Market-driven regulation for next generation ultra-wide-band technology: Technical-economic management of a 3G cell with coexisting UWB devices

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Outline

UWB impact (good and bad)

- UWB is an exciting new technology with many benefits[1]
- It can coexist over spectrum assigned to other technologies, allowing spectrum “recycling”
- Incumbent technology may be negatively affected
- Traditional approach to protecting incumbent:
  - to outlaw UWB, or (recently, and *only* in some regions)
  - to limit power emissions to level of “unintended emitters”
- Problem: Many “needs” cannot be met (range too short!)
- Alternative approach: economic mitigation!

Economic mitigation

- Intuition: for a given level of power emission, estimate the economic cost of UWB disruption, and compensate incumbents fairly.
- Possible mechanisms:
  taxes, user licenses (like radio/TV viewer's licenses), "real time" fees based on interference sensors, etc.
- Similar idea in use today:
  Spain's "Canon por copia privada"
  - buyers of recording equipment (CD/DVD burners, blank CDs and DVDs, etc) pay a special fee
  - Money is used to "mitigate" revenue loss of authors/artists
- Analytical basis: work by renown economists such as Varian[2] and Nobel-laureate Coase[3]

Case study: 1 3G cell + noise rise

- A 3G/CDMA network is populated by data terminals
- New technology is introduced, and noise level rises
- New technology does *not* compete with 3G for customers
- Basic question:
  what would be the "fair" economic mitigation to 3G?
- Basic answer:
  - Estimate the cell revenue before rise (call it R)
  - Estimate the cell revenue after rise (call it r)
  - Fair economic mitigation equals $R - r$

Some numerical experiments

- Results of some numerical experiments follow
- Interference levels do *not* correspond to existing UWB regulations

Revenue as noise level increase uniformly

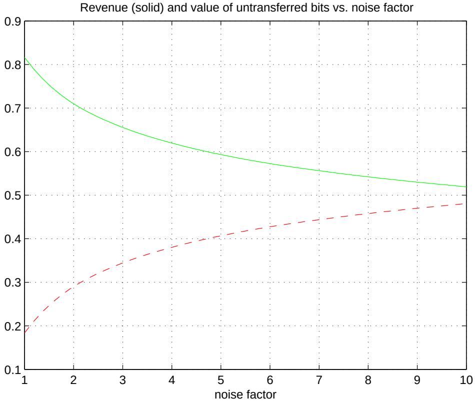


Figure: Noise is amplified everywhere by the factor shown. After noise doubles (3 dB) normalised revenue goes from ≈ 0,8 to ≈0,7.

Various densities of noise-rising devices

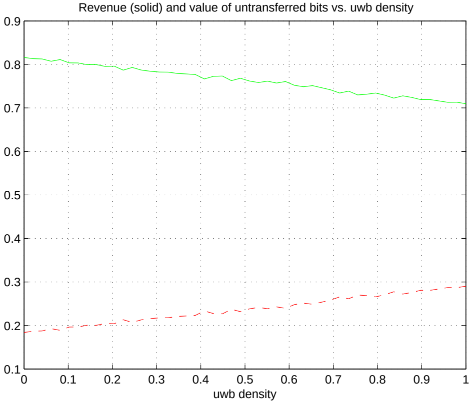


Figure: With a noise factor of 2 (3dB), revenue decreases as density grows from 0 to 1.

Additional bandwidth as mitigation

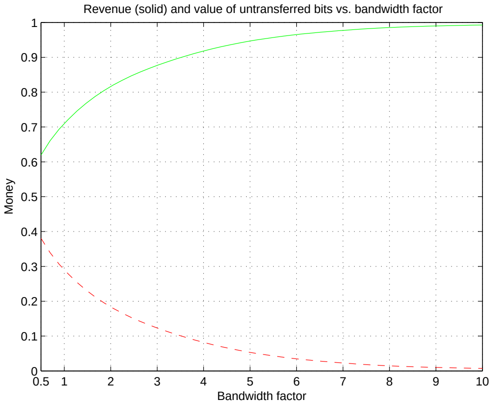


Figure: Doubling bandwidth cancels the effect of a 3dB noise rise. This could be the basis of a fair monetary mitigation to 3G.

Network redesign as mitigation

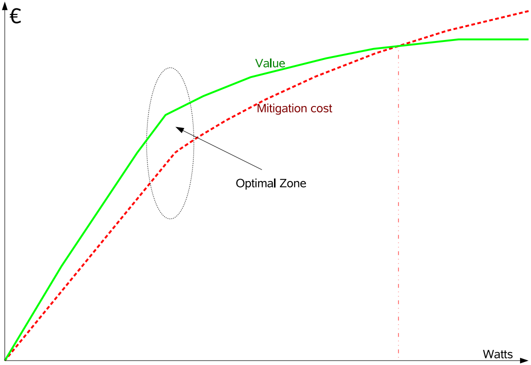
Figure: Under a nf of 2 (3 dB), the 830m cell performs like a 1Km cell prior to noise rise. A fair mitigation to 3G: the cost of the network redesign!

Recapitulation

- Regulator's operating assumption so far: the *only* way to protect incumbent networks from UWB is to either
  - outlaw UWB, or
  - cripple it !
- The problem: it leaves many needs unmet
- Our analysis shows another way: economic mitigation
- Incumbent loss due to a "noise rise" given in close form
- UWB should be allowed its desired power level, if it "covers" that loss
- Other possibilities exist. UWB can give incumbents:
  - more base stations (smaller cells!)
  - more "processing" (MIMO, multiuser detectors, etc)
  - even, more spectrum! (think market-driven DSA now)

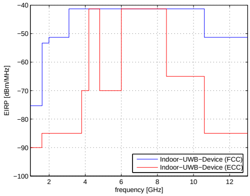
Optimal emission level

- The higher the transmission power, the greater the cost of mitigation.
- There is an economically-efficient level of interference



“Invisible hand” regulation

- Other incumbent technologies can be similarly considered.
- The efficient level will depend on the spectrum band
- Thus, the regulatory “spectrum mask” can be entirely drawn by the “invisible hand” of the market



Next generation UWB

- A new generation of powerful UWB devices that can satisfy a greater set of consumer needs can arise.
- The beneficiaries contribute toward the “economic mitigation” of negative effects caused by the extra power on incumbent networks
- Present devices may continue to be allowed (exempt from economic contribution)
- Manufactures and consumers could choose whether to support one or both classes of devices

POWER to the PEOPLE!!

MORE POWER to the PEOPLE!!

THANK YOU!

How to compute revenues (before and after)?

- Assume a fixed amount of spectrum
- Network serves data-downloading terminals
- Each terminal has 3 parameters:
  data rate R_i, channel gain h_i, “willingness to pay”, β_i
- A terminal’s benefit is proportional to $\beta_i R_i (L/M) f(x)$
- L information bits in M-bit packet
- $f(x)$ is the packet-success probability, with x the signal-to-noise ratio (SNR) (neglect downlink interference!)
- Network charges terminal per unit SNR
- Terminal maximises benefit minus cost
- If network quotes a price c terminal buys SNR $x(c)$
- Network chooses the c that maximises revenue ($c \times x(c)$)

Opposing interests meet

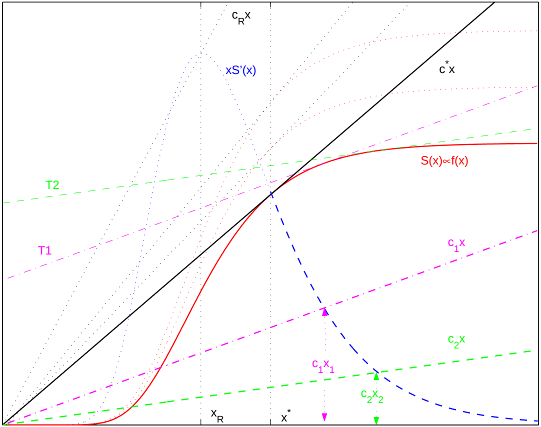


Figure: Terminal maximises benefit minus cost: $S(x) - cx$. Network chooses $c = c^*$ and terminal $x = x^*$. Revenue: $c^* x^* \propto \beta R f(x^*)$

Many terminals present?

- Assume network can set an individual price per terminal
- Previous analysis applies terminal per terminal
- The link configuration with the largest $(L/M)f(x^*)/x^*$ maximises revenue/Hertz and should be *common*!!
- With common link-layer, terminals choose $x_i = x^*$, but this may conflict with downlink power constraint, $\sum P_i = \bar{P}$

Which terminals to serve?

- With convenient units,
  - revenue from i, if served, is $\beta_i R_i$
  - Terminal i "consumption" is R_i/h_i
- Choose terminals in order of "revenue per Hertz"

$$\beta_i R_i \div R_i/h_i = \beta_i h_i$$

- Total revenue has the form: $\sum \beta_i R_i$
  sums cover all terminals that can be served with given power/bandwidth constraints

What about the noise rise?

- Previous development is based on SNR
- It applies before AND after noise rise.
- Therefore:
  - Service SNR, x^*, and matching cost c^* remain the same!
  - Network revenue per served terminal remains the same
- What is the problem, then??:
  Fewer terminals can be served (more power to achieve x^*)!
- With terminals sorted by rev/Hertz, revenue loss is:

$$\sum_{j^*+1}^{J^*} \beta_i R_i$$

$J^*$and j^* denote the number of terminals that can be served before and after the noise rise

UWB Basic definition (per FCC)

With

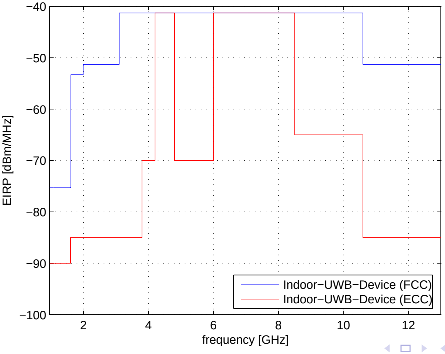
- W : transmission bandwidth
- f_c : Centre frequency

Ultra-wide band technology is a wireless transmission scheme such that

- $W/f_c \geq 20\%$
  OR
- $W \geq 500$ MHz[4]

FCC/European allocation

- License-free use in the 3.1-10.6 GHz band subject to modified Part 15.209 rule according to a “mask”
- Rules imply an average transmit power limit of about $\frac{1}{2}$ mW
- European rules are more stringent



Advantages of UWB

- High throughput at low power (without sophisticated error-control coding or high-order modulations)
- Better resistance to multipath impairment.
  This results from:
  - Ultra-fine resolution of multipath arrivals, which leads to
  - Ultra small probability of destructive combining
- Transceivers of low complexity and cost
- Radio-spectrum “creation” (recycling/reuse) [1]

Potential applications of UWB

- FCC imposes power emission limits of the order of $\frac{1}{2}$ mW
- Thus, UWB limited to short-distance links (0-10 meters)
- UWB seems ideal for personal area networks (PAN) (such as IEEE 802.15) and body-area networks (BAN)
- Specific consumer uses may include
  - "Cable replacement" (main equipment/peripherals)
  - Streaming digital media between electronic appliances
  - body networks for medical, security, military, etc uses
- Industrial use may include location/tracking and security applications
- With more flexible power limits, many other applications are possible (ultra-fast WLANs, WANs, etc)

For Further Reading I

- S. Roy, J. Foerster, V. Somayazulu, and D. Leeper, “Ultrawideband radio design: The promise of high-speed, short-range wireless connectivity,” *Proceedings of the IEEE*, vol. 92, pp. 295–311, February 2004.
- H. R. Varian, “A solution to the problem of externalities when agents are well-informed,” *The American Economic Review*, vol. 84, pp. 1278–93, Dec. 1994.
- R. Coase, “The problem of social cost,” *Journal of Law and Economics*, vol. 3, pp. 1–44, 1960.

For Further Reading II

Federal Communications Commission, “Revision of part 15 of the commision’s rules regarding ultra-wideband transmission systems.” ET-Docket 98-153, Washington, DC, USA, 1998.
Adopted:Feb. 2002.