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CAF 2

Modeling fixed wireless capacity for CAF 2 deployments

October 2015

Overview

Use capacity modeling to estimate the ability of LTE-Advanced to support fixed broadband subscribers per CAF2 performance requirements

- Must support equivalent of wired broadband
  - Similar monthly volume
  - Similar busy hour loads
- Methodology
  1. Estimate offered loads through end of CAF2 term of support
  2. Estimate capacity required to meet performance at the required load vs. number of subscribers
  3. Test required capacity against estimated sector capacity
- Summarized results
  - Projected offered load = approximately 1.7 Mbps per subscriber in 2020
  - For a 10 MHz LTE-Advanced channel:
    - Estimated sector capacity = 26 Mbps
    - Each sector supports 7 to 10 subscribers

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CAF 2

- Objectives
  - Deliver 10 Mbps throughout the rural FCC supported network
  - Through Six-year term of support (through 2020)
- Bandwidth Capacities
  - Projected busy hour loads through CAF 2 term
  - Projected subscriber capacities per dedicated sector (fixed wireless)

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Traffic Growth

Estimating Future Subscriber Loads

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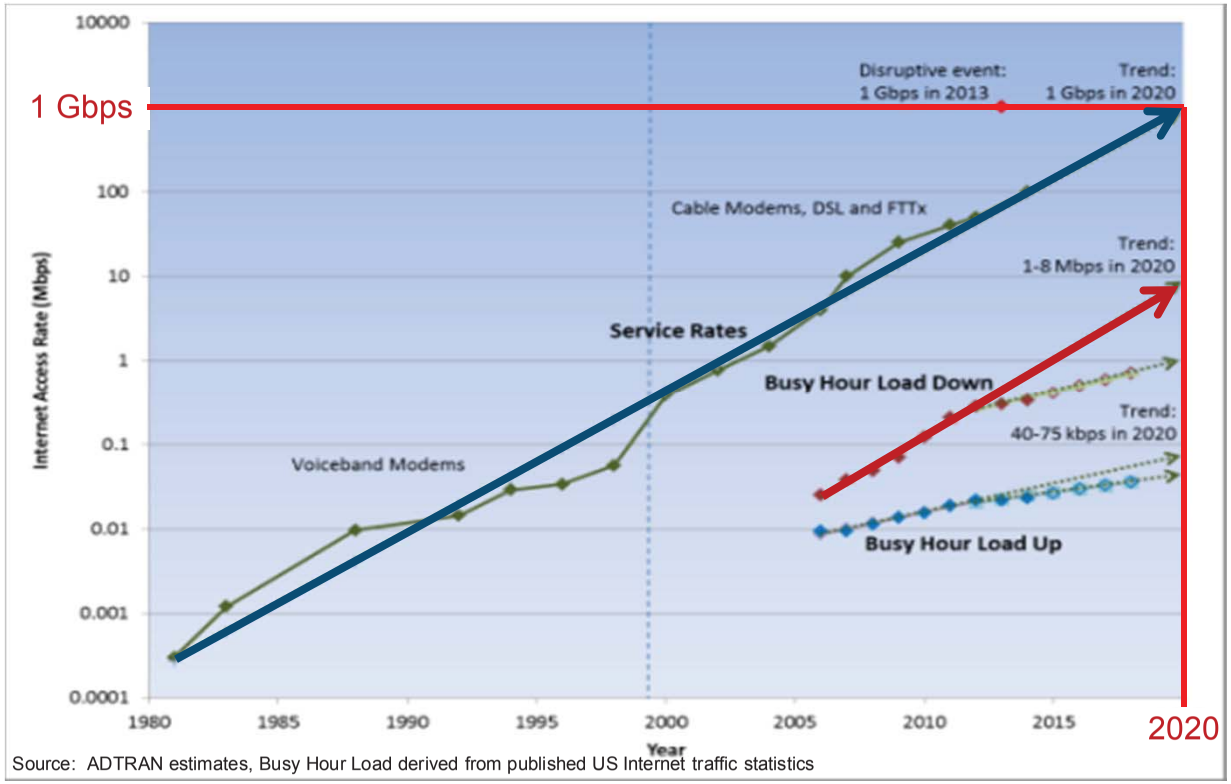
Historical Service Rate and Traffic Growth

- Service rates
  - Annual growth has averaged 45% over 30 years
  - At this rate, 1 Gbps will be widely available by 2020
- Traffic Growth
  - 40% annual growth from 2006 to 2012
  - Cisco Visual Networking Index* forecasts lower growth through 2019
    - North America consumer Internet growth forecast = 26%
      - Combined fixed & mobile
      - At the low end of regional forecasts (24% to 52%)
    - Global consumer Internet growth forecasts: fixed = 24%, mobile = 59%
  - Overall Busy Hour Load (BHL) per subscriber may grow to 1.5 to 6 Mbps in 2020
  - However, the numbers change for subscribers at 10 Mbps (see following slides)



Source: ADTRAN estimates, Busy Hour Load derived from published US Internet traffic statistics

*http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.html

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Factors in Traffic Growth

- Average traffic growth over time has two factors
  1. Growth due to migration to higher service tiers
     - Higher rates support new, higher rate applications (UHD video, virtual reality, etc.)
     - "Virtuous cycle" of higher rate adoption → new application development → higher rate adoption
     - Greater convenience of non-real time applications promotes increased use (e.g., at 1 Gbps, download a movie in <10 seconds)
  2. Growth within a service tier
     - Existing applications (supported by a service tier) are more widely adopted
     - Existing applications become more content-rich (e.g., ad insertion, video auto-play)
- For CAF 2 deployments at 10 Mbps
  - No service tier migration through 2020
  - Traffic growth is slower than overall average growth

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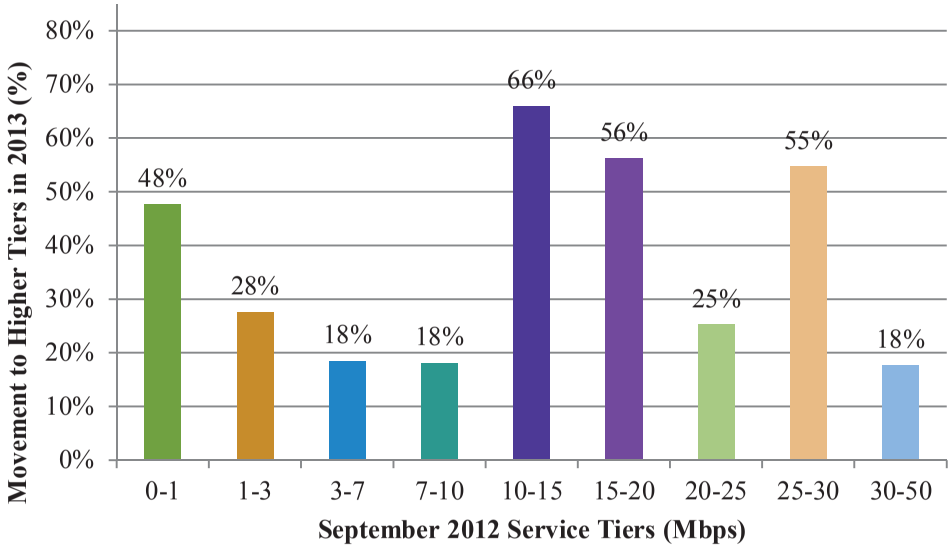
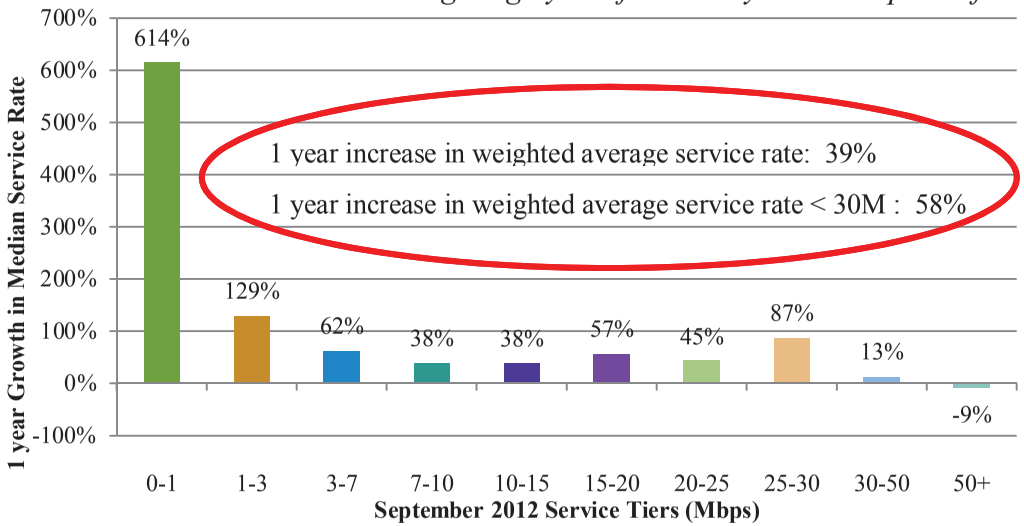
Are customers increasing their service rate? -- YES



FCC Measuring Broadband American 2014 Report

Data derived from
FCC Measuring Broadband America 2014 Report
Weighting by % of testers by tier and speed of tier



FCC data agrees with historical trend data

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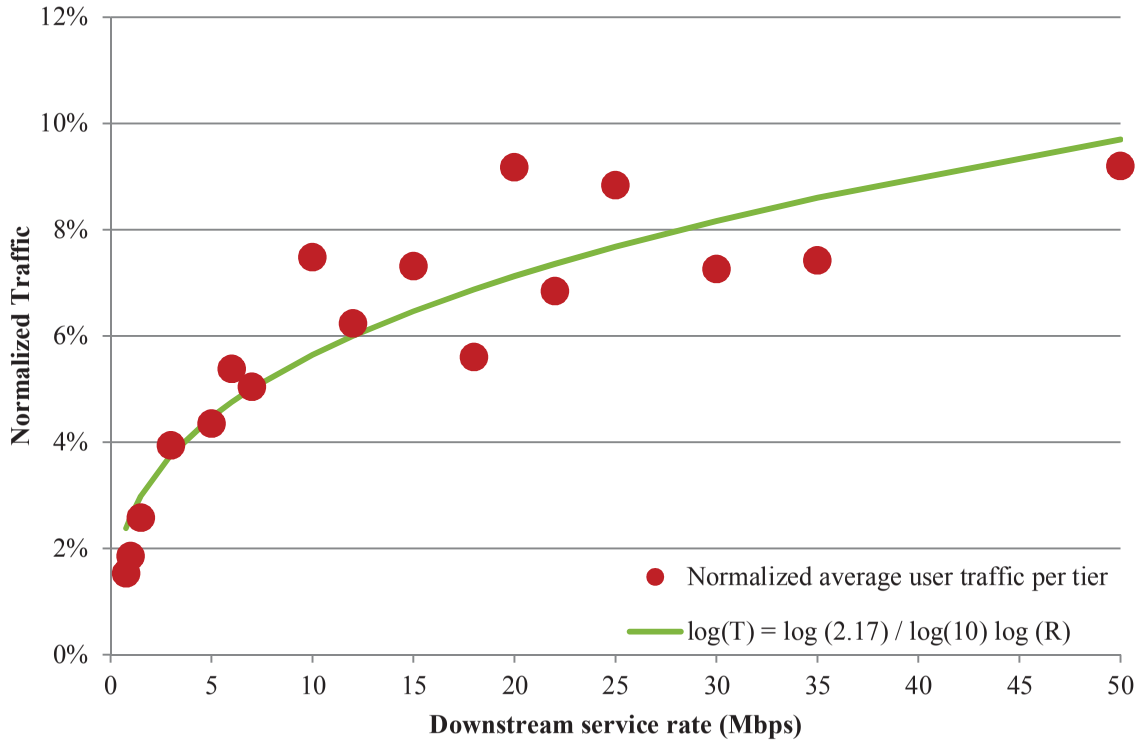
Traffic and Service Rate



FCC Measuring Broadband American 2013 Report

- Traffic is highly correlated with service rate
  - 10x increase in service rate correlates to ≈2.2x increase in subscriber traffic

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Components of Traffic Growth

T_{total} = Overall Growth Rate for Busy Hour Load (BHL)

Decompose into 2 components:

1. Growth due to migration to higher service tiers (T_{rate})
2. Growth within the same service tier (T_{tier})

$$1 + T_{total} = (1 + T_{rate})(1 + T_{tier})$$

From the rates vs. traffic chart we see that T_{rate} is tied to growth in service rates (S_{rate})

$$T_{rate} = (1 + S_{rate})^{log_{10}(C)} - 1$$

Where *C* is the proportional increase in traffic for every decade increase in service rate (from the FCC data, *C* ≈ 2.2)

Once we know T_{rate} we can calculate the growth rate within a service rate tier

$$T_{tier} = \frac{1 + T_{total}}{1 + T_{rate}} - 1$$

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BHL Growth at 10 Mbps

- Assumptions (use ranges for all parameters)
  - Service Tier Growth Rate $S_{rate} = 35\%\ to\ 55\%$
  - Overall Traffic Growth Rate $T_{total} = 20\%$ to 40%
  - BHL growth *C* per decade in service rate $C = 2.0$ to 2.4
  - Current Busy Hour Load $BHL_{2015} = 600$ kbps

S_{rate}	T_{total}	C	T_{rate}	T_{tier}	BHL_{2020}
35%	20%	2.4	12.1%	7.1%	0.84 Mbps
45%	30%	2.2	13.6%	14.5%	1.18 Mbps
55%	40%	2.0	14.5%	22.7%	1.67 Mbps

Traffic growth rate within a tier (7.1% to 22.7%) is significantly less than the overall growth rate (20% to 40%)

BHL in 2020 at 10 Mbps service rate = 0.84 to 1.67 Mbps

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Required Capacity

Based on Traffic and Required Performance

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Required Capacity Calculation (basic version)

The required capacity to support an average throughput T can be estimated by adding T to the average load $(n-1) * L$ used by all of the other subscribers:

$$C = \frac{T + (n-1) * L}{1 - m}$$

Variables:

- C = estimated required capacity
- T = required throughput (= 10 Mbps)
- n = number of subscribers
- L = average offered load (= 1.67 Mbps)
- m = margin for protocol overhead (= 6%)

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Required Capacity Calculation with Compensation

We can add compensation for load variation due to small subscriber populations by including a factor $\nu(n, P_L)$:

$$C = \frac{T + (n-1) * \nu(n, P_L) * L}{1 - m}$$

Variables:

$\nu(n, P_L)$ = compensation for load variation in subscriber subset

n = number of subscribers

P_L = percentile threshold that sets how conservatively we want to compensate

- Higher = more conservative
- P_L= 75% means that 75% of nodes/sectors require less capacity than C
- At P_L= 75%, $\nu(n, P_L)$ is in the 1.3-1.4 range for the numbers of subscribers simulated

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Capacity of LTE-Advanced

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Capacity of LTE-Advanced

- Considerations in designing LTE networks for fixed broadband access
  - Average sector capacity
    - Product of average spectral efficiency and channel bandwidth
    - Corresponds to the required capacity *C* estimated by the model on previous slides
  - Cell edge spectral efficiency
    - Affects fixed broadband subscribers more than mobile subscribers (if they live at the cell edge their fixed broadband service is always affected)
    - Accommodations for cell-edge customers may lower the overall average spectral efficiency
- Average sector capacity can vary widely
  - What components of LTE-A are deployed (carrier aggregation, MU-MIMO, CoMP, etc.)
  - User equipment and MIMO design
  - Channel bandwidths and frequencies
  - Cell placement
  - Scheduling algorithms
- Tradeoffs between average spectral efficiency and cell edge performance
  - MU-MIMO improves average efficiency at cost to cell-edge efficiency
    - SU/MU-MIMO dynamic switching can be used to trade off one for the other
  - Proportional scheduling improves average efficiency at cost to cell-edge performance
    - Weighting cell edge users higher helps them but hurts average

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Capacity of LTE-Advanced (2)

- Required downlink performance for LTE-Advanced (Microcellular case)
  - Average spectral efficiency ≥ 2.6 bits/sec/Hz
  - Cell edge spectral efficiency ≥ .075 bits/sec/Hz
  - Simulated spectral efficiencies vary widely, from less than required values to 4.31 bits/sec/Hz (dual codebook, ZFBF MU-MIMO 8x2 with max 4 layers)*
- Practical deployments optimized for fixed broadband may be unlikely to achieve much more than minimum required average spectral efficiency
  - MU-MIMO not widely deployed
  - MU-MIMO trades off cell edge efficiency for average efficiency
  - Fixed broadband deployments will have to meet 10 Mbps at cell edge
    - For a 10 MHz channel this requires 1 bit/sec/Hz

*Chaiman Lim, Taesang Yoo, Bruno Clerckx, Byungju Lee, and Byonghyo Shim, "Recent trend of multiuser MIMO in LTE-advanced," IEEE Communications Magazine, Vol. 51, Issue 3, pp. 127-135.

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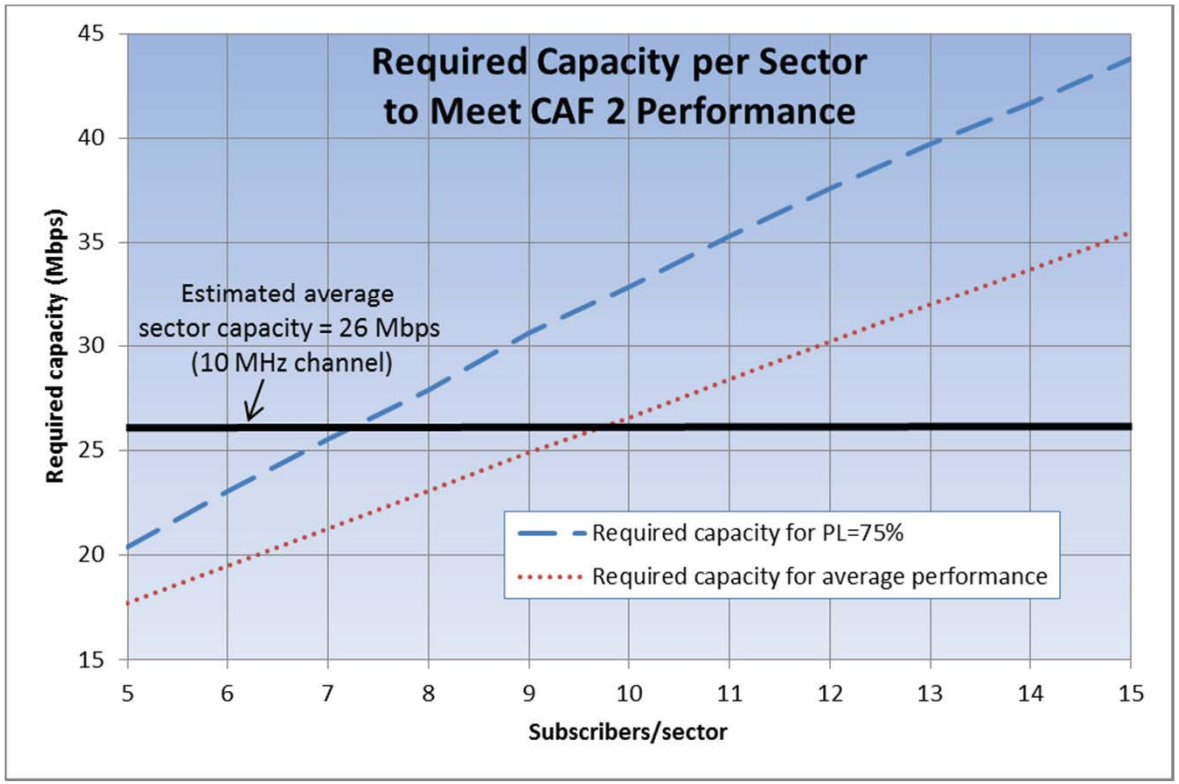
Required Capacity per Sector

- Capacity required to support a given number of subscribers at 10 Mbps in year 2020
  - 45% overall service migration rate
  - 40% overall traffic growth rate
  - 23% CAF 2 traffic growth rate (Y2020 BHL = 1.7 Mbps)
- Black line: LTE-Advanced average sector capacity
  - 10 MHz channel
  - 2.6 bits/sec/Hz average spectral efficiency
    - Must support ≥1 bit/sec/Hz to cell edge subscribers



- Blue dashed line: 75% of sectors must meet 10 Mbps average performance
  - Each sector measured independently
  - 26 Mbps supports 7 subscribers
- Red dotted line: performance is averaged across entire subscriber population
  - Sectors averaged together
  - 26 Mbps supports 10 subscribers

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Questions?
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