Moore's Law & What We Do When We Get There: Squeezing Moore Out of the Electromagnetic Spectrum

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- *The FCC Approach to Licensed Wireless Services*
- *A Successful Policy Model and Necessary Preconditions*
- *Customary Approach to Radio System Design*
- *A Move toward Proactive Design Model using Software Radios*
- *Creating Extra Communications Capability out of Existing Radio Licenses*
- *Thoughts on Spectrum Policy Implications for Redistribution of Efficiency Gains from the Proactive Design Model*

FCC's Spectrum "Management" Goals

TRANSPARENCY → EFFICIENCY → RELIABILITY

- **Promote the** highest and best use of spectrum **domestically and internationally in order to encourage the growth and rapid deployment of** innovative **and** efficient **wireless communications technologies and services.**

- **Advance** spectrum reform **by developing and implementing** market-oriented **allocation and assignment policies.**

- **Vigorously protect against** harmful interference **and enforce public safety-related rules.**

- **Conduct** effective and timely licensing activities **that encourage efficient use of the spectrum.**

- **Provide** adequate spectrum **for public safety and commercial purposes, including rural areas.**

Formula for Successful Spectrum Management

- **Provide Flexibility** (provides for efficient use)
  - Maximum technical and operational autonomy for licensees
  - Rapid transition of spectrum to highest and best uses using market forces as much as possible
- **Ensure Competition** (provides for effective use)
  - Intermodal/Intramodal competition/Mass Media competition
  - LNP, intercarrier compensation, universal service, public interest
  - CMRS, PCS, MSS/ATC, MVDDS, DBS versus local, long distance, radio, television, movies, ISPs
- **Enforce Opportunity Costs of Using Spectrum** (provides market and economic discipline)
  - Auctions
  - Secondary Markets

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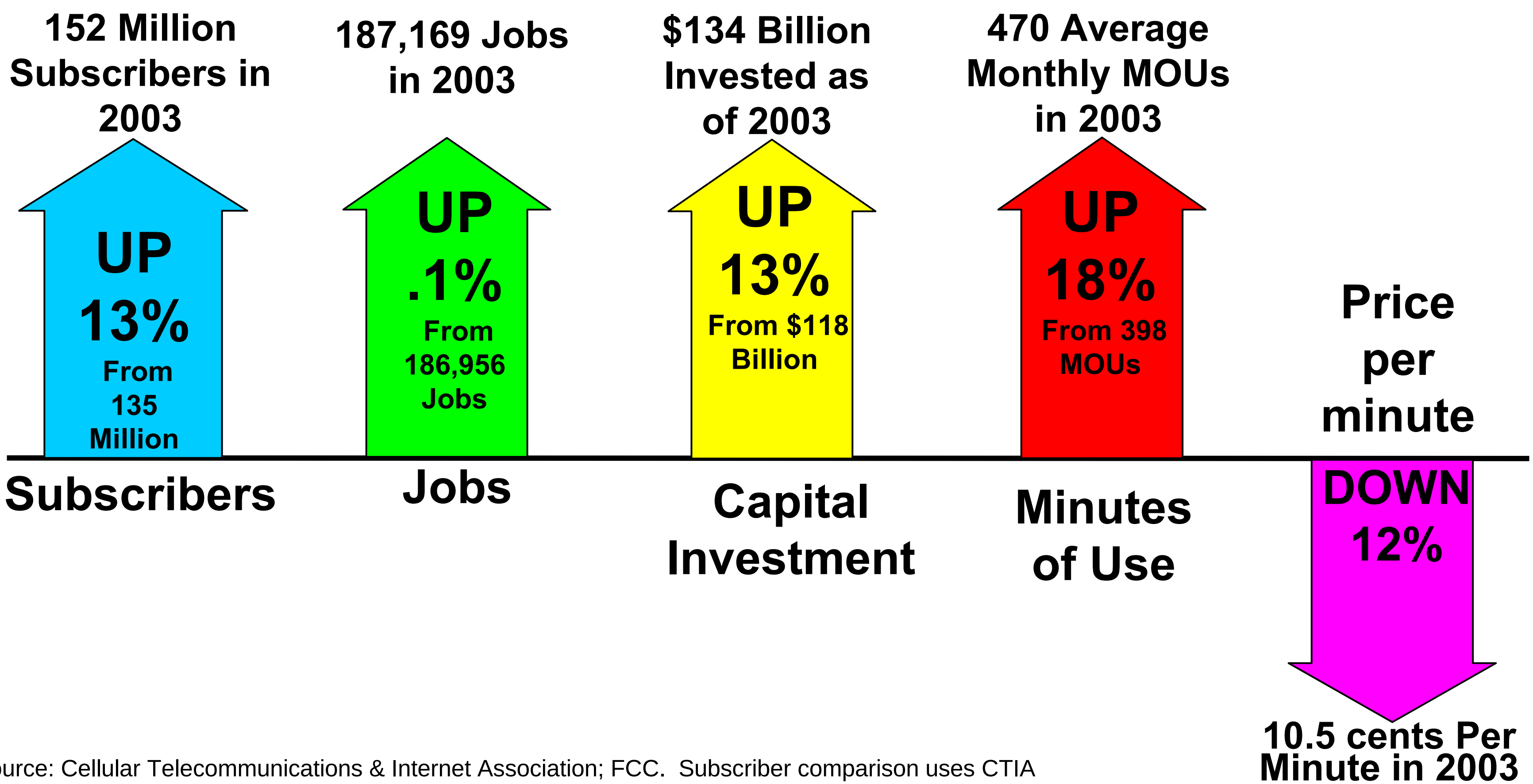
Spectrum "Management" Success Story:

The Mobile Wireless Story (June 2002 - June 2003)



Source: Cellular Telecommunications & Internet Association; FCC. Subscriber comparison uses CTIA estimate for June 2002 and FCC estimate for June 2003. June 2003 MOU estimate is preliminary.

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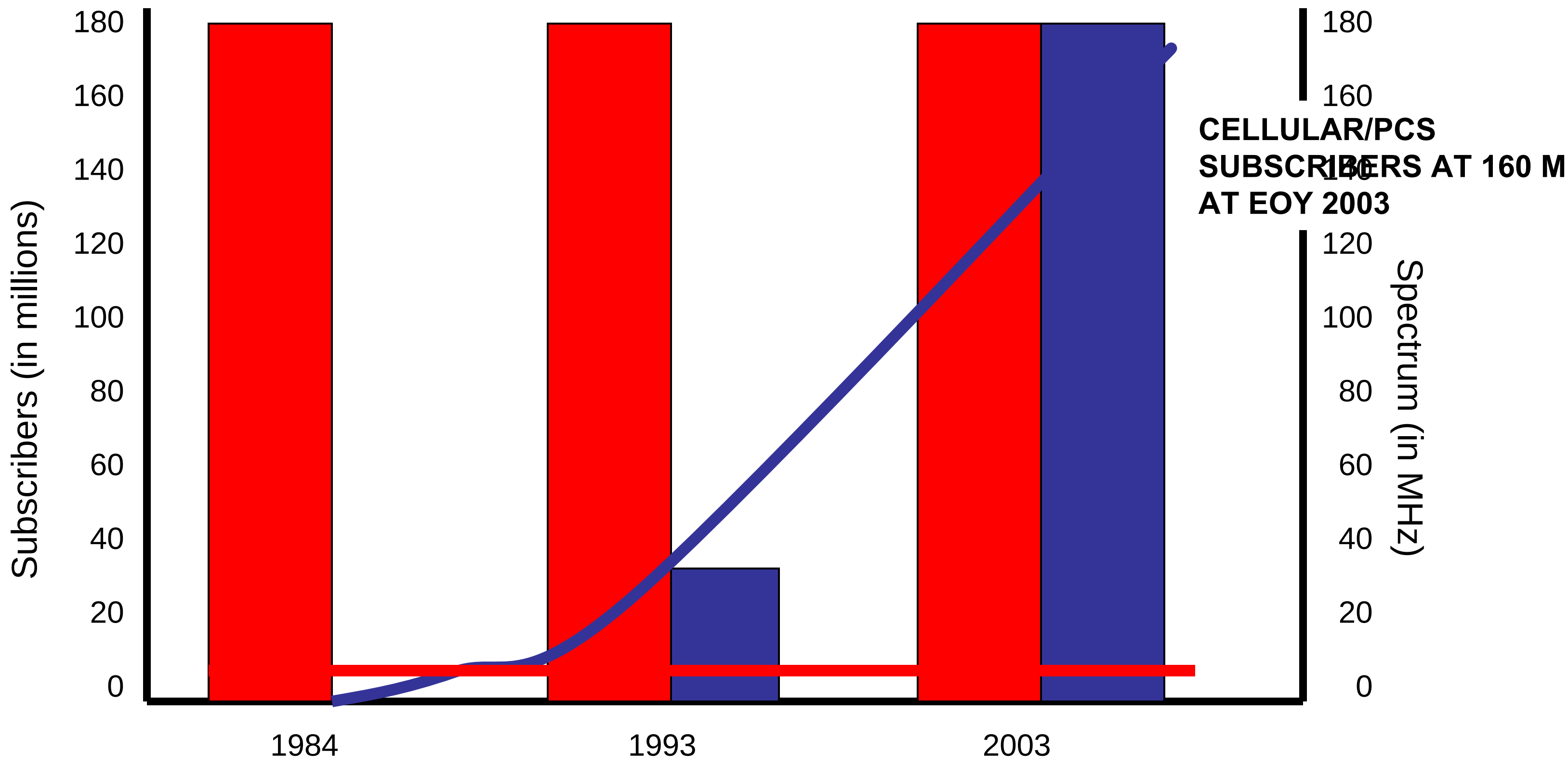
AN ILLUSTRATIVE EXAMPLE OF HOW FLEXIBLE REGULATIONS IMPACT MARKET ADOPTION RATES **



**** Not to Scale**

Upcoming Licensed Spectrum Opportunities

- **MDS/ITFS Band (2.5-2.69 GHz)**
  - Flexibility (√)
  - Competition (?)
  - Opportunity Cost (?)
- **70/80/90 GHz**
  - Flexibility (√)
  - Competition (?)
  - Opportunity Cost (?)
- **MVDDS**
  - Flexibility (√)
  - Competition (√)
  - Opportunity Cost (√)
- **CMRS (Cellular, PCS, ESMR SMR)**
  - Flexibility (√)
  - Competition (√)
  - Opportunity Cost (√)
- **3G/AWS**
  - Flexibility (√)
  - Competition (√)
  - Opportunity Cost (√)
- **3650 MHz**
  - Flexibility (√)
  - Competition (?)
  - Opportunity Cost (?)

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- Customary design of digital wireless communications systems requires trade-offs among engineering design parameters with the goal of ***achieving Quality of Service ("QoS") valued by the marketplace. (QoS = Desired Reliable Data Rate)***

- Under the customary design approach system-wide QoS goals are met within the constraints of communications resources of power and bandwidth that are primarily governed by FCC regulations. ***The customary design is hard wired with no slack capacity in the enabling devices….***

- ***We suggest a different, more useful design approach----taking advantage of the FCC's technical flexibility----and using software radios techniques to dynamically create where possible valuable extra communications capacity under existing licenses.***

- ***We further posit that any resulting efficiency gains from this new approach should not be redistributed by government fiat, but by marketplace mechanisms such as secondary markets (leasing), private commons, two sided auctions, voluntary exchange mechanisms.***

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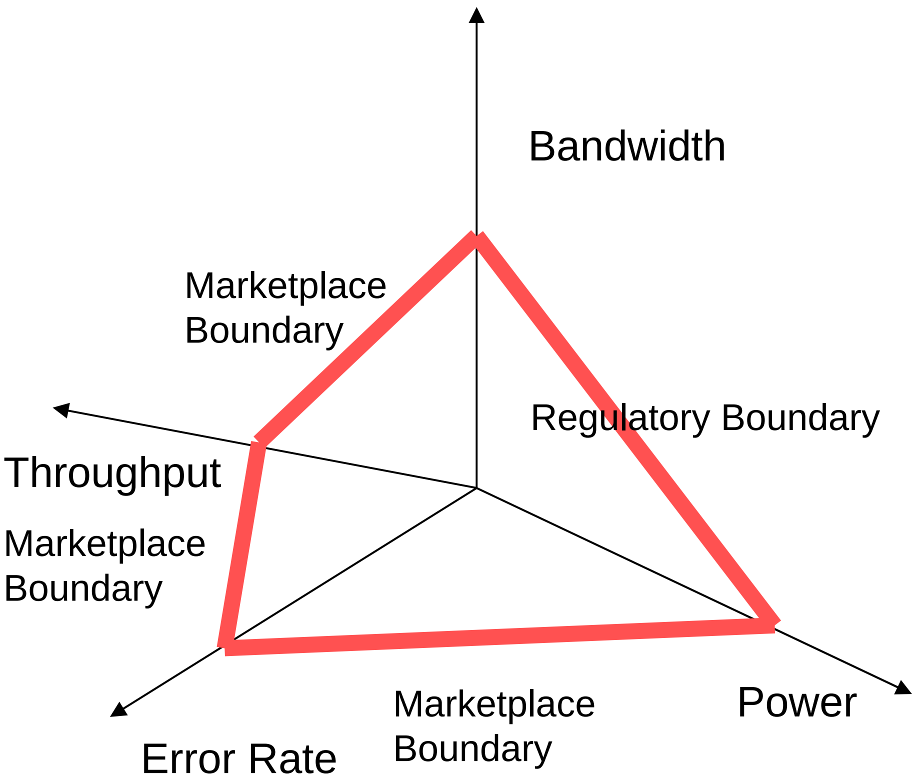
- Desired QoS for competition, *e.g.*, a reliable bit stream consisting of
  - a minimum desired data rate and
  - a maximum bit error rate or probability of bit error
- and fixed communications resources of
  - power and
  - bandwidth,

- Proactive approach to designing digital radio systems using software radios is recommended to yield an enhanced system design with
  - not only a QoS meeting or exceeding the design QoS,
  - but also, where possible, extra communications capability, such as access to extra bandwidth or ability to operate at higher noise levels.



COMMUNICATIONS SYSTEMS DESIGN: PARAMETERS & MEASURES

- **Digital Communications System Design:** From a commercial perspective,
  - Can begin with desired
    - transmission bit rate **R** (bits/seconds) and
    - reliability or bit error rate $\mathbf{P_b}$ and
  - May include other factors, *e.g.*, capacity, complexity, costs, *etc.*
- **Communications Resources & Environment:**
  - Subject to FCC regulation:
    - Bandwidth **W** (megahertz) and
    - Power (watts) or energy-per-bit $\mathbf{E_b}$ (watt-seconds)
    - Interference considerations
  - Subject to nature:
    - Noise $\mathbf{N_o}$
- **Measures of Performance & Efficiency:**
  - Reliability or bit error rate $\mathbf{P_b}$
  - Power or energy efficiency $\mathbf{E_b/N_o}$
  - Bandwidth efficiency **R/W**

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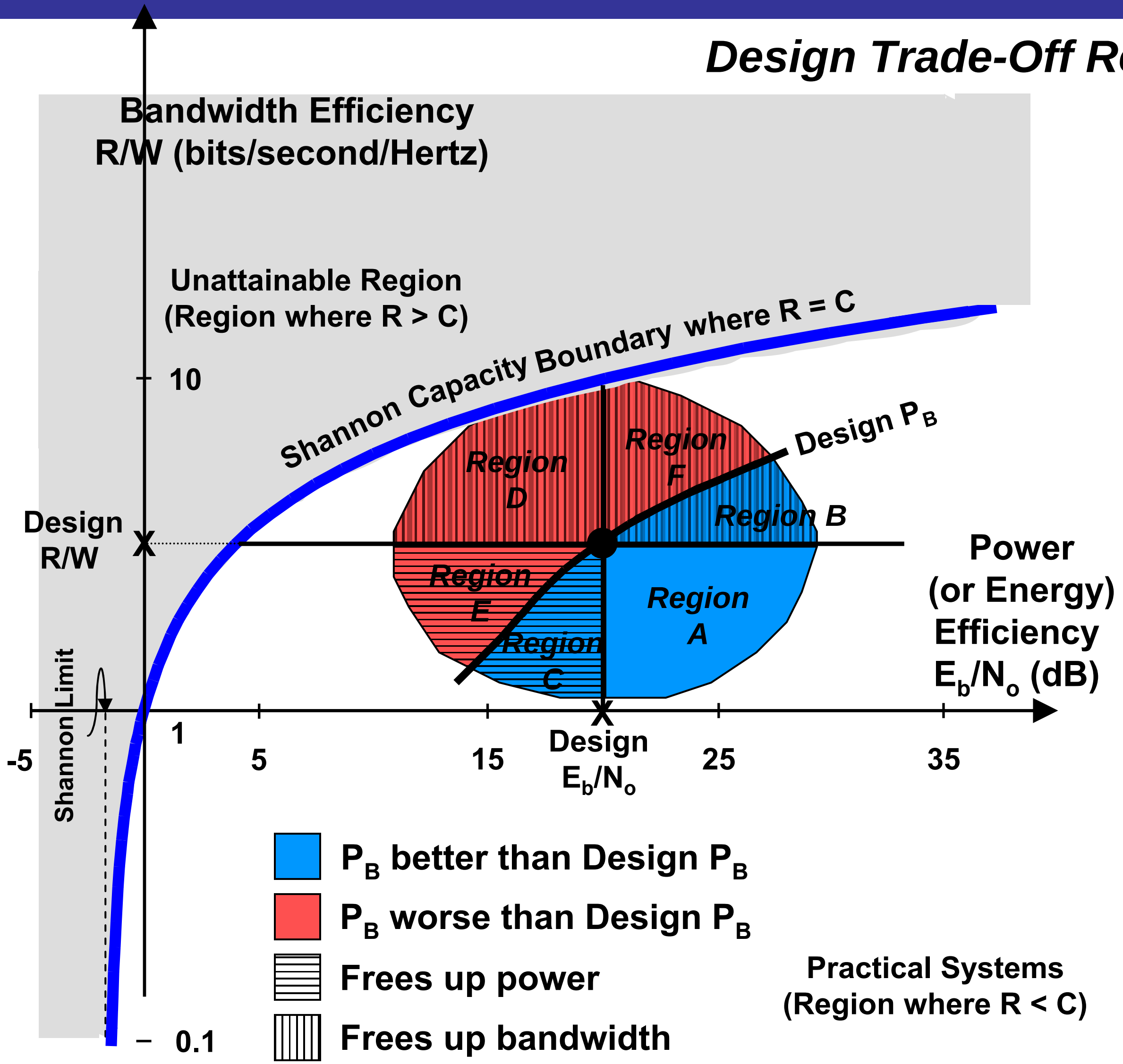
Design Trade-Off Regions



- **Trade-offs in parameters define six regions about the design operating point.**
- **Region A: Achieves enhanced QoS, but would require more power <u>and</u> bandwidth, relative to optimized design. Presumably, both power and bandwidth are not available.**
- **Regions B & C: Achieves enhanced QoS and creates extra communications capabilities, if extra power <u>or</u> extra bandwidth is available:**
  - **Region B: Extra power frees up additional bandwidth,**
  - **Region C: Extra bandwidth frees up power or alternatively higher noise level tolerated.**
- **Regions D, E, & F: Resulting QoS is worse that Design QoS; but if lower QoS is commercially acceptable, ...**

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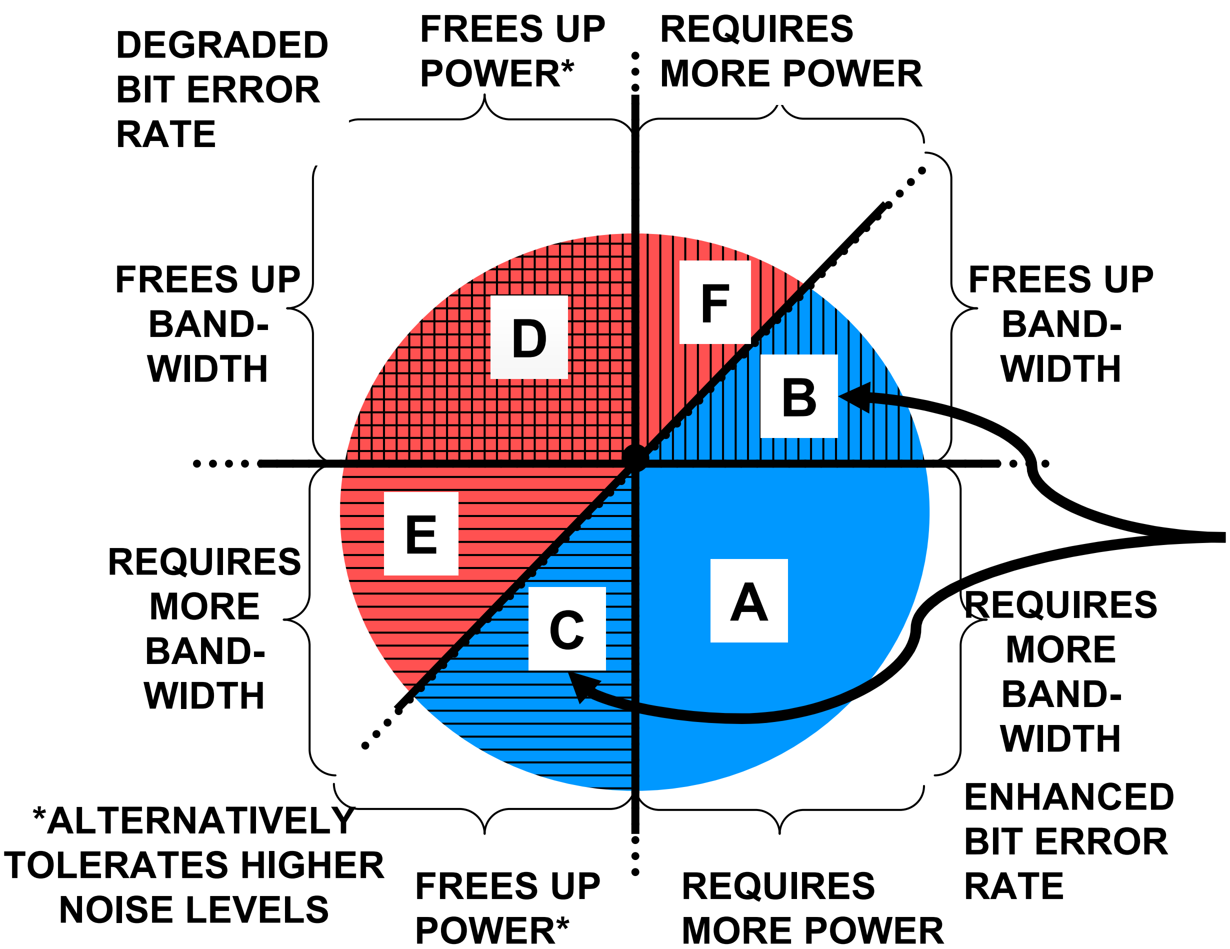
DESIGN TRADE-OFFS: SIX REGIONS AROUND THE DESIRED QoS POINT



DESIGNS WITH OPERATING POINTS IN AREAS B & C INCREASE QoS & CREATE NEW COMMUNICATIONS CAPABILITY

QoS: MINIMUM DESIRED DATA RATE & MAXIMUM DESIRED BIT ERROR RATE

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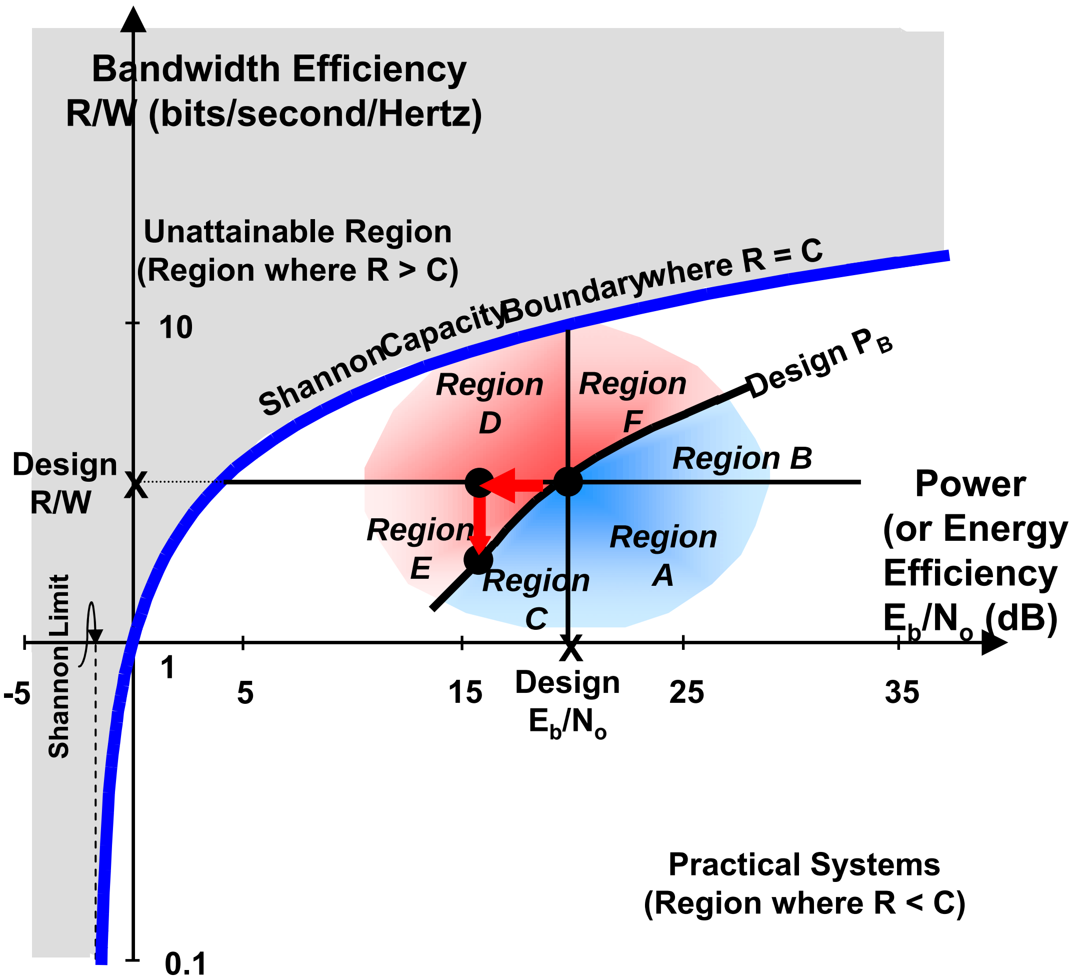
An Example of A Dynamic Noise Floor Where Additional Bandwidth Restores QoS



- An operating point (modulation & coding scheme) is established for a Design P_B:
  - a Design R/W and
  - a Design E_b/N_o.
- A desired QoS is achieved based on
  - a minimum Design R and
  - a maximum P_B.
- Designing to an increase in the noise floor lowers the E_b/N_o to less than the Design E_b/N_o, moving the operating point between Regions D & E, if no resources are expended.
- The QoS is degraded, since
  - the P_B is lower than the Design P_B,
  - while the R/W remains the same.
- **If a degraded QoS is unacceptable, then the desired QoS may be restored at the expense of investing additional resources, if available:**
  - Additional power can restore QoS:
    -- E_b/N_o is increased, restoring P_B,
    -- while the R/W remains the same;
  - **Additional bandwidth can restore QoS:**
    -- a lowered E_b/N_o remains the same,
    -- but a lowered R/W restores P_B, which is achieved by maintaining the Desired R and increasing W.

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The Engineering Implications of the New Design Model

- ***Proactive Design Model (Invest for Competitive QoS & Increased Communications Capability):***
  - Maximizing/minimizing trade-offs are made among the usual parameters, but the objective changes: licensees now can do tradeoffs to achieve both desired QoS, while increasing spectrum capacity, where possible.
  - ***Current industrial thinking assumes that noise floor and other aspects of radio environment is static; we suggest that it can be managed by design***
- ***In the new software radio world, the communications system designer should design a radio assuming:***
  - Maybe a more dynamic (or variable) noise and interference environment.
  - Modulation and coding decisions are made within the fundamental limitations of information theory as described above…

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FCC Flexibility Regime and The Implications of the New Design Model

- Our Proactive Design Model is defined as the development of Wireless Digital Communications Systems using software radios dynamically responding to the environment; ***its objective is to promote efficiency in Spectrum Utilization, while enabling licensees to offer competitive service in the marketplace (No longer a Hobbesian Choice).***

- This design approach will create more access to spectrum capacity and more intense use of spectrum where the ***Increased Spectrum Capability can be utilized for improving the existing service or developing new services.***

- ***The FCC's flexible spectrum technology policies already encourage licensees to invest in expanded software radio designs to meet both a desired QoS and while achieving an increase in communications capacity, where possible.*** Enable customary tradeoffs under constraints, but assumes dynamic radio (*i.e.*, interference boundaries, noise floor, *etc*.) environment.

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So What More Can Be Done on Spectrum Policy towards this Model?

- ***To the extent possible, policy should rely on market forces to determine what is the best use of the extra communications capability developed by licensees.***

  - In the new world of dynamically managed radio environment, redistributing excess spectrum capability by ***fiat*** could be a disincentive to licensees to invest in more efficient use of spectrum. ***We posit that any resulting efficiency gains from the new Design Model should be, in the first instance, redistributed using marketplace mechanisms***

  - Market oriented policy mechanisms being implemented or being considered for rewarding licensees for increasing their investment in spectrum utilization are:
    - *Secondary markets (Leasing),*
    - *Enabling private commons,*
    - *Developing two-sided auctions*
    - *Enabling transferable voucher mechanisms for voluntary exchanges (spectrum)*