Technical-Economic impact of UWB personal area networks on a UMTS cell: Market-driven dynamic spectrum allocation revisited

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Outline

Preamble I: "Pay as you go" spectrum

- At start of a dynamic spectrum allocation (DSA) period, a "spectrum manager" auctions (sells?) spectrum licenses
- Networks consider the interests of their active users and purchase (bid for) spectrum
- Manager issues short-term licenses to each network
- At the end of a short period, all licenses expire and the whole process is re-initiated "from scratch"
- Above can be done "cell by cell" among CDMA networks by employing 2-layer spreading as in UMTS
- Doing so when non-CDMA networks are present is much trickier due to interference control
- Manager can arise from a "pooling" business model
- Several publications on this model are available (e.g., [1])

Preamble II: UWB impact (good and bad)

- UWB is an exciting new technology with many benefits[2]
- 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
  - Basic idea: estimate the economic cost to incumbent of UWB disruption, and compensate the incumbent fairly.
  - Analytical basis: work by renown economists such as Varian[3] and Nobel-laureate Coase[4]

Simple scenario: 1 3G cell + noise rise

- A 3G cell participates in market-driven DSA
- 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 $R - r$

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

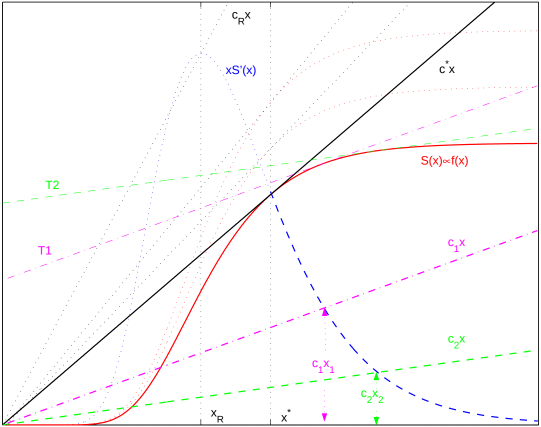


Figure: Terminal maximises benefit minus cost: $S(x) - cx$. Network chooses $c = c^*$ and terminal $x = x^*$. Revenue: $c^* x^* \propto \beta Rf(x^*)$

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 auction?

- Assume 2nd-price (Vickrey) auction
- For now suppose only one band is auctioned
  - Highest bidder wins, but payment equals highest *losing* bid
  - Optimal bid equals the "value" of the band (revenue!)
  - Apply the preceding analysis to compute revenue
  - That is the network's bid!
- If many bands are auctioned the analysis is almost the same (see paper)

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

Summary

- 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 "normal" power usage, if it covers such 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)

Outlook: what now?

- What about a 2nd round of UWB regulations leading to 2 classes of devices
  - class A : unlicensed, stricter regulation, but *NO* special fee
  - class B : licensed, "normal" power, but pays a special fee
- More work has been and will be done (see next IST mobile summit)
- We hope to have convinced you that:
  - The general approach is sound and promising
  - Solid analytical work by reputable economists supports it
  - Similar ideas are in present use (see Spain's "Canon por copia privada")
  - Further studies are warranted

THANK YOU!!!

Some numerical experiments

- The results of some numerical experiments follow
- Notice that the given values may *not* correspond to present UWB regulations in any given region

Revenue as noise level increase uniformly

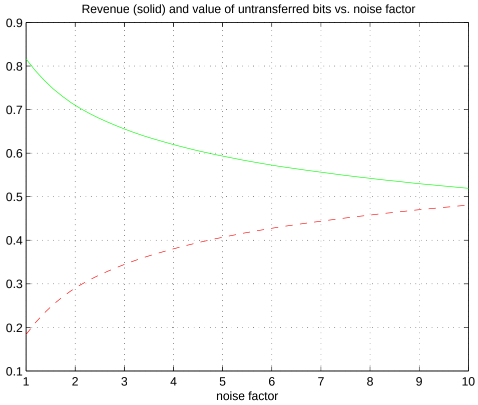


Figure: Noise is amplified everywhere by the factor shown. After noise doubles (3 dB) normalised revenue goes from ≈ 0,8 to ≈0,7.

Various densities of noise-rising devices

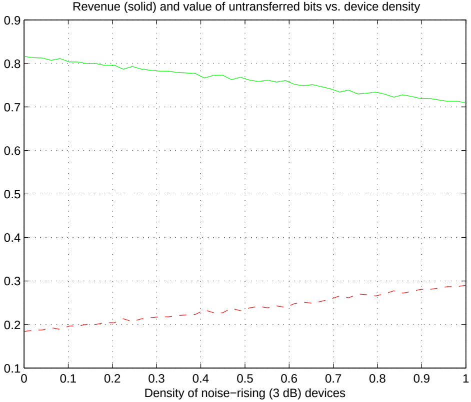


Figure: With a noise factor of 2 (3dB), revenue decreases as density grows from 0 to 1.

Additional bandwidth as mitigation

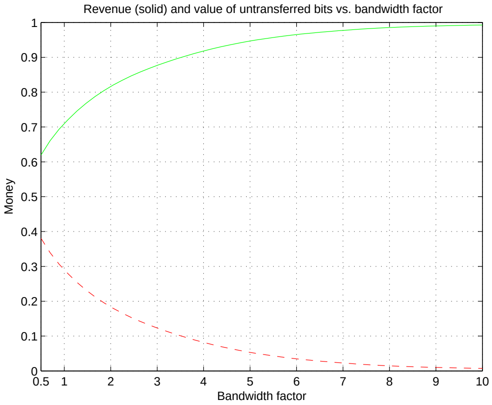


Figure: Doubling bandwidth cancels the effect of a 3dB noise rise. This could be the basis of a fair monetary mitigation to 3G.

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!

UWB Basic definition (per FCC)

With

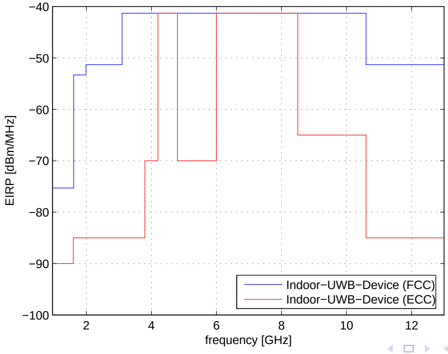
- W : transmission bandwidth
- f_c : Centre frequency

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

- $W/f_c \geq 20\%$
  OR
- $W \geq 500$ MHz[5]

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) [2]

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

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- 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.

For Further Reading II

R. Coase, “The problem of social cost,” *Journal of Law and Economics*, vol. 3, pp. 1–44, 1960.

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