A novel approach to Dynamic Spectrum Management in FTTdp Networks

Chano Gomez – Marvell Semiconductor Inc

G.fast Summit, Paris, May 2015

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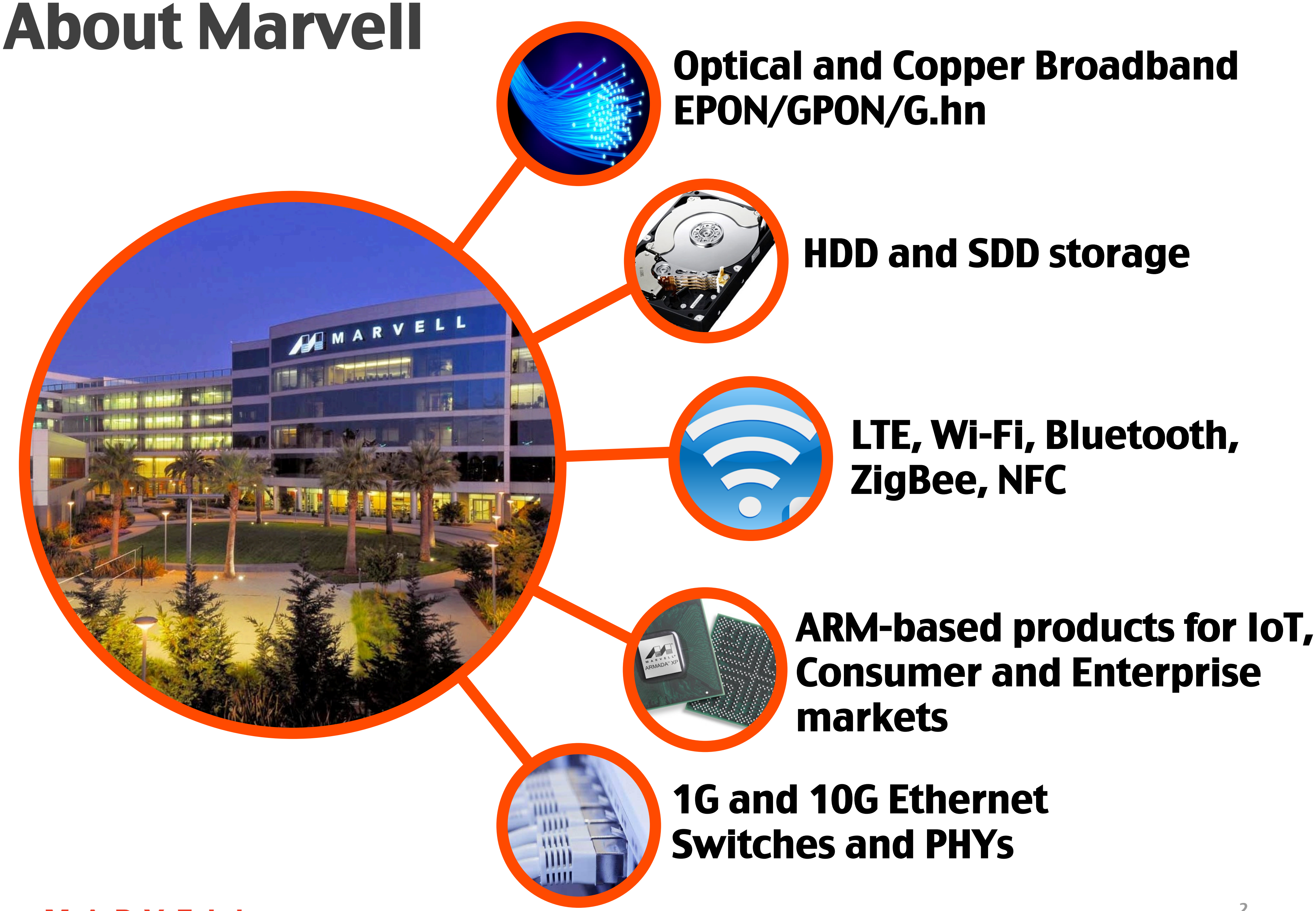
About Marvell



Optical and Copper Broadband EPON/GPON/G.hn

HDD and SDD storage

LTE, Wi-Fi, Bluetooth, ZigBee, NFC

ARM-based products for IoT, Consumer and Enterprise markets

1G and 10G Ethernet Switches and PHYs

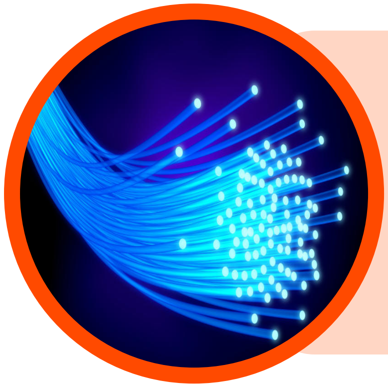
About Marvell

Optical and Copper Broadband EPON/GPON/G.hn

Marvell, in collaboration with other partners, provides semiconductor solutions for the broadband industry:

- EPON/GPON ONTs & SFP modules
- Residential Gateways
- xDSL/G.fast/G.hn Distribution Points (DP) and Customer Premises Equipment (CPE)
- Reverse-powered DPs
- MDU switches
- G.hn home-networking
- Wi-Fi Access Points
- Wi-Fi Extenders
- Wired and Wireless IPTV STBs

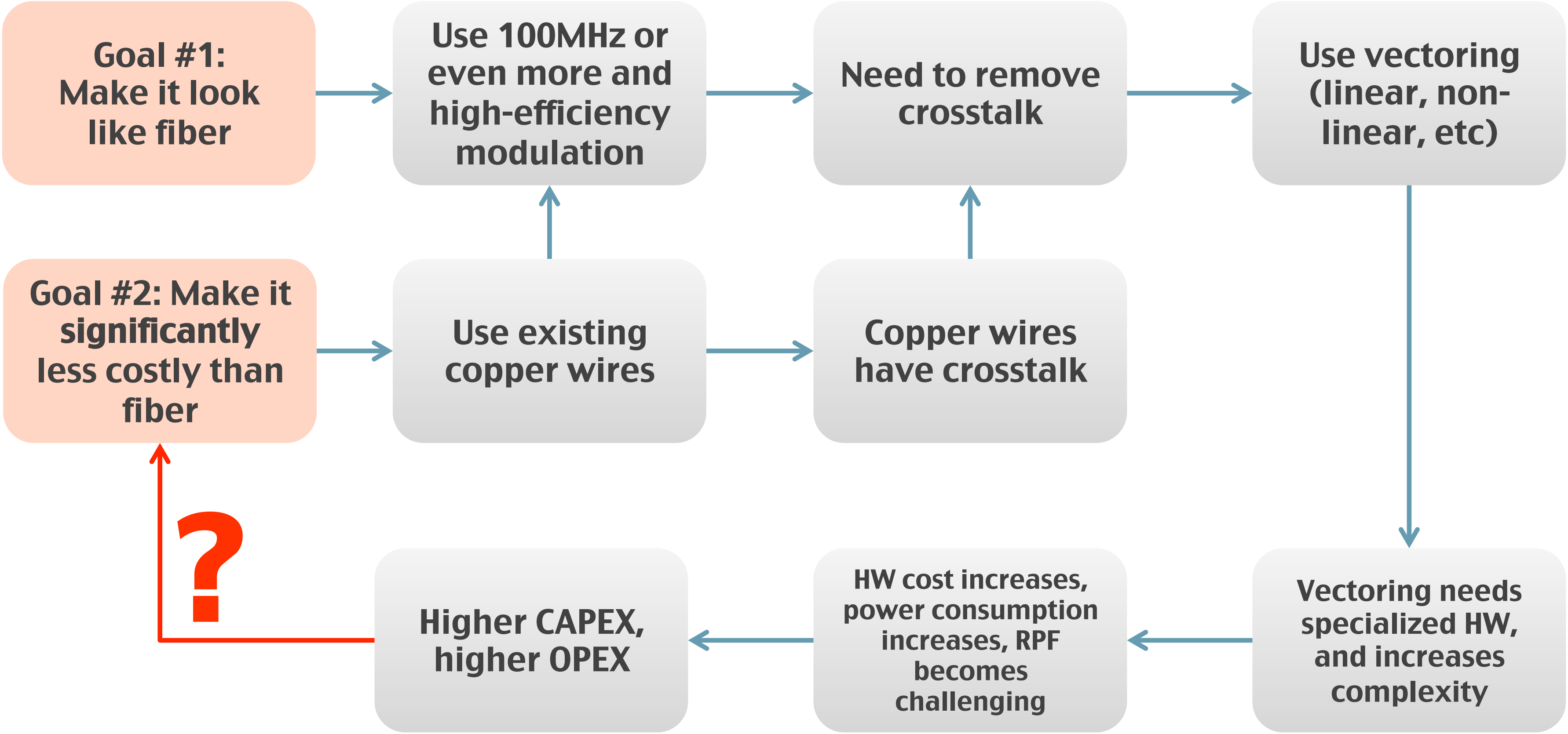
Why are we here?



Carriers want to deliver a "broadband experience" as close as possible to FTTH

Carriers need a solution with costs (CAPEX & OPEX) significantly lower than FTTH

Achieving the goals for FTTdp networks


Goal #1: Make it look like fiber
Use 100MHz or even more and high-efficiency modulation
Need to remove crosstalk
Use vectoring (linear, non-linear, etc)
Goal #2: Make it **significantly** less costly than fiber
Use existing copper wires
Copper wires have crosstalk
?
Higher CAPEX, higher OPEX
HW cost increases, power consumption increases, RPF becomes challenging
Vectoring needs specialized HW, and increases complexity

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But if we look at the original goals more carefully…

Goal #1:
Make it look like fiber

Goal #2: Make it significantly less costly than fiber

- Telco’s today deploy GPON networks that provide 2.5Gbps (downstream capacity), shared across a large number of users (32 or 64 per OLT port, typically).
- If you do the math, 2.5G divided by 64 is <40 Mbps, but carriers describe these as “gigabit service”.
- And nobody complains…
- And the reason is that statistical multiplexing works!!

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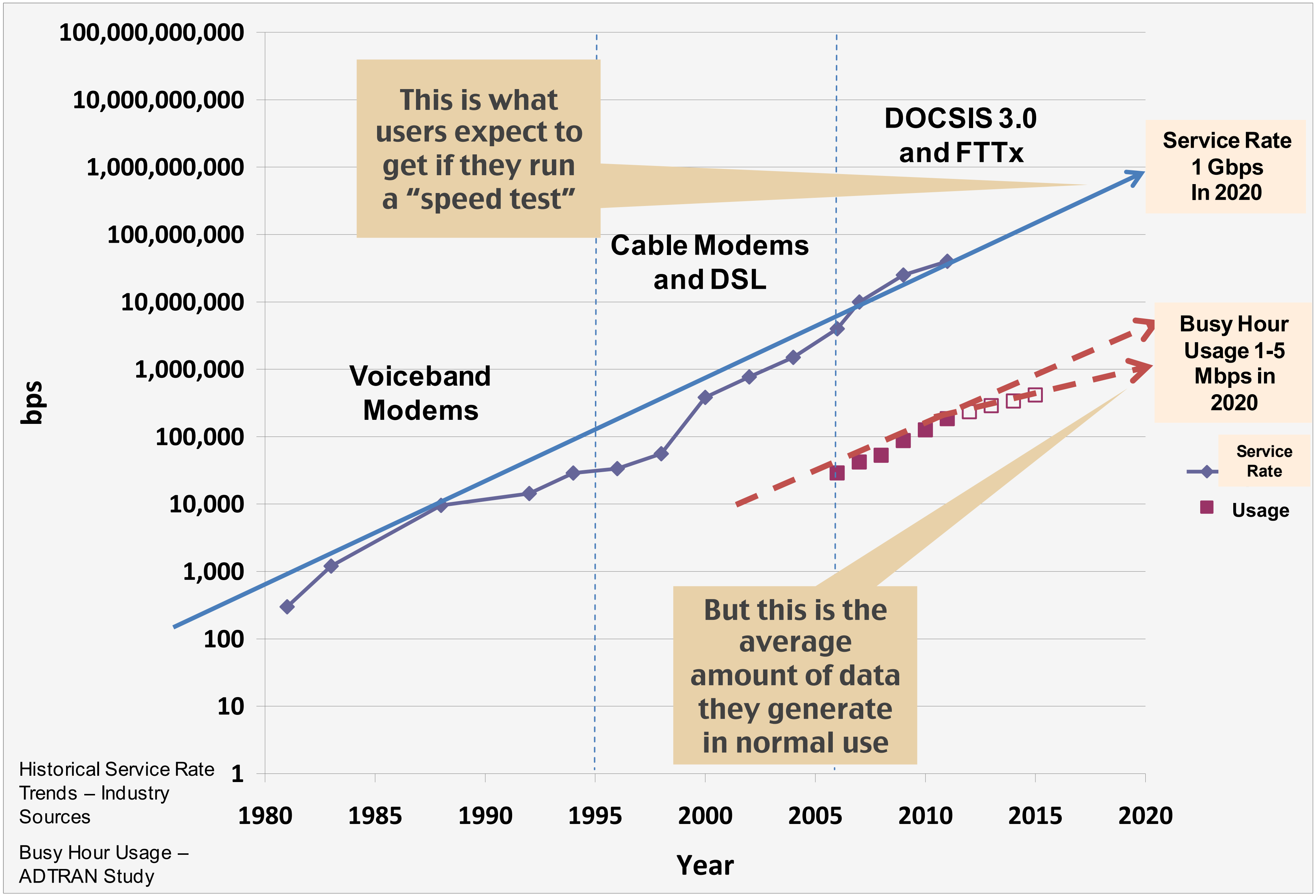
Service Rate vs Busy Hour Usage



This is what users expect to get if they run a “speed test”

Service Rate 1 Gbps In 2020

Busy Hour Usage 1-5 Mbps in 2020

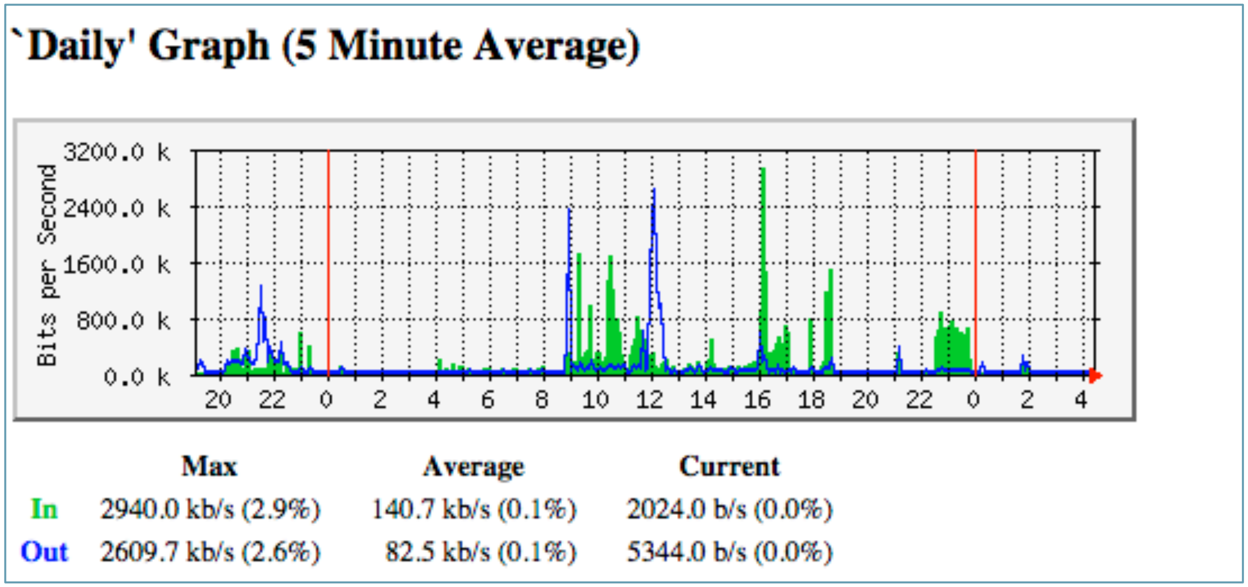
But this is the average amount of data they generate in normal use

Historical Service Rate Trends – Industry Sources

Busy Hour Usage – ADTRAN Study

Source: Adtran, ITU-T Q4/SG15 Contribution 11RV-061.doc, Nov 2011

Broadband Traffic from Residential and SMB users is "bursty"

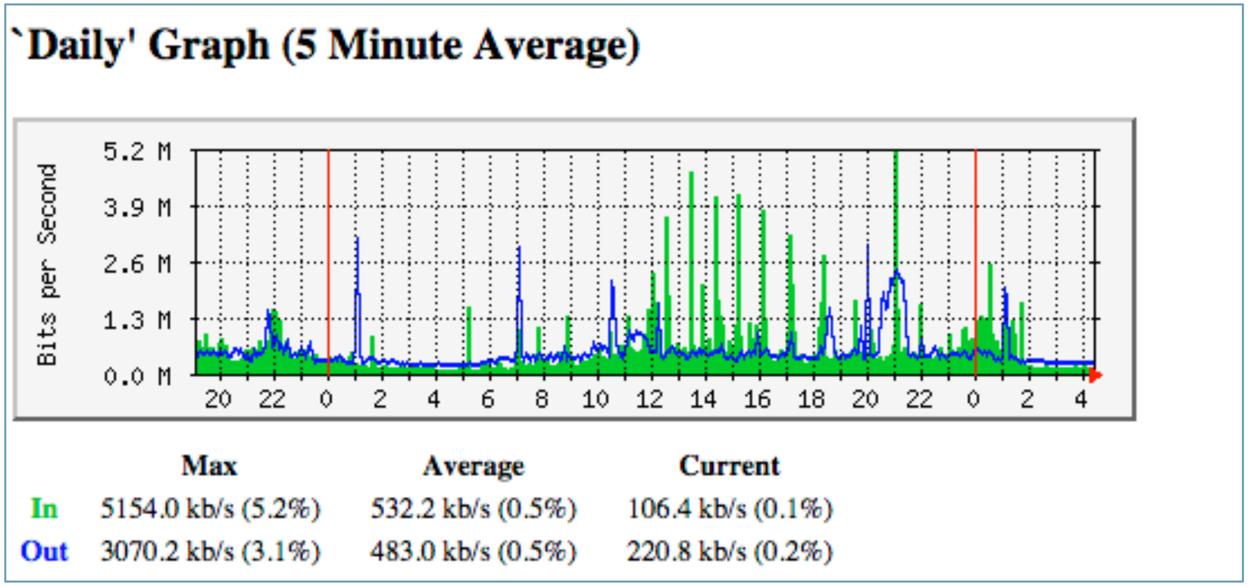


`Daily' Graph (5 Minute Average)

	Max	Average	Current
In	2940.0 kb/s (2.9%)	140.7 kb/s (0.1%)	2024.0 b/s (0.0%)
Out	2609.7 kb/s (2.6%)	82.5 kb/s (0.1%)	5344.0 b/s (0.0%)

Example traffic log
from one broadband user

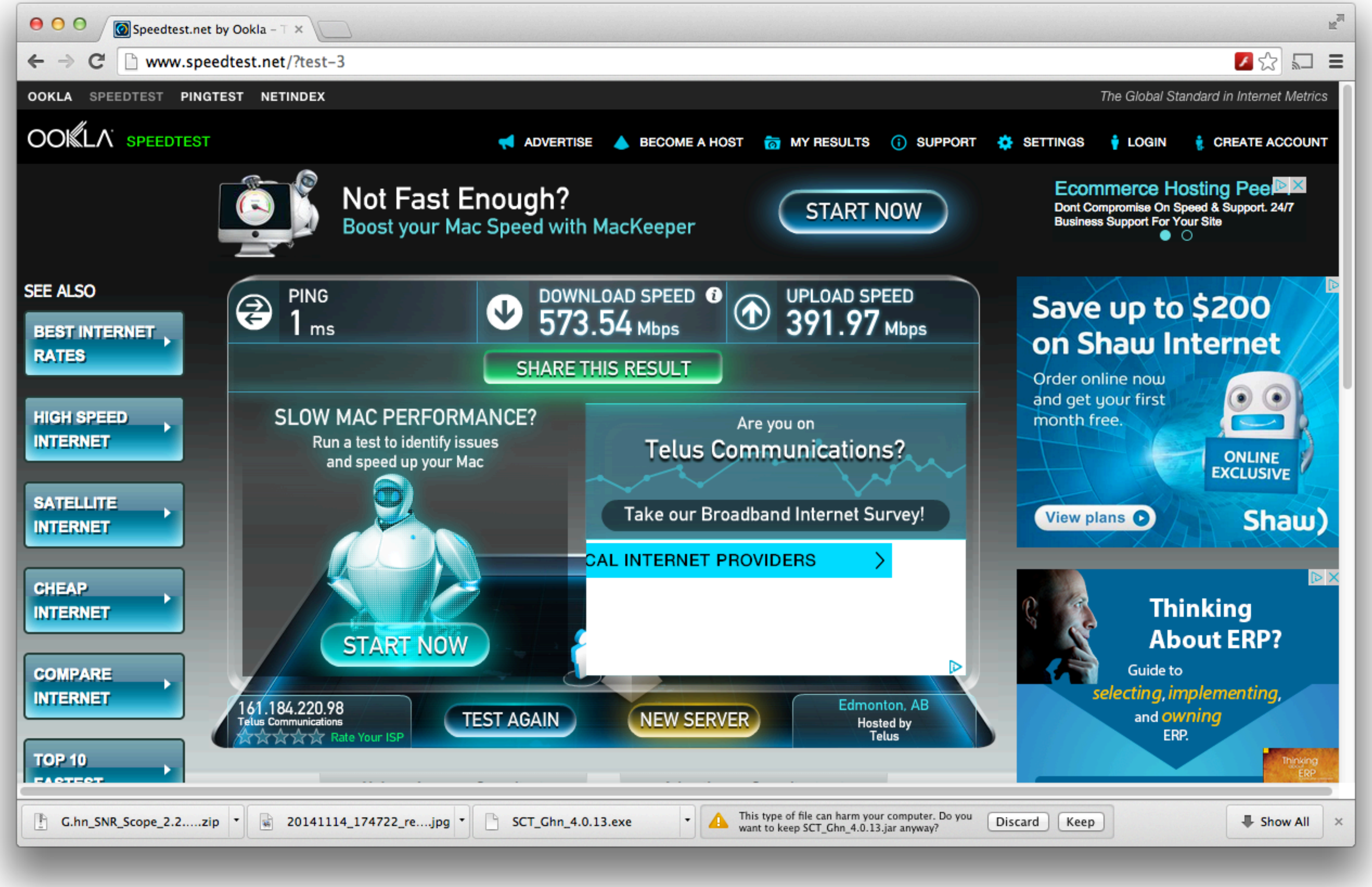
Example traffic log
from one broadband user



`Daily' Graph (5 Minute Average)

	Max	Average	Current
In	5154.0 kb/s (5.2%)	532.2 kb/s (0.5%)	106.4 kb/s (0.1%)
Out	3070.2 kb/s (3.1%)	483.0 kb/s (0.5%)	220.8 kb/s (0.2%)

How do users measure their own broadband performance?



The Global Standard in Internet Metrics

PING 1 ms

DOWNLOAD SPEED 573.54 Mbps

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Guide to selecting, implementing, and owning ERP.

This type of file can harm your computer. Do you want to keep SCT_Ghn_4.0.13.jar anyway?

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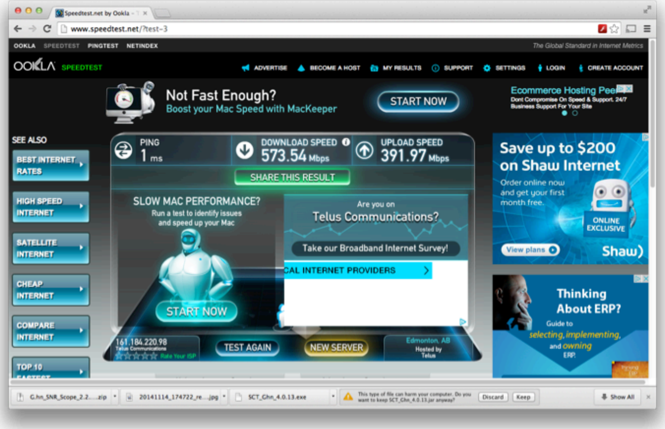
Can we use this when designing an FTTdp system?

From time to time, some users will run “speed tests” to measure their performance


Speedtest.net by Ookla
www.speedtest.net/?test-3
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Guide to selecting, implementing, and owning ERP
G.hn_SNR_Scope_2.2....zip
20141114_174722_re....jpg
SCT_Ghn_4.0.13.exe
Discard
Keep
Show All

PING 1 ms

DOWNLOAD SPEED 573.54 Mbps

UPLOAD SPEED 391.97 Mbps

161.184.220.98 Telus Communications

Rate Your ISP

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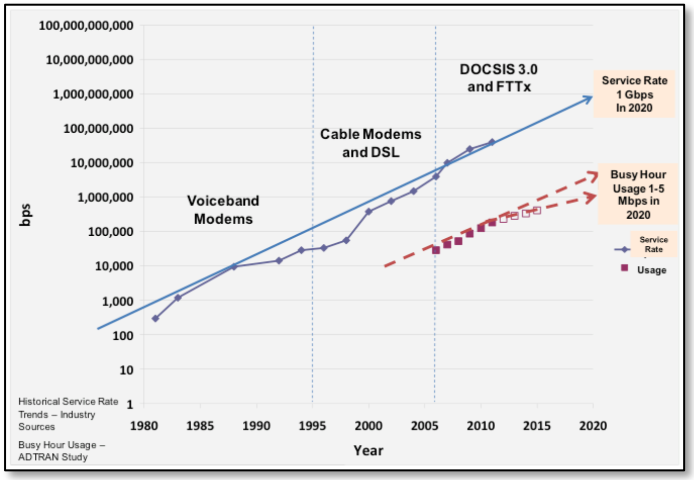
This type of file can harm your computer. Do you want to keep SCT_Ghn_4.0.13.jar anyway?

But most of the time, user traffic will be 10x to 100x times lower than “service rate”



Historical Service Rate Trends – Industry Sources

Busy Hour Usage – ADTRAN Study

How can we use statistical multiplexing to build a system that delivers “gigabit experience”, while keeping cost/complexity super-low?

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Questioning several principles of traditional xDSL network deployment (I)

From time to time, some users will run “speed tests” to measure their performance

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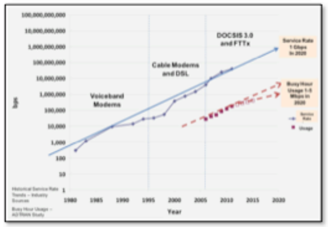

How can we use statistical multiplexing to build a system that delivers “gigabit experience”, while keeping cost/complexity super-low?

If traffic from most users is very bursty…

- Do we need all lines to be transmitting at full-power all the time?
- Do we need all lines to be using the full 100MHz spectrum all the time?
- Do we need all lines to be transmitting with a 100% duty cycle all the time?
- In other words, can we adjust the transmit power/ frequency/time in real-time depending on traffic conditions?

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Questioning several principles of traditional xDSL network deployment (II)

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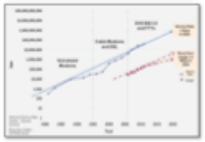

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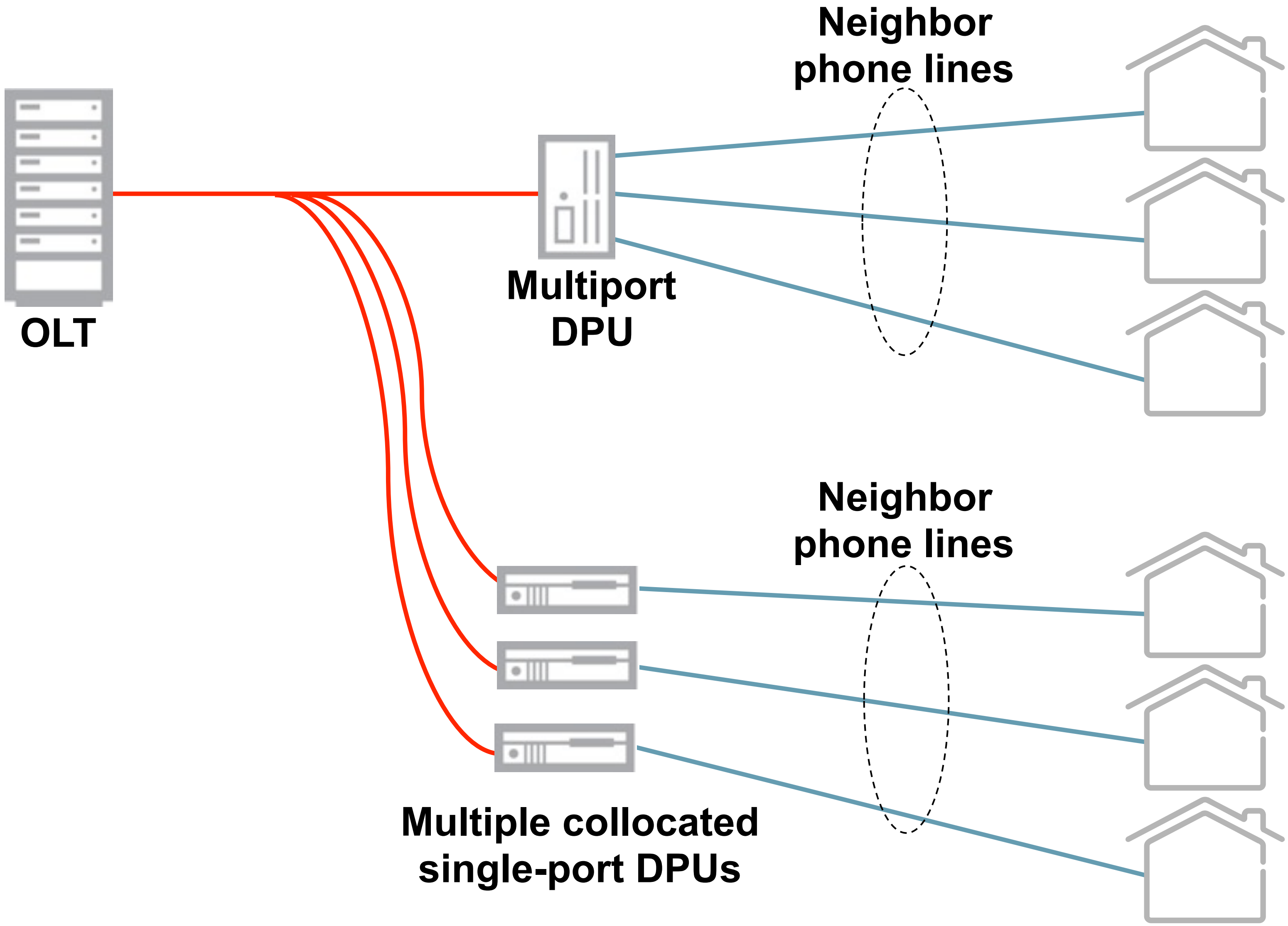
With traditional xDSL technologies, the response to all these questions was…

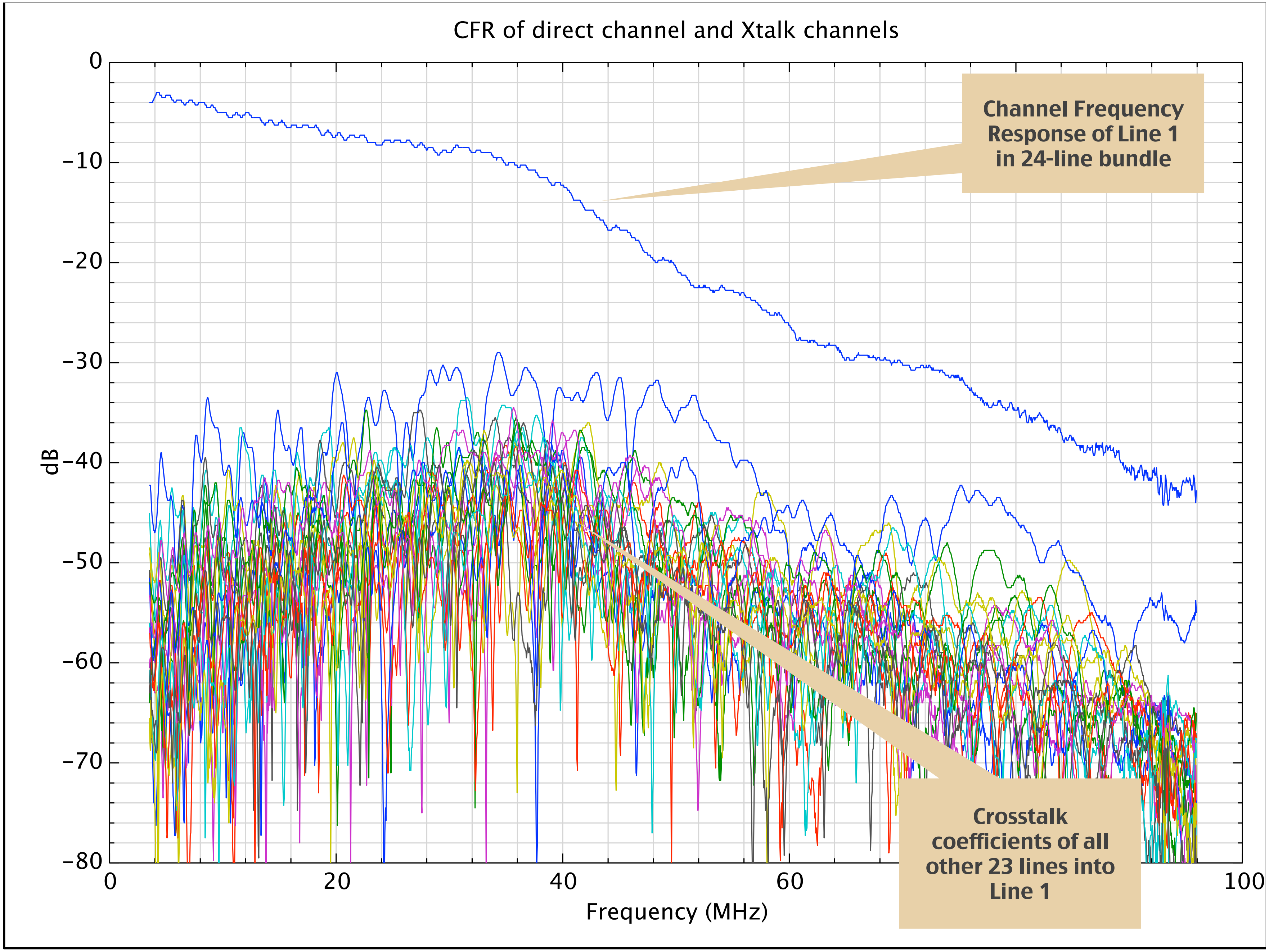
Unfortunately, YES

…because we couldn't change xDSL operating parameters quick enough to react to changes in user traffic.

But new broadband technologies (such as G.fast and G.hn) can potentially adapt much quicker to real-time traffic changes.

Physical Architecture



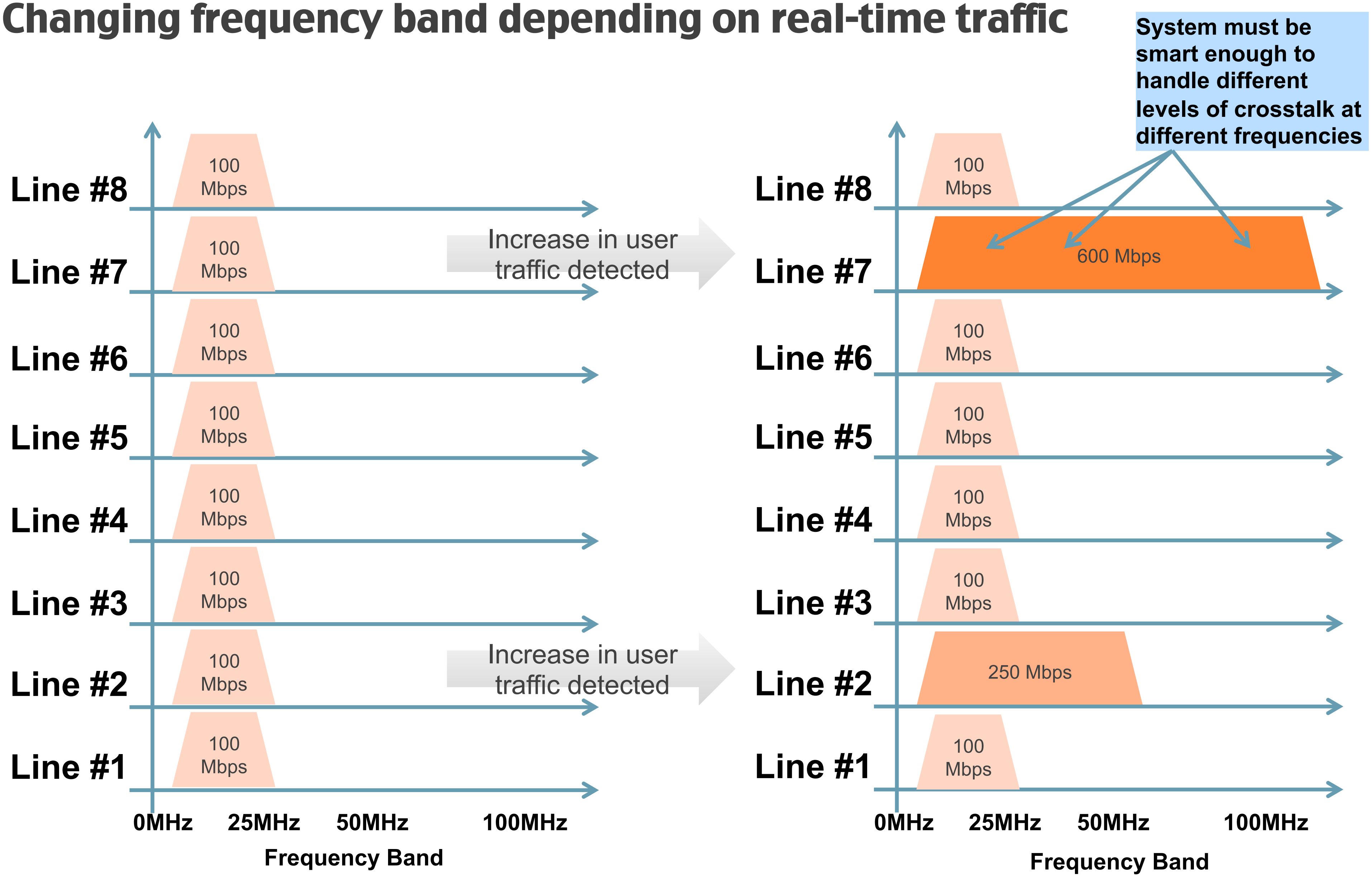


Channel Frequency Response of Line 1 in 24-line bundle

Crosstalk coefficients of all other 23 lines into Line 1

Basic Example #1:

Changing frequency band depending on real-time traffic


System must be smart enough to handle different levels of crosstalk at different frequencies
Line #8
Line #7
Line #6
Line #5
Line #4
Line #3
Line #2
Line #1
100 Mbps
Increase in user traffic detected
Increase in user traffic detected
600 Mbps
250 Mbps
0MHz
25MHz
50MHz
100MHz
Frequency Band

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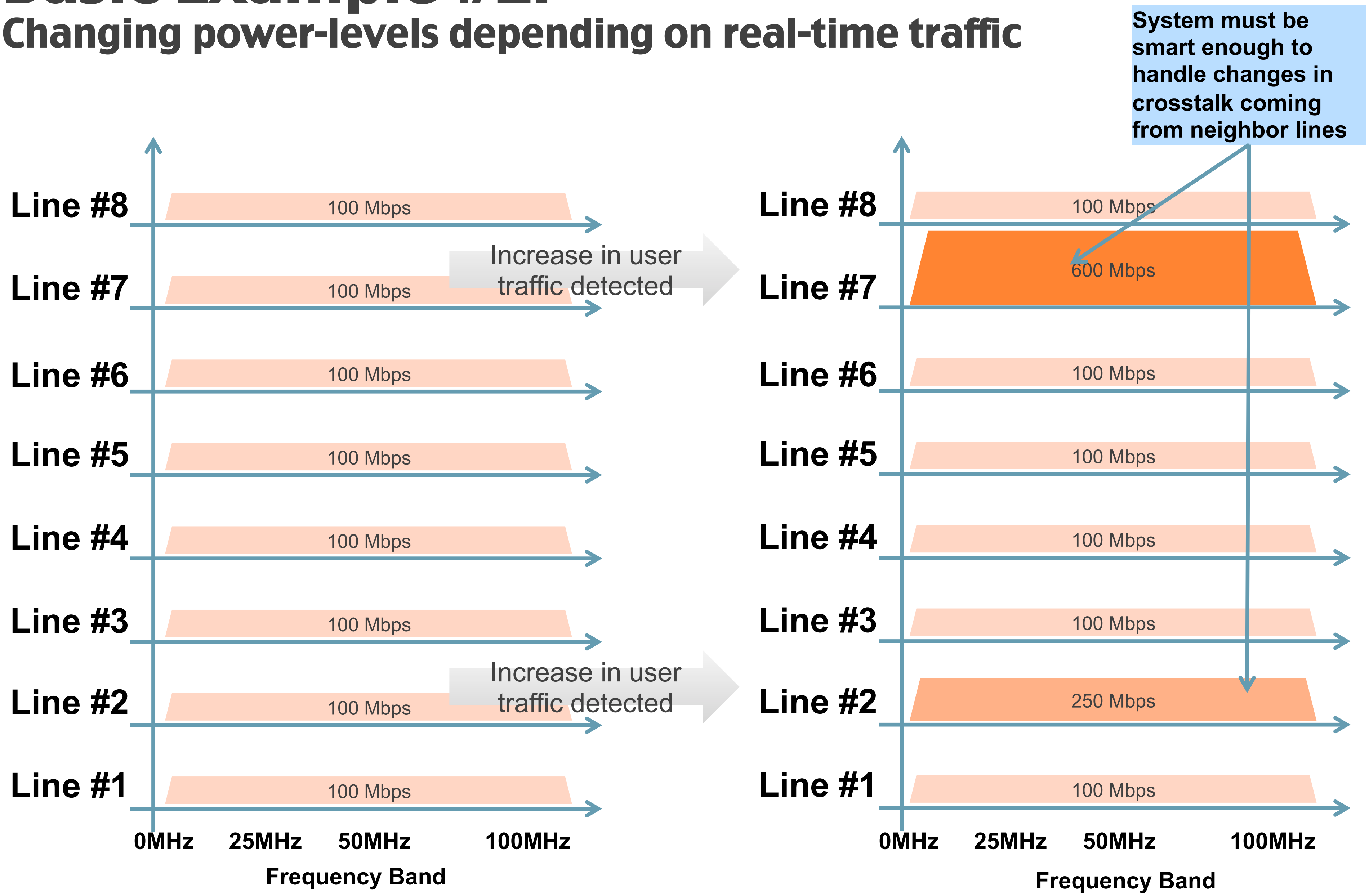
Basic Example #2:

Changing power-levels depending on real-time traffic



System must be smart enough to handle changes in crosstalk coming from neighbor lines

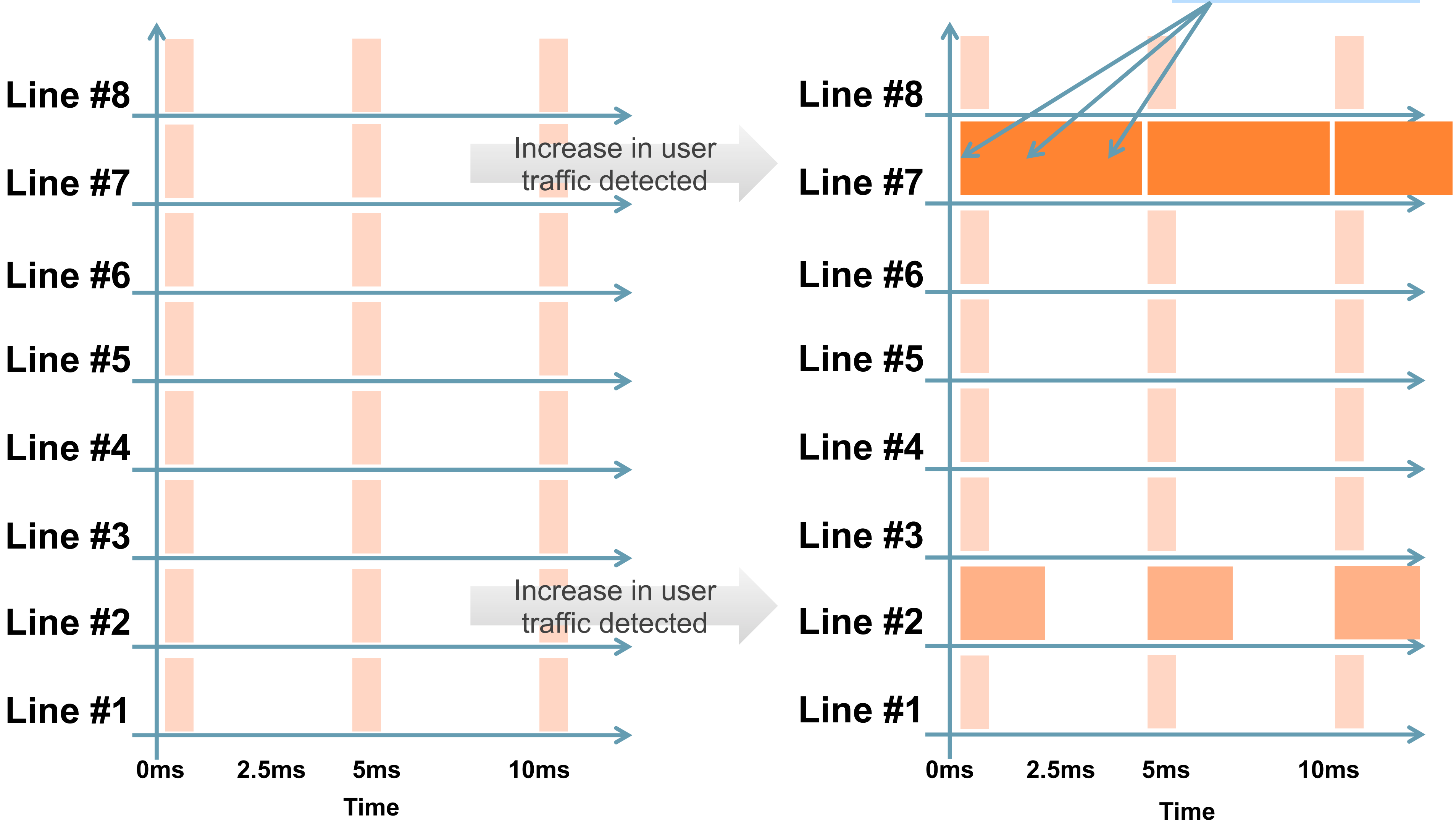
Increase in user traffic detected

Increase in user traffic detected

Basic Example #3:

Changing “discontinuous operation” profile depending on real-time traffic

System must be smart enough to handle different levels of crosstalk at different periods



Increase in user traffic detected

Increase in user traffic detected

Many more degrees of freedom become available

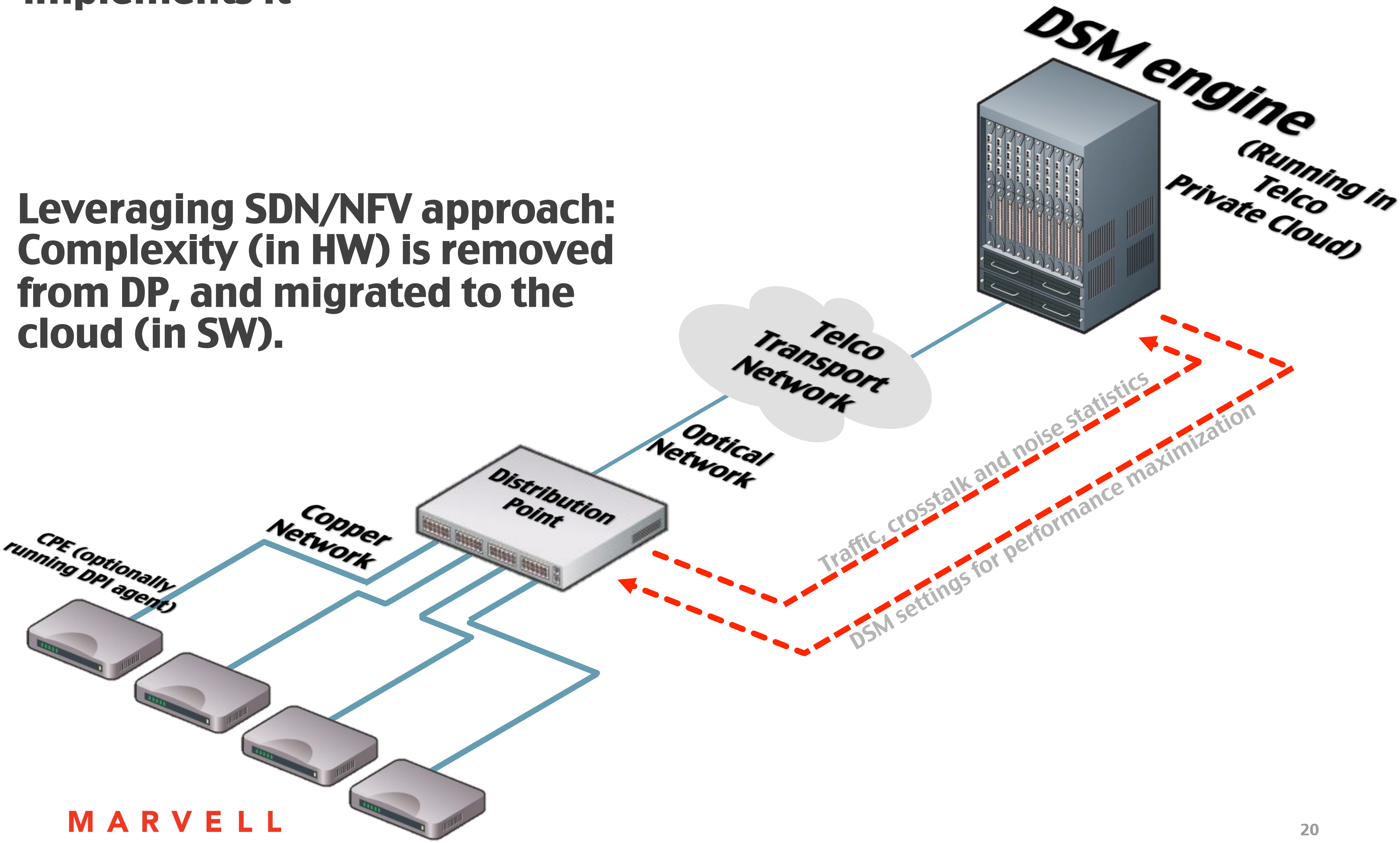
- Previous examples are just “DSM 101”
- More sophisticated systems would use channel information to jointly optimize PSD across N lines, M sub-bands and R time-regions using real-time traffic information
  - Some architectures (fewer degrees of freedom) can be addressed with relatively simple convex optimization techniques
  - More general architectures (more degrees of freedom) require non-convex optimization methods

Are any new technologies needed?

- Quick adaptation of PHY bit-loading to changes in crosstalk
  - Both G.hn and G.fast can do this today
- Quick (100–500 ms) detection of changes in user traffic
  - You can do it “the cheap way”: look at running-average of byte counters
  - You can do it “the fancy way”: use DPI (Deep Packet Inspection) at the CPE/RG to identify individual traffic flows even faster
- Common time base across all lines
  - Easy to do whether lines are part of same DPU, or even different DPUs (using IEEE 1588 sync)
- A software agent that selects the optimal DSM policy (“frequency-based” vs “power-based” vs “time-based” vs “all of the above”) in real time
  - This is best run in the cloud, where “computing cycles” are “almost free” (and algorithms get faster each year, thanks to Moore’s law).

DP collects local information (traffic, noise, crosstalk estimates, etc) and sends it to DSM engine. DSM engine computes optimal DSM settings (PSD, duty-cycle, etc) and sends it back to DP, which implements it

Leveraging SDN/NFV approach: Complexity (in HW) is removed from DP, and migrated to the cloud (in SW).


DSM engine
(Running in Telco Private Cloud)
Telco Transport Network
Optical Network
Distribution Point
Copper Network
CPE (optionally running DPI agent)
Traffic, crosstalk and noise statistics
DSM settings for performance maximization

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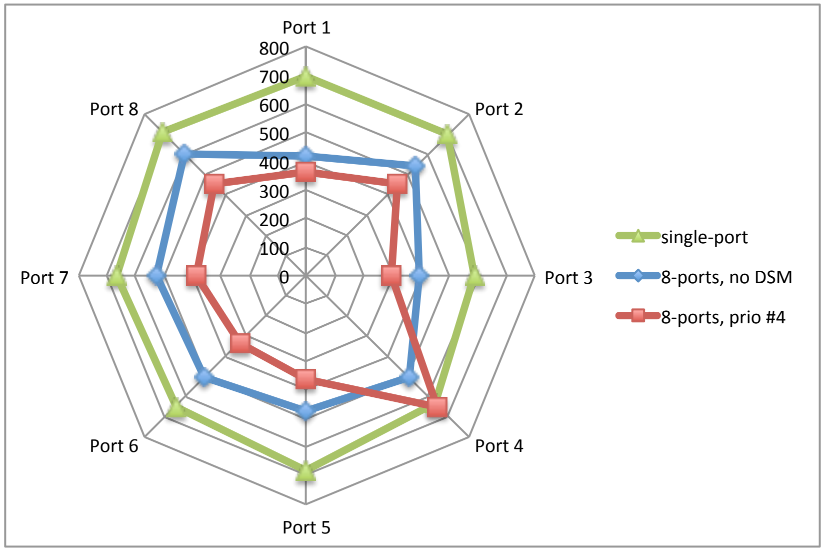
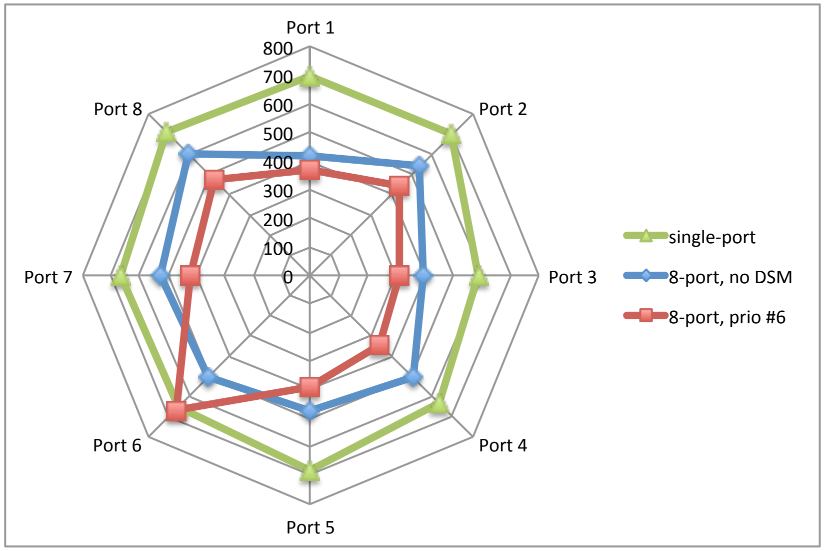
Example Results





- Test on 100m-long phoneline binder .
- 8-port DPU, using 100MHz G.hn, G.9964-compliant PSD. (Relative results can be extrapolated to G.fast).
- First measure cross-talk free bit-rate for each line, to establish a baseline (green line)
- Enable all ports at "full PSD" (ie, no DSM), and measure bit-rate again (blue line).
- Enabled "real-time DSM" and use a traffic generator to create a mix of "background traffic" (100 Mbps UDP) and "heavy traffic" (uncapped TCP) on different lines.
- The system dynamically reallocates capacity depending on real-time traffic, and immediately reconfigures bit-loading in each line in a synchronized way.
- (Red lines) show the measured bit-rate in each line at different instants, when port 4 is heavily loaded (top), and when port 6 is heavily loaded (bottom).

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But what if all the subscribers in a building decide to run a speed test at the same time? (*)

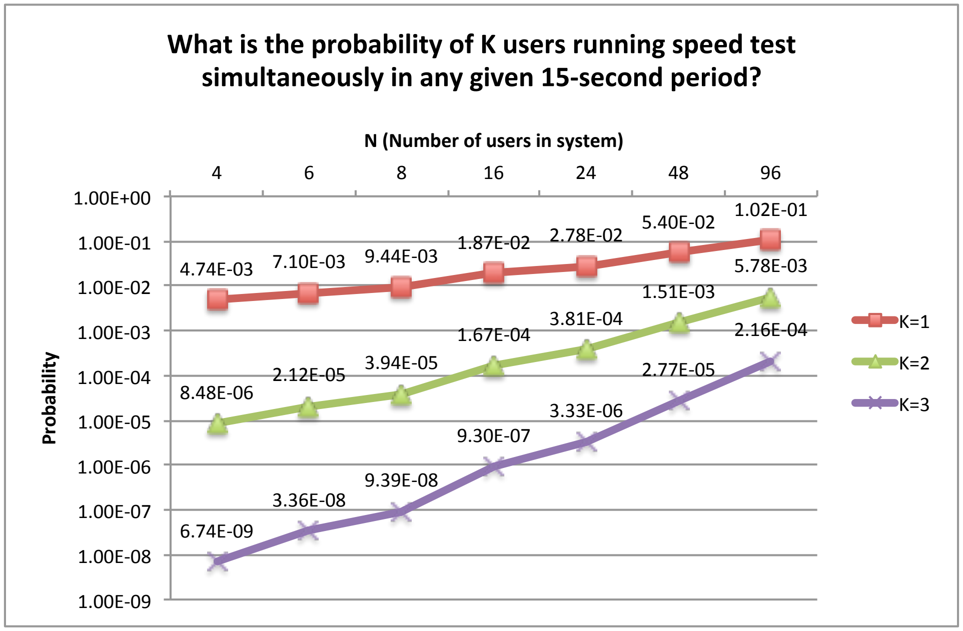
(*) Let’s forget for a moment the fact that if all users run a speed test at the same time, the GPON uplink will become the bottleneck…

What is the probability that multiple users will run “speed tests” at the same time?

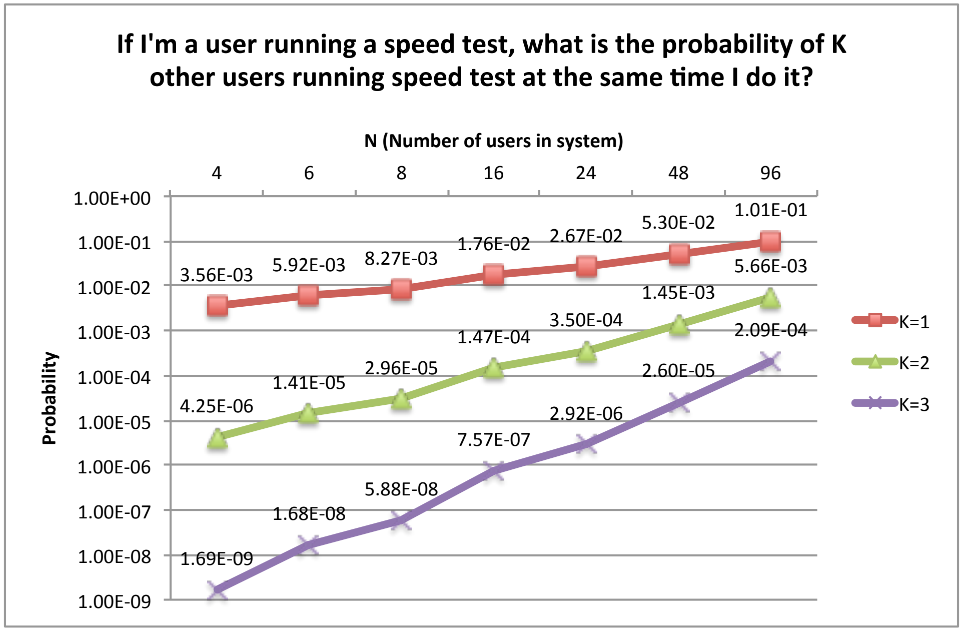
- **Model:**
  - N users (N=4, 6, 8, 16, etc)
  - Busy period (from 5pm to 12pm)
  - Test duration (15 sec)
  - Average # of test per user per day: 3 (ie, paranoid user)
  - Probability a certain user will be running a test during a certain 15-sec period:

$$P_{test} = \frac{3\times 15}{(24-17)\times 3600} = 0.00119048$$

  - Probability K users are running speed tests simultaneously is given by binomial distribution



What is the probability of K users running speed test simultaneously in any given 15-second period?



If I'm a user running a speed test, what is the probability of K other users running speed test at the same time I do it?

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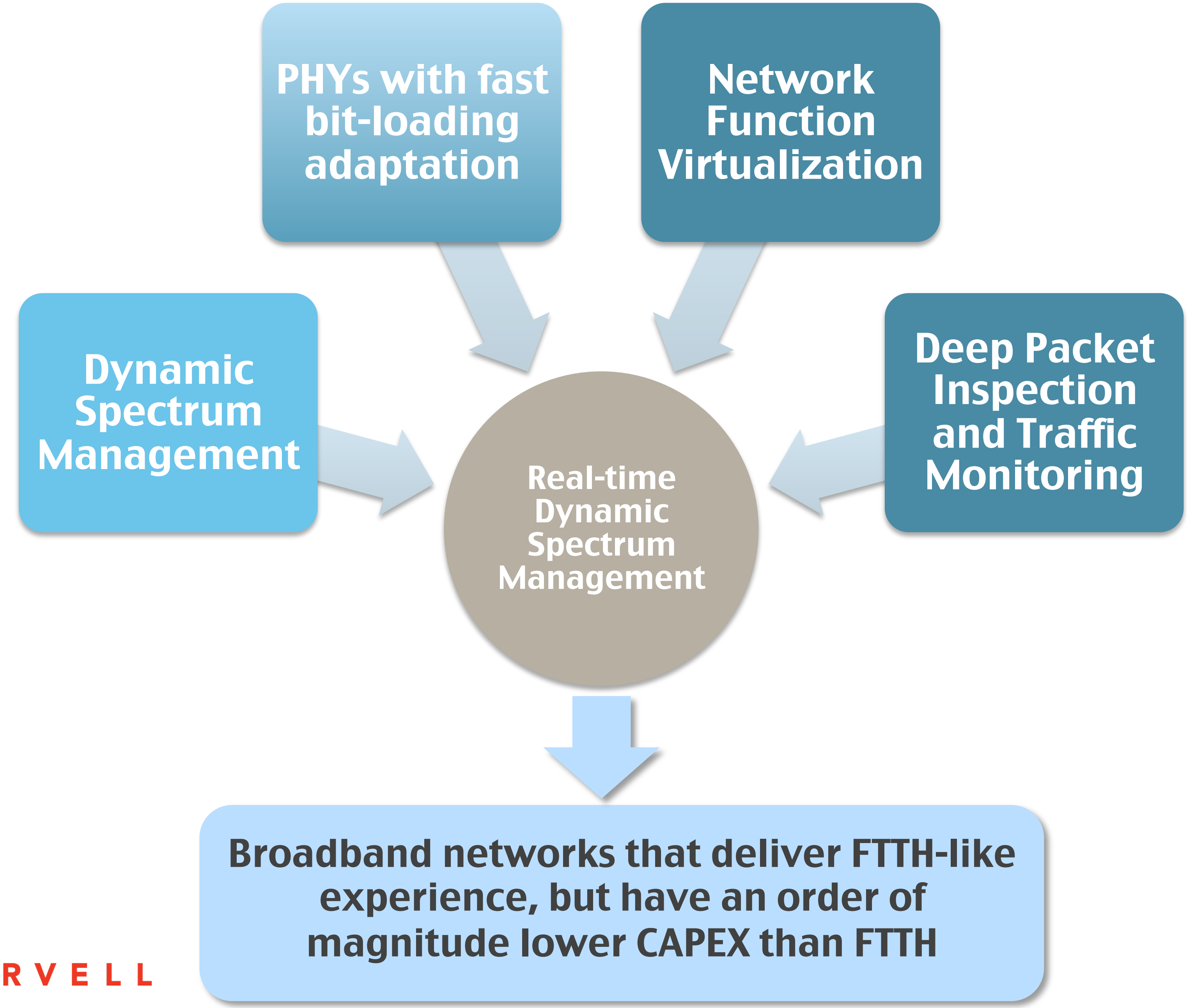
Putting it all together…



PHYs with fast bit-loading adaptation

Network Function Virtualization

Dynamic Spectrum Management

Deep Packet Inspection and Traffic Monitoring

Real-time Dynamic Spectrum Management

Broadband networks that deliver FTTH-like experience, but have an order of magnitude lower CAPEX than FTTH

Marvell's experience with real-time DSM

- **Marvell and its customers have built systems based on the "real-time DSM" architecture presented today.**
  - **Using off-the-shelf 100MHz G.hn transceivers (ie, low cost and low power)**
    - TDD, 12 bits/tone, LDPC FEC, programmable up/down ratio
  - **Combining several of the approaches discussed earlier (power-based, frequency-based, etc)**
  - **Running on hardware that can be reverse-powered up to 250m (including GPON transceiver)**
  - **Without using a precoding module**
  - **Using cloud-based entity for computing optimal DSM policies based on real-time user traffic**
- **In multi-line scenarios, with heavy crosstalk, this approach enables users to experience "crosstalk-free" performance, when using realistic traffic patterns.**
  - **While delivering multi-channel 4K IPTV streams and high-speed internet to everybody else in the same binder**

Wrap-up

- **New PHY technologies such as G.fast and G.hn allow system designers to question some of the established methodologies in xDSL system design.**
  - "Fast bit-loading reconfiguration" is key
- **Making the system "traffic aware" allows designers to use DSM technology in "real time" manner.**
- **Frequency/Time/Power-based capacity sharing mechanisms become possible, including combinations of multiple techniques simultaneously.**
- **This provides a new set of tools for network designers, that can complement precoding-based DSM solutions to achieve very low-cost targets.**
  - Also addresses scenarios in which traditional vectoring is not feasible (ie, regulation, etc)
- **The use of cloud-based policy engines enable carriers to increase performance in the access network as computing power increases over time, while reducing HW cost/complexity.**