Technical-economic evaluation of spectrum regimes: static, dynamic and utopian allocations for B3G CDMA with coexisting UWB devices

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Outline

1. Preamble
2. Framework for spectrum regime evaluation
3. Experimental results
4. Closing Comments

"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, 2])

How the network bids?

- Suppose only one band is auctioned
- Assume 2nd-price (Vickrey) auction
  - Highest bidder wins, but payment equals highest *losing* bid
  - Optimal bid equals the "value" of the band
- Network reponse
  - Compute revenue the band would produce (if won)
  - Bid = revenue
- If many bands are auctioned the analysis is almost the same (see paper)

How to compute revenue?

- 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: $\beta_i R_i (L/M) f(x) - cx$
- 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

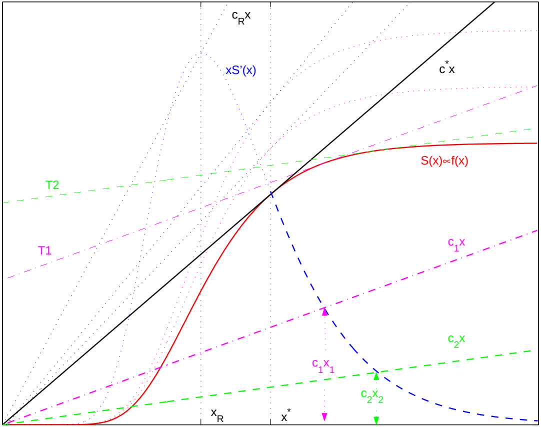

Figure: Terminal maximises benefit minus cost: $S(x) - cx$. Network chooses $c = c^*$ and terminal $x = x^*$. Revenue: $c^* x^* \propto \beta R f(x^*)$

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

Alternative spectrum regimes

- Static allocation: permanently divide bandwidth among networks, either
  - equally, or
  - in proportion to "market share"
- Utopian (1 network gets all spectrum and customers)

Environment for evaluation

- 3 islands, 3 regimes: FSA, DSA, Utopia
- each DSA network has "twin" in FSA island
- arrival and service processes are "mirrored" in the islands
- a "market share" vector indicates each network's share of the system's arrival rate.
- "right" amount of spectrum: arrival rate $\times$ "average need"
- average need: "average" data rate $\div$ "average" channel gain
- *Unless otherwise* indicated:
  - system bandwidth and arrival rate are held constant, as number of networks change
  - market shares are identical
  - FSA spectrum shares are identical

Technical-economic metrics

- Terminal level : "value" of transferred bits
- Network level
  - revenue
  - value of unstransferred bits ("unmet demand")
- System level
  - total network revenue = value of all transferred bits

DSA gain vs no. of bands in a “pooling” scenario

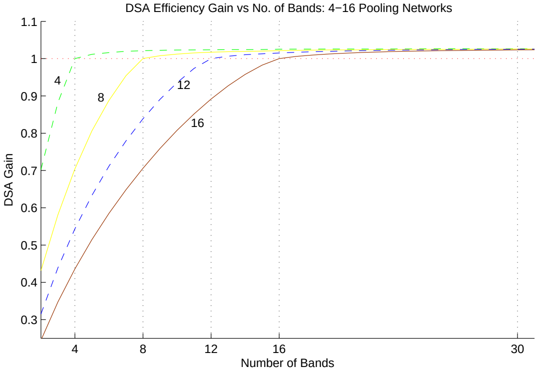

Figure: With identical “pooling” networks, DSA efficiency can be dismal if No. bands < No. of networks. With more bands than networks, DSA modestly outperforms FSA.

DSA gain vs no. of bands under "market fragmentation"

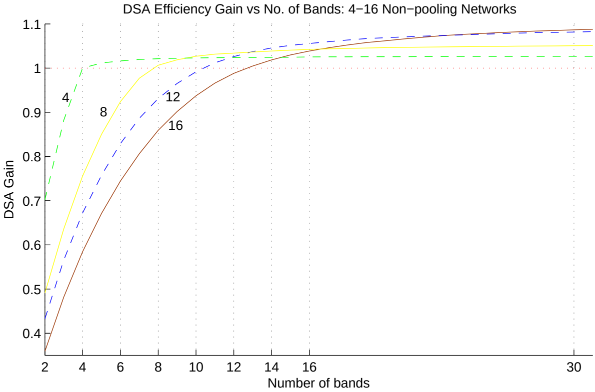

Figure: With system spectrum and arrival rate held constant, DSA gain increases with the no. of bands and with the no. of identical networks.

Network loss vs noise factor

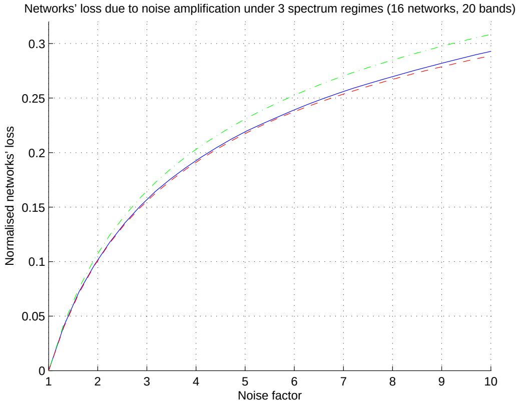

Figure: Noise is amplified by the factor shown. Solid, dash and dash-dot lines represent DSA, FSA, and Utopia.

Performance vs noise and No. of networks

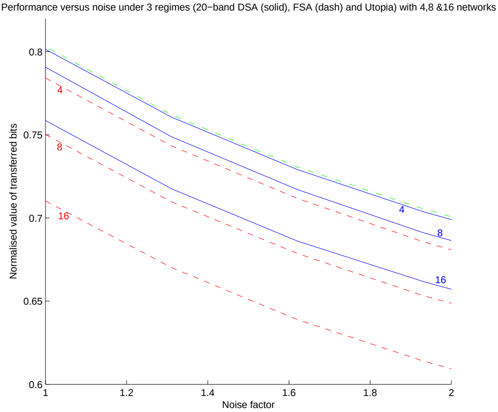

Figure: With total spectrum and market size held constant, the fewer the networks, the better the performance. With 4 nets, DSA ≈ Utopia

DSA vs market-share proportional FSA

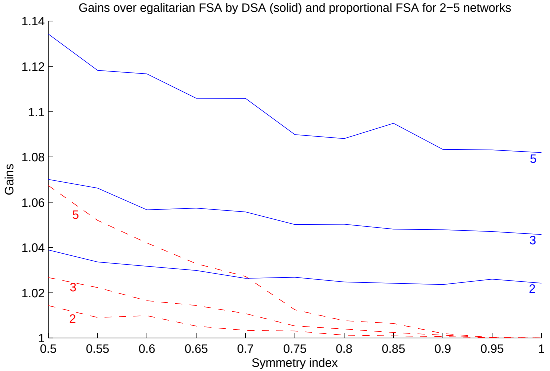

Figure: With a symmetry index of a the market share of network $j+1$ is a times that of network j. The greater the asymmetry, the greater the 20-band DSA gain over egalitarian FSA. Dash lines denote market-share-FSA.

DSA gain grows with inequality

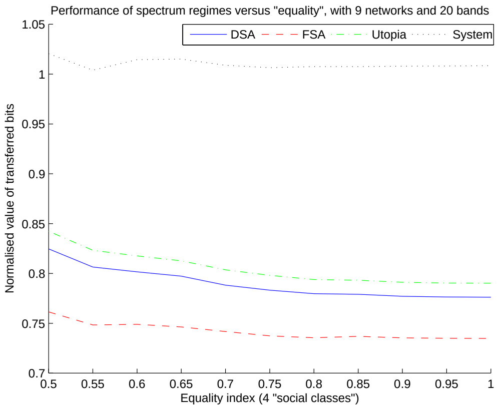

Figure: wtp's $\propto [1\ a\ a^2\ a^3]$ with value of total system bits (dotted line) held constant

Conceptual summary

- The technical-economic performances of 3 spectrum regimes considered: static (traditional), auction-based DSA, and an utopian "federated" network.
- Cellular CDMA networks are populated by data-downloading terminals.
- A terminal has own data rate, channel state, and "willingness to pay".
- Key performance figure: economic value of transferred bits.
- Utopia "wins", but DSA often follows very closely.
- Impact of noise rise (relevant to "higher power" UWB) considered on all regimes

Results summary

- DSA "gain" of 2-3%, when *identical* networks pool spectrum and customers.
- With system spectrum and arrival rate held constant, as new networks join, performance suffers, but the DSA gain grows with number of networks and bands to 10% and beyond
- bands should be as small as technologically feasible.
- With 5 unevenly loaded networks, DSA gain $\approx$ 15%, and still significantly outperforms market-share-proportional FSA.
- DSA and utopian gains grow with "social inequality" to $\approx$ 10%
- Network loss of $\approx$10% after 3db noise rise (relevant to higher power UWB under "economic mitigation" [3])

THANK YOU !!

For Further Reading I

- V. Rodriguez, K. Moessner, and R. Tafazolli, "Market driven dynamic spectrum allocation over space and time among radio-access networks: DVB-T and B3G CDMA with heterogeneous terminals," *Mobile Networks and Applications*, vol. 11, pp. 847–860, 2006.
- V. Rodriguez and F. Jondral, "Technical-economic impact of UWB personal area networks on a UMTS cell: Market-driven dynamic spectrum allocation revisited," in *IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks*, (Dublin, Ireland), April 2007.

For Further Reading II

V. Rodriguez and F. Jondral, "Market-driven regulation for next generation ultra-wide-band technology: Technical-economic management of a 3G cell with coexisting UWB devices," in *IST Mobile & Wireless Communication Summit*, (Budapest, Hungary), July 2007.