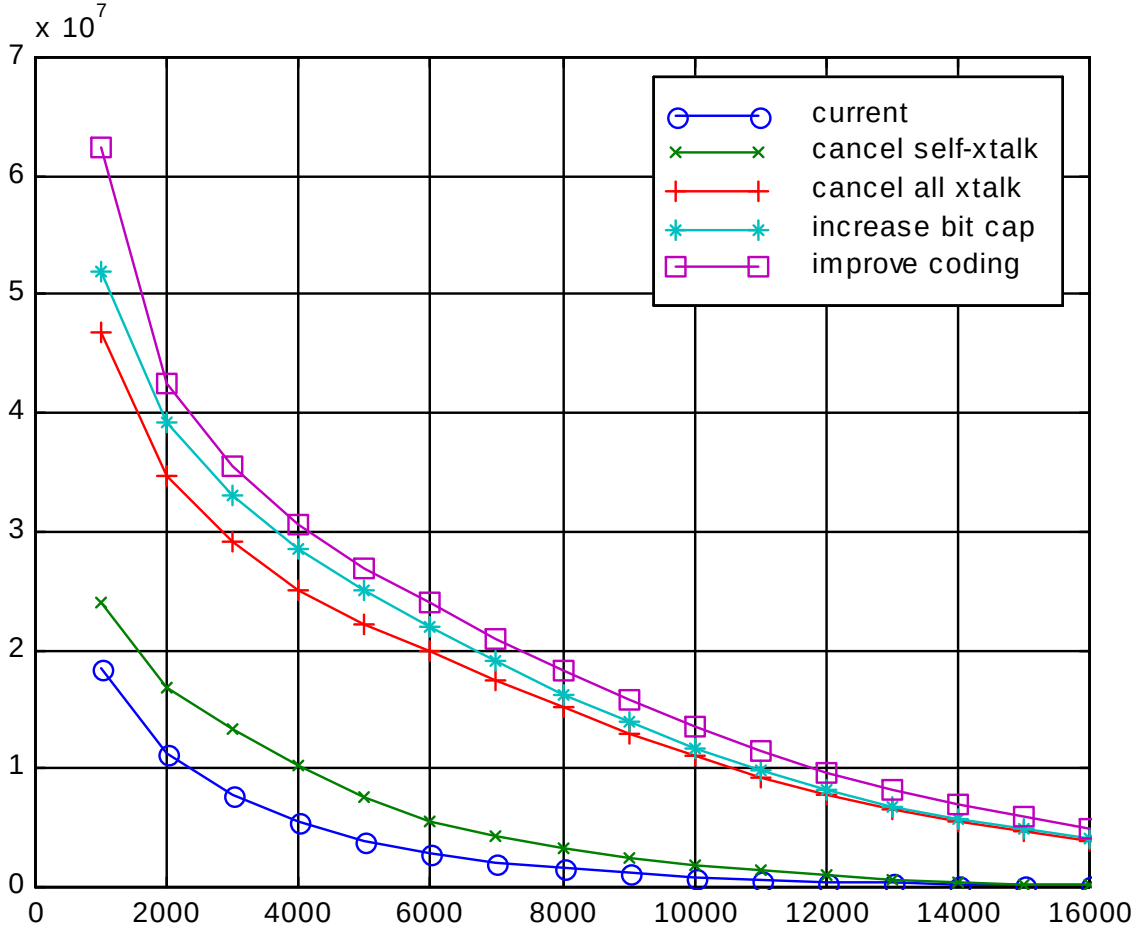
Up (see correction)

Rate Regions

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

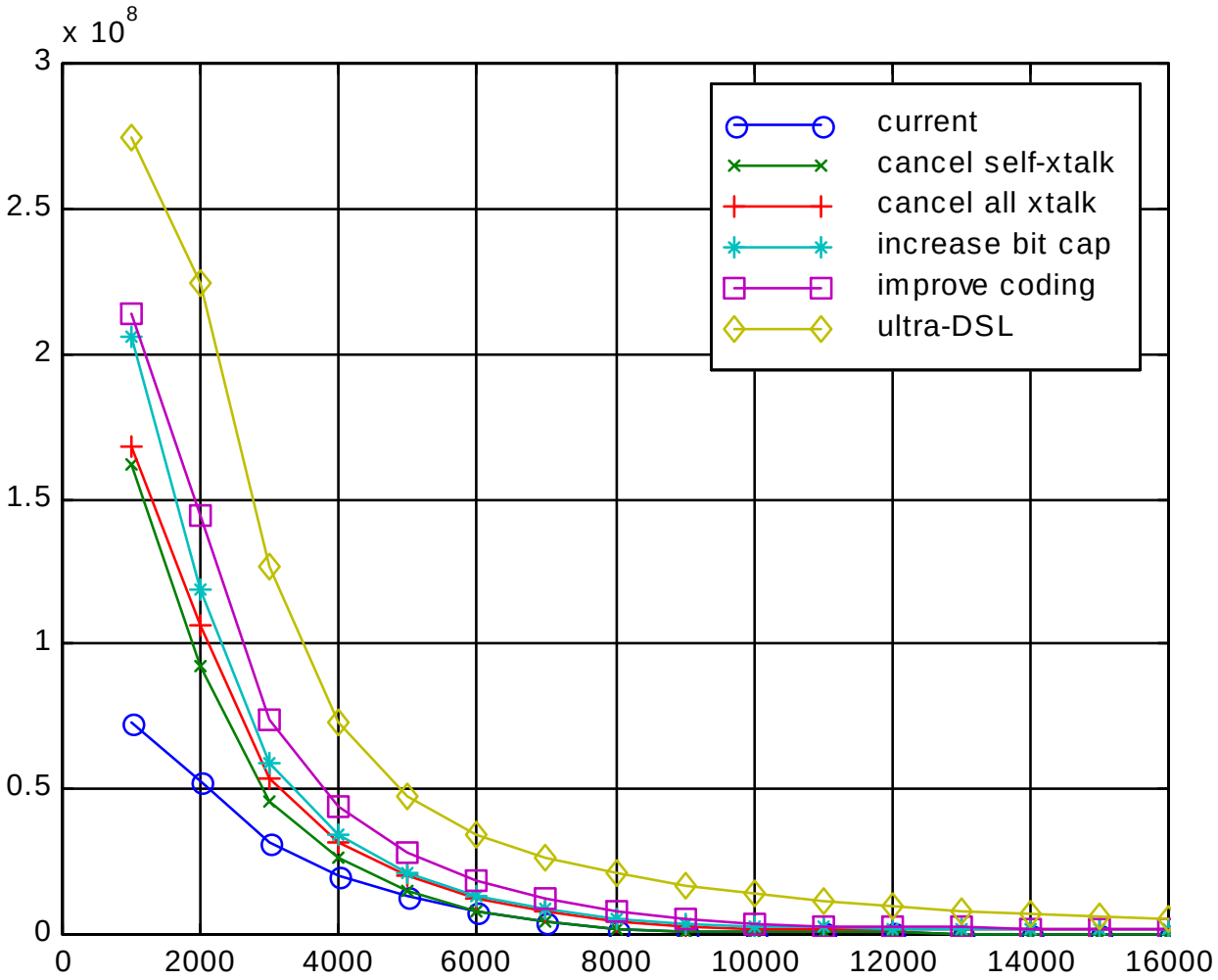


How much better can we do? (ADSL)



Multiuser Wonders

Ultimate VDSL



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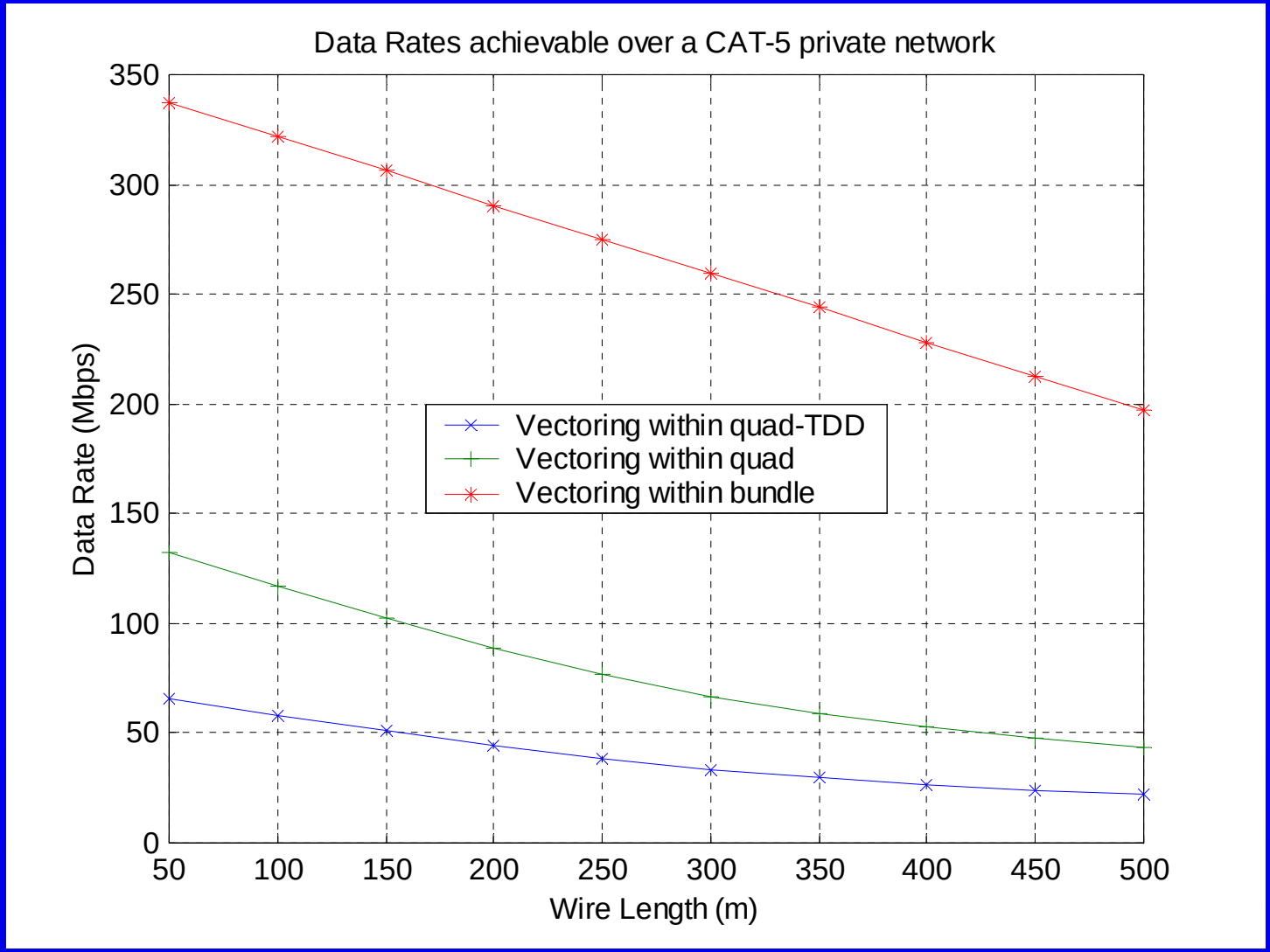
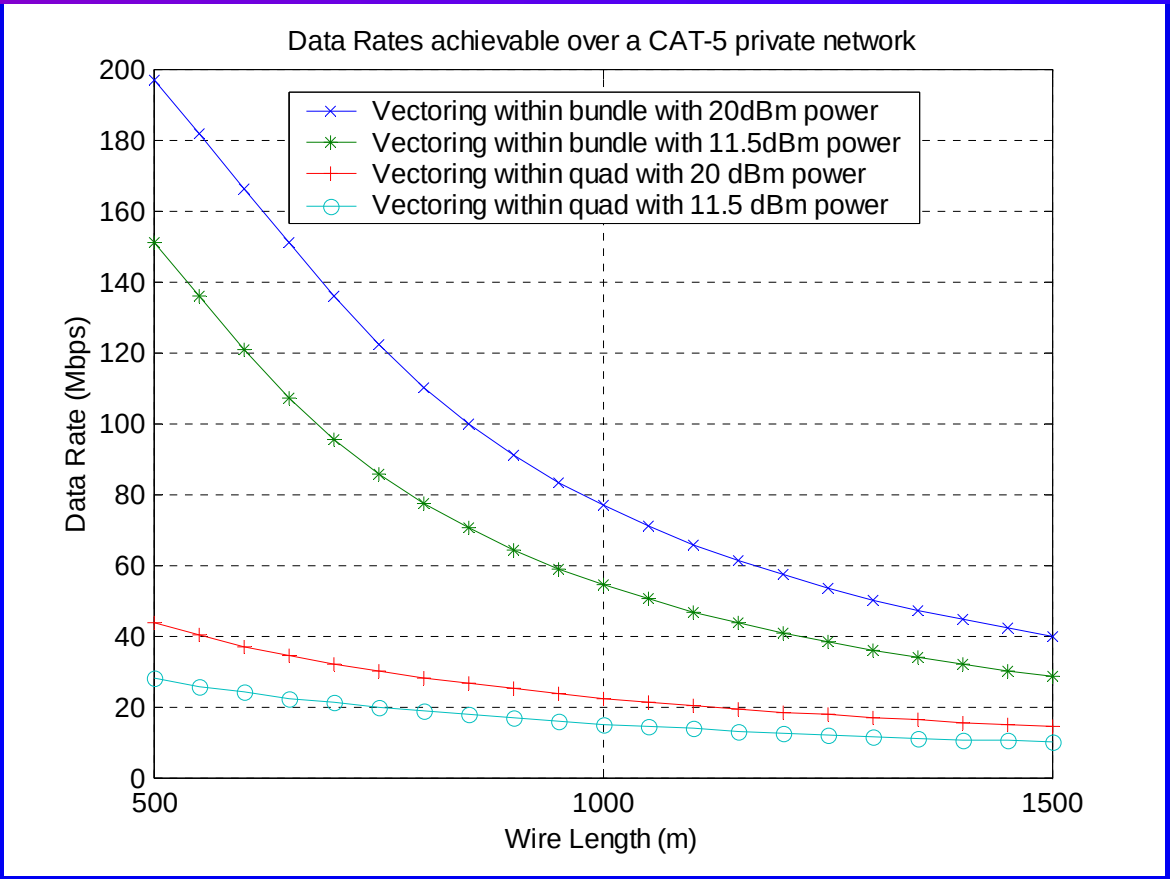
EFM Examples

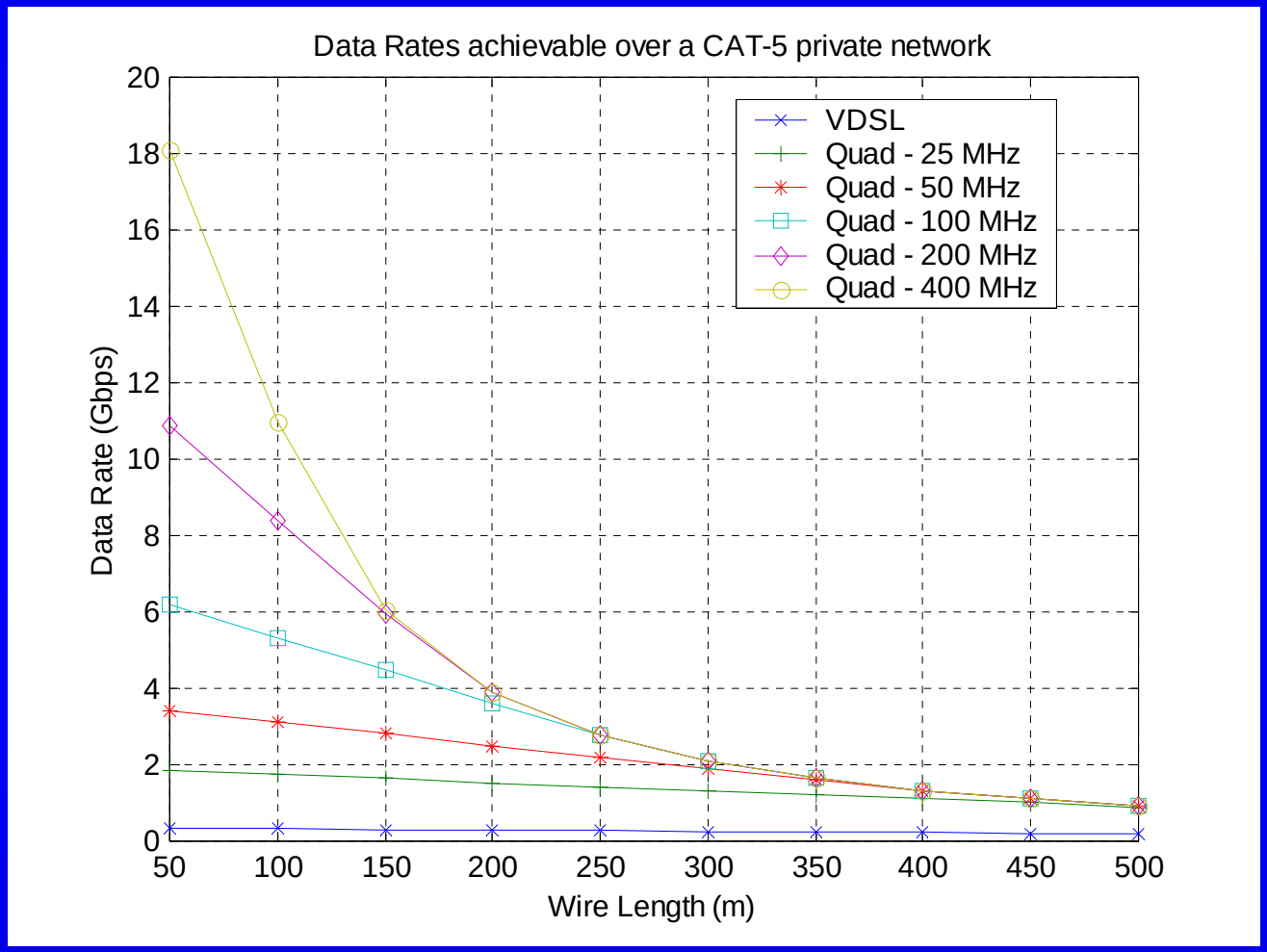


EFM Range



- 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

Parts 3 and 4: Outline/Schedule

- 2:00-2:45 MU Theory
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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.

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