Influence of Information Theory on the 802.16 Wireless Standard

Relationships Between the Value of Wireless Links, Information Theory and Architectural Standards

Overview

- **What makes a wireless link valuable?**
- **How does theory impact link value?**
  - What are the relevant theoretical limits?
  - How do these theoretical limits constrain link value?
- **What is impact on the 802.16 standard?**
- **Summary**

What makes a wireless link valuable?

- **Capacity: the rate of reliable information transfer**
- **Link value is defined by *Return-on-investment (ROI)***
  - ***Revenue*** $\propto$ link capacity
  - ***Investment*** $\cong$ (Interface + modem + tuner + amplifier + antenna + BW) cost

$$ROI \propto \frac{Link\ Capacity}{Total\ System\ Cost}$$

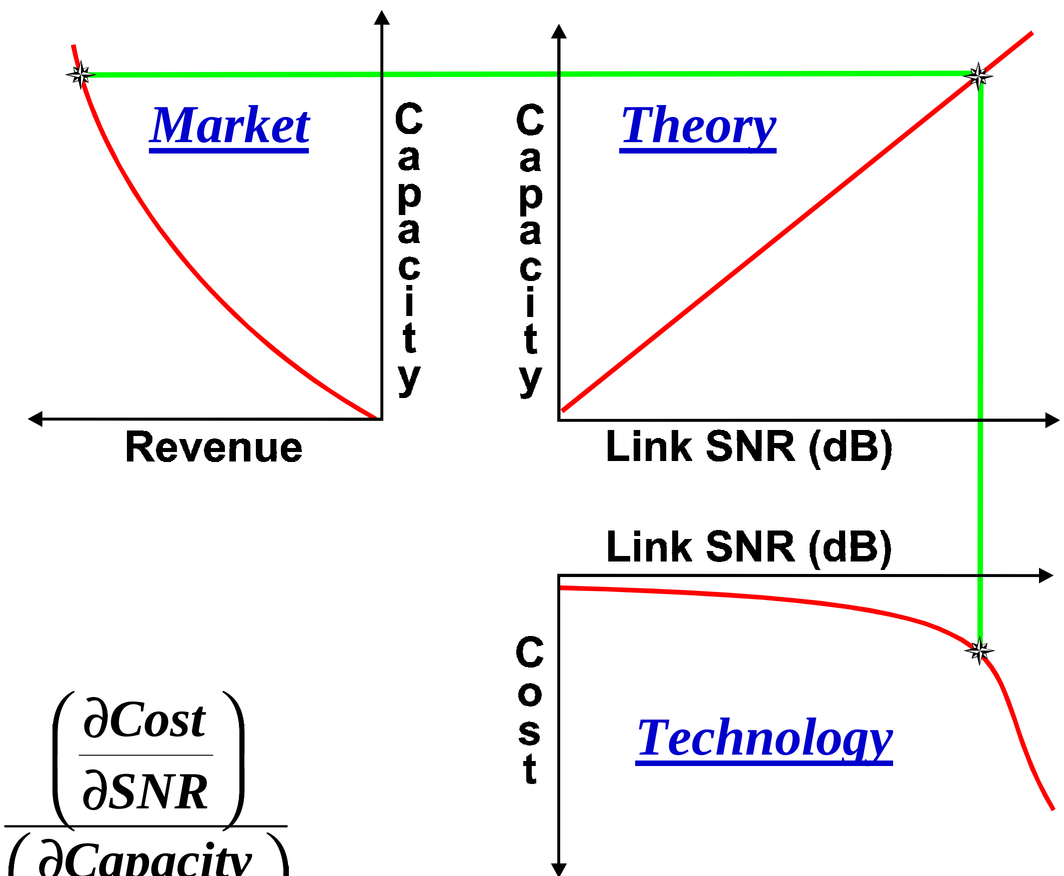
- **Maximize ROI to maximize link value**
  - ***For PTP, maximize link capacity***
  - ***For PTM, maximize average aggregate link capacity***

How does theory impact link value?

- **Theory relates link capacity to link parameters**
  - SNR
  - Error correction coding
    - Message length (packet size)
  - Link distortion
  - Synchronization
  - Sensitivity to implementation imperfections

- **These relations must be reflected in our standards**

Link Capacity Value Paradigm



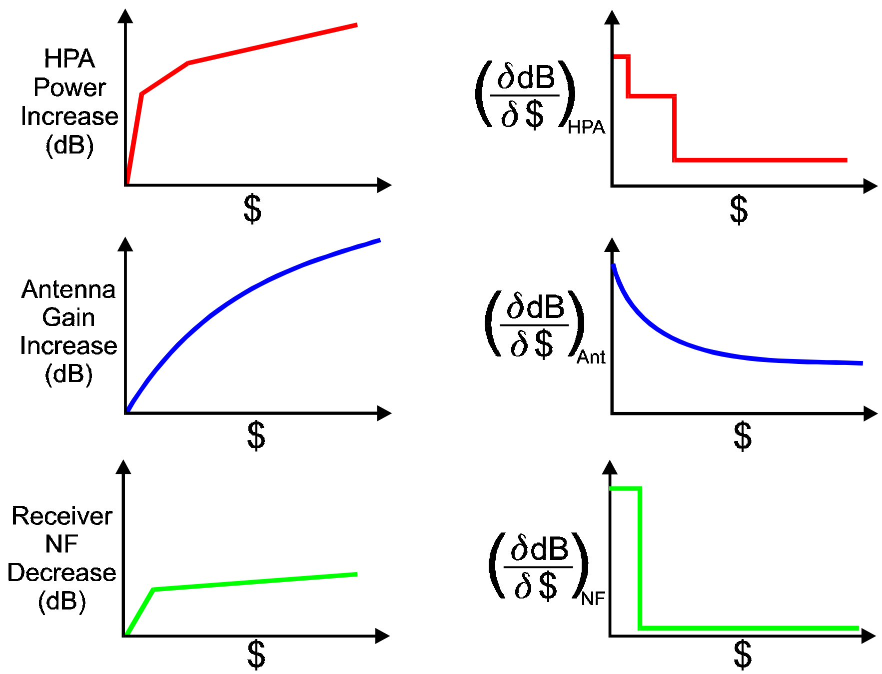
At market equilibrium:

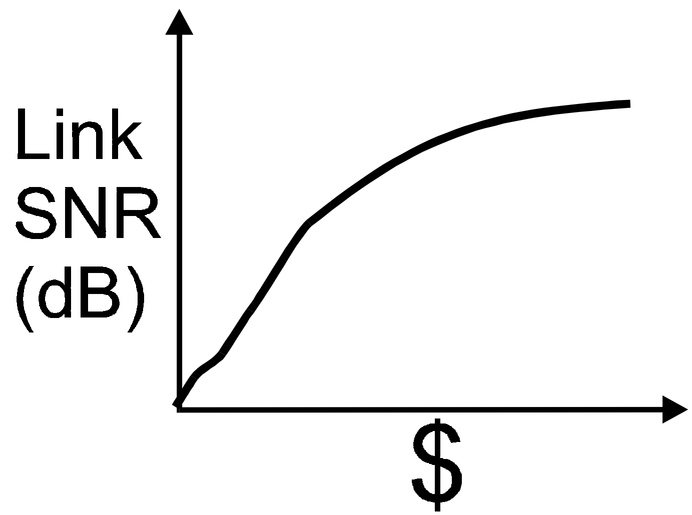
$$\left(\frac{\partial \mathbf{Re}venue}{\partial Capacity}\right)=\left(\frac{\partial Cost}{\partial Capacity}\right)=\frac{\left(\dfrac{\partial Cost}{\partial SNR}\right)}{\left(\dfrac{\partial Capacity}{\partial SNR}\right)}$$

Example: Link Cost vs Link SNR

- **Link design is *rationally* related to component costs**

$$\left(\frac{\delta dB}{\delta \$}\right)_{winner} > \left(\frac{\delta dB}{\delta \$}\right)_{loser}$$



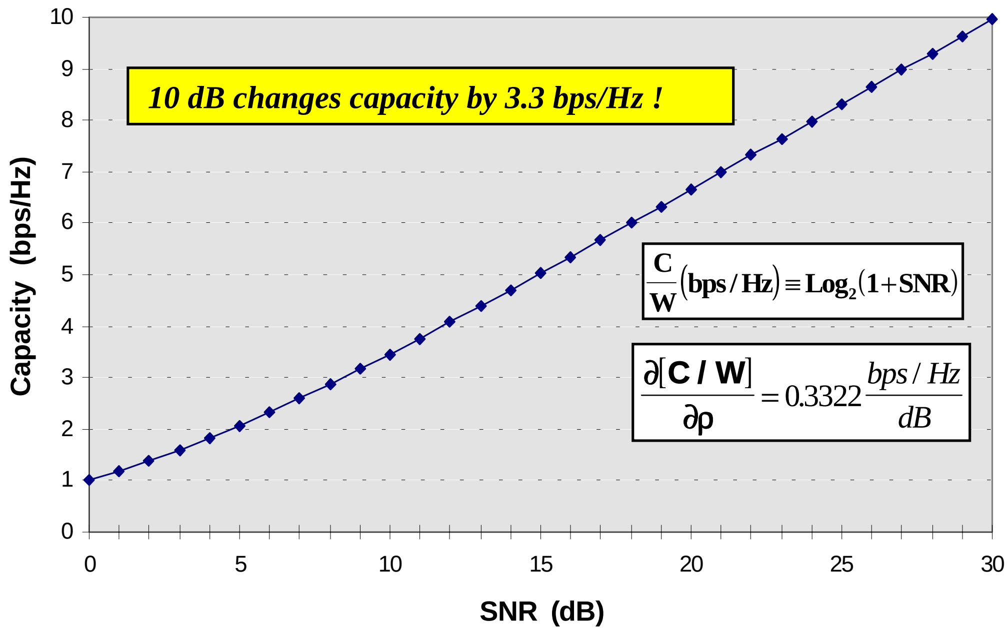


Limitation on Scope of Discussion

- **Space-Time Processing (STP) is beyond scope**
  - STP promises large capacity gains
    - Beamforming
    - Space-time coding
    - Transmit-diversity
  - Individual beams/links are each subject to SNR constraints
  - This briefing will *not* treat STP issues; big topic – little time

- **SNR determines capacity for individual links**
  - Key fundamental capacity relationships have been derived
    - dependence on **SNR**
      - Link coherence
      - Link distortion
    - dependence on **data block size**

Link Capacity vs Link SNR

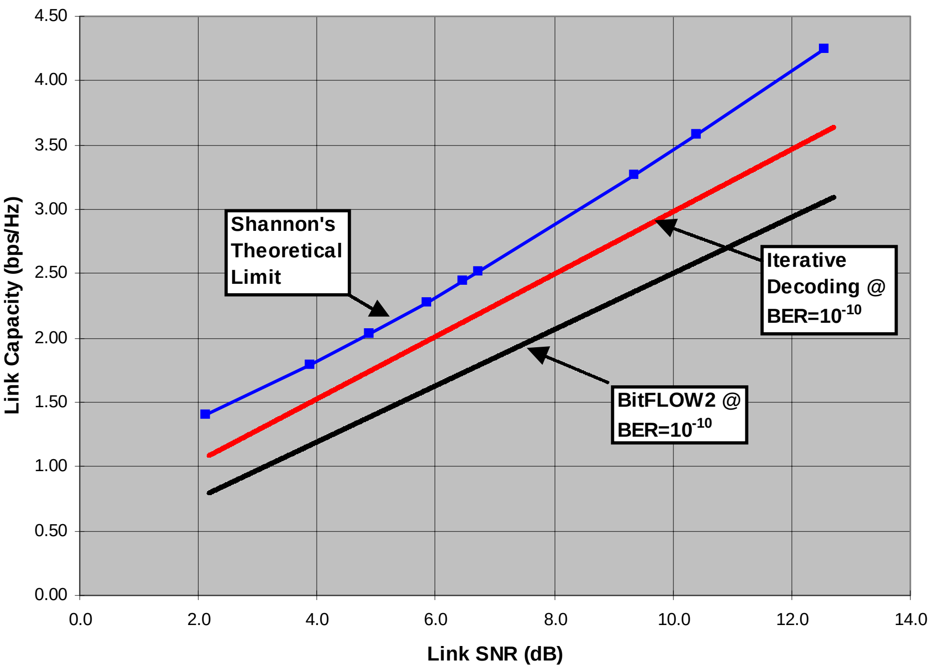


- **Each dB of SNR can increase capacity 0.33 bps/Hz**
- **How can standards exploit this theoretical limit?**
  - Better forward error-correction coding (FEC) enhances link capacity
  - Dynamic modulation/FEC further enhances *average* link capacity
  - MAC enhancements can also enhance capacity

Better FEC enhances link capacity.

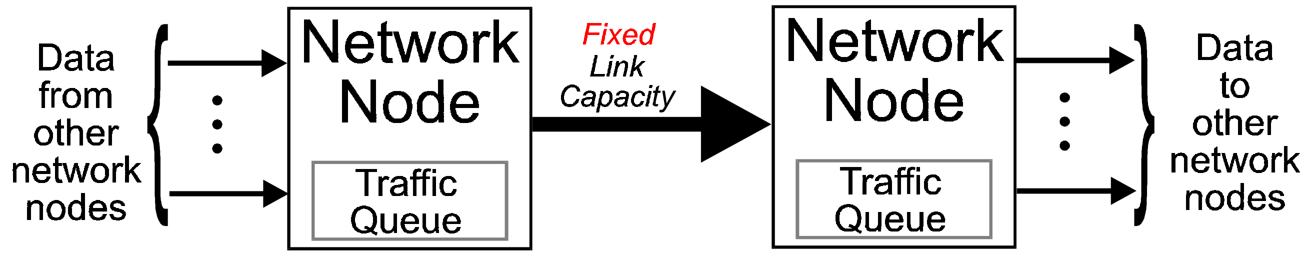
- **Current state of installed FEC technology**
  - CW data: concatenated PTCM/RS; 2-3 dB from Shannon
  - Burst data: RS or BCH; 5-6 dB from Shannon

- **Emerging FEC features**
  - Iterative decoding
    - Parallel trellis ("Turbo")
    - Serial trellis
    - Block product
    - LDPC
  - ≈1 dB from Shannon limit
  - Affordability
    - Cost (shrinking $/gate)
    - Power consumption

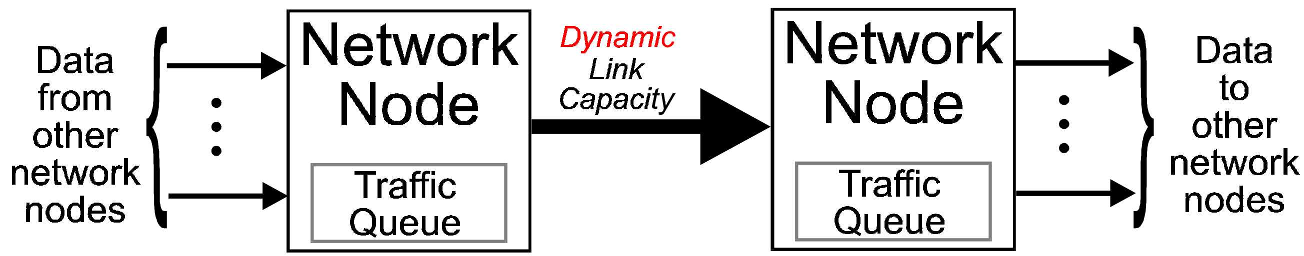


Management of Capacity Dynamics

- **Wire-line**



- **Wireless**

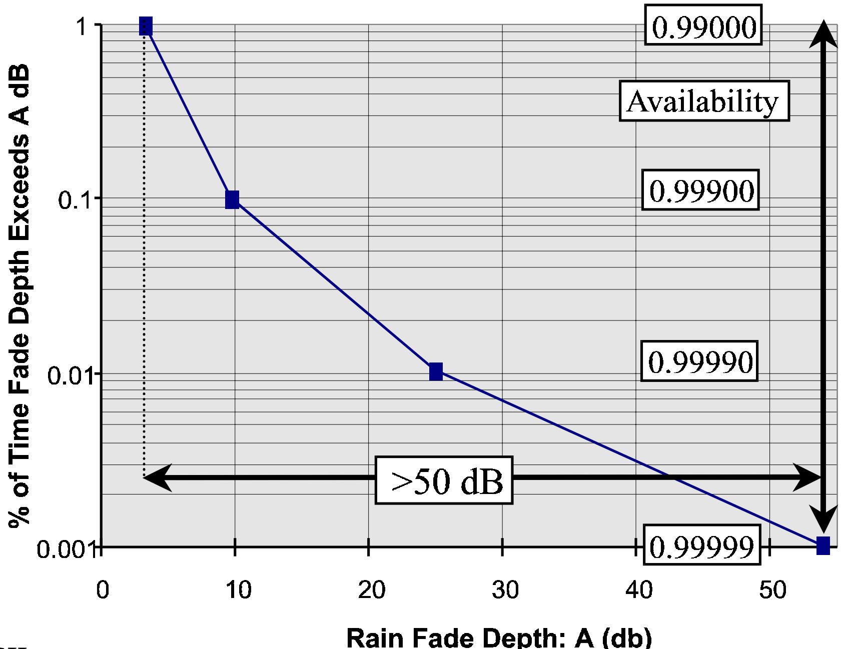


- **An entirely new paradigm is required for wireless**
  - *Constantly maximize capacity, maintaining a constant link BER*

Benefits of Dynamic Modulation/FEC

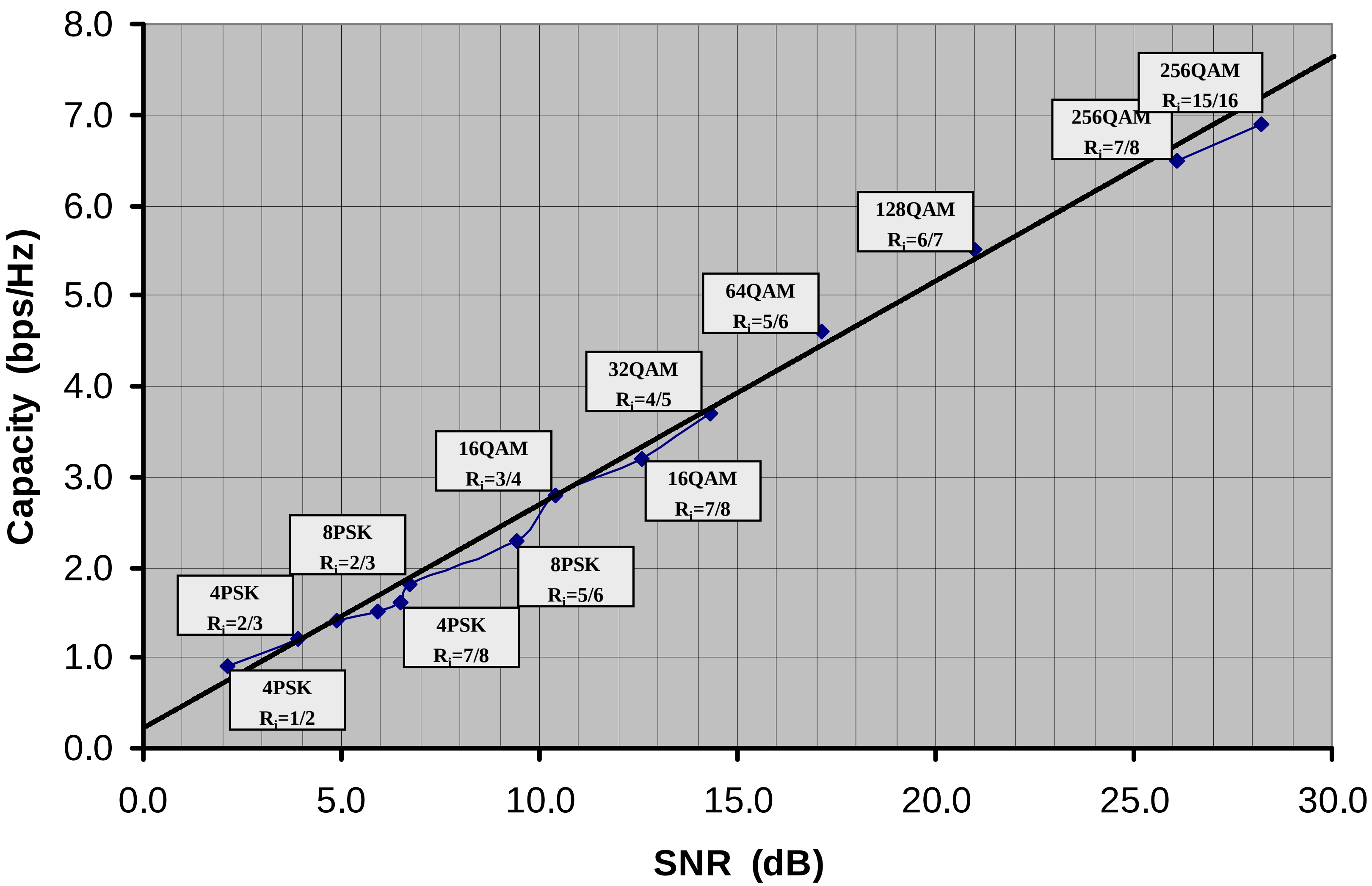
- **Link designed to support a fixed rate at .99999 availability**
  - 99% of the time, greater than 50 dB (54 dB - 4 dB) link margin exists [Ref: 1]
  - **Goal**: ***convert excess link margin*** into ***revenue-generating link capacity***
  - Note: traffic committed at 0.99999 level is *not impacted by adding 0.99 traffic*

- **Potential Benefit**
  - 16 bps/Hz = (50 dB) x (0.33 bps/Hz/dB)
  - Current LMDS networks: 2 bps/Hz
  - ***Increased average capacity!***
    - >4-fold increase is possible
  - What is practical?



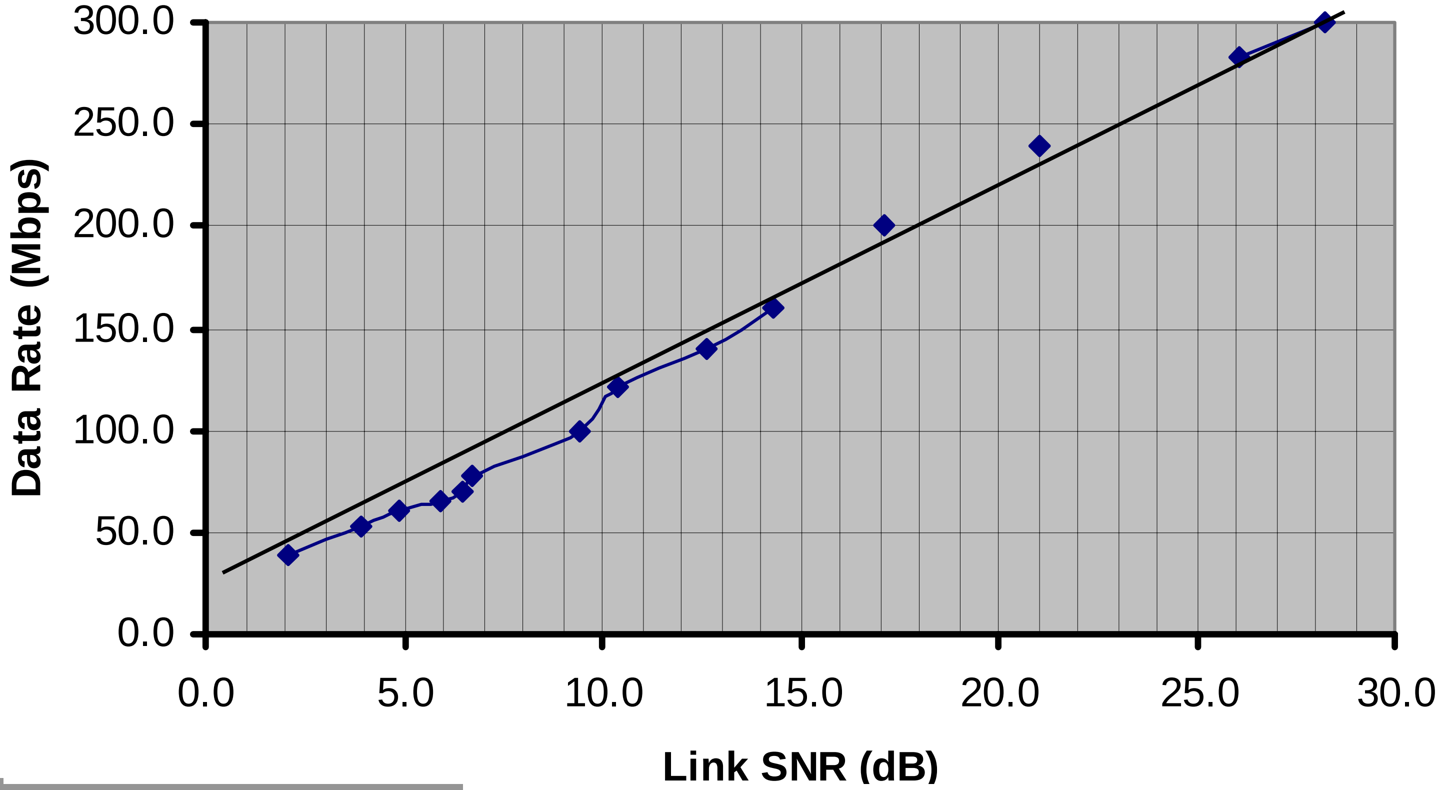
Ref: Path loss predictions based on ITU P.530-7; Region M (Dallas); 2.5 km links; 28 GHz

Capacity vs Link SNR: *Typical Modem*



Data Rate vs Link SNR: Example

- *Assume*: Channel Bandwidth = 50 MHz
  Nyquist Factor (α) = 0.15
  Symbol Rate = 43.5 Msps

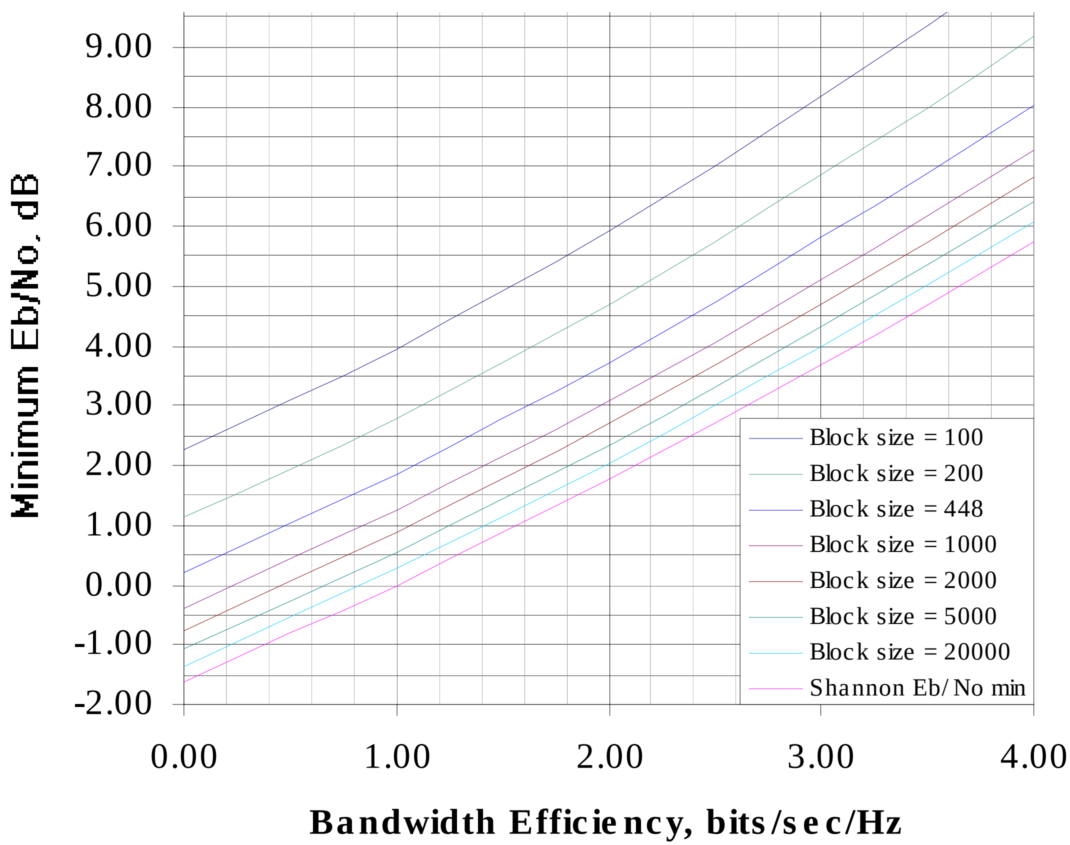


Does message length impact capacity?

- **PTM traffic efficiency needs short transmissions**
  - Packet/Cell issues
  - MAC issues
- **FEC gain needs long code-blocks**
  - Significant SNR loss incurred using short code blocks
- ***Reconciliation***
  - Transmission blocks need not equal message lengths
  - Code blocks need not equal message length
    - Latency-critical voice can sacrifice BER with short code-blocks
    - Latency-insensitive data can improve BER with long code-blocks

FEC gain depends on code-block length.

- **Longer message code-blocks improve FEC gain**
  - 448-bit blocks lose ~2 dB compared to 20 kbit blocks

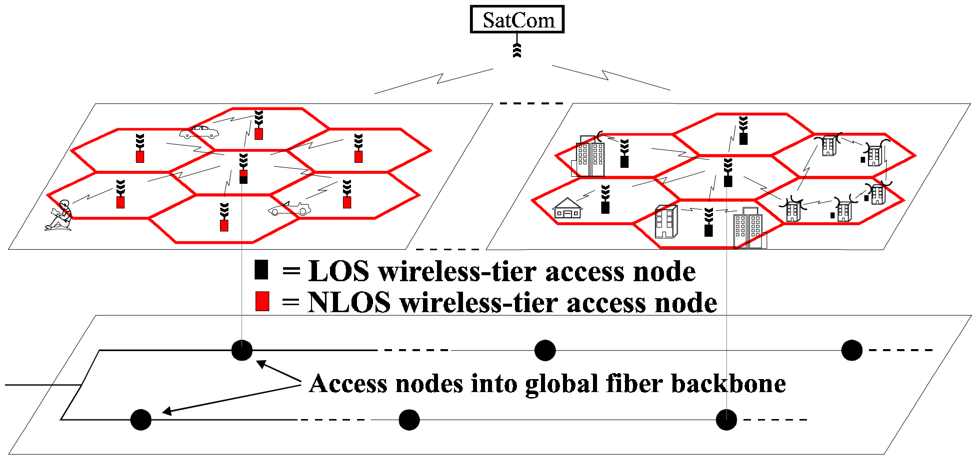


How does 802.16 reflect these limits?

- **Dynamic modulation/coding**
- **Iterative decoding (optional)**
- **Variable packet length**
  - Potential to evolve to multi-packet decoding
- **Framework is in place to evolve the standard**
  - Major accomplishment to find common ground
  - Basis for evolving the standard to reflect evolving needs

Whither Wireless Access?

- **Broadband wireless connectivity may well evolve into multi-tier structure**
- **Tier 1: Non-line-of-sight (NLOS) mobile/fixed coverage**
  - Transmit-diversity and OFDM: great coverage, but poor power-efficiency
  - Microcells:
    - solve power-inefficiency problem, since loss varies as R^4
    - offer high capacity via frequency re-use
    - significantly increase infrastructure expense, with large increase in hubs required
- **Tier 2: Line-of-sight (LOS) fixed connectivity**
  - High-capacity LOS links connecting μcells to fiber backbone
  - Migration of functionality away from 'dumb' μcells to central hub



Summary

- **Wireless link value is defined by link capacity and ROI**
- **Integrated *wireless link value paradigm* ties it all together**
    - Market Forces + Information Theory (**IT**) + Component Technology (**CT**)
- **Standards ideally reflect *combined IT and CT* aspects**
    - Standards should emphasize value rather than standard components
    - Industry-driven standards tend toward this value-driven goal
        - "It's an obviously flawed system, but we can't seem to devise a better one."
- **How is the 802.16 standard assisting wireless progress?**
    - 802.16.3 will define NLOS standard
    - 802.16.1 is defining LOS standard
    - Provides basis for multi-tiered integrated wireless access framework
    - Provides wireless access infrastructure for other applications (e.g. 802.11)