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"Economic aspects of national radio frequency spectrum management”
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Flexible Spectrum Use and Laws of Physics

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Outline

1. Flexible Spectrum Use
2. Radio wave propagation
3. Signal hyperspace
4. Unintended interactions
5. Open questions
6. Trends
7. Concluding remarks

Flexible use concept

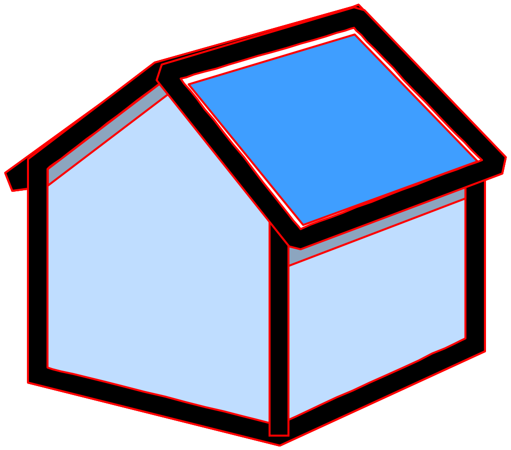
- Matheson RJ: Flexible Spectrum Use Rights
  - Tutorial at International Symposium on Advanced Radio Technologies (ISART) 2005
- Spectrum traded, aggregated, divided and *freely* used for a wide range of user-selected services, under 2 rules only:
  1. *Transmit within signal power restrictions inside your licensed 'electrospace' region*
  2. *Keep your signals below 'X' outside your licensed region*

  Note: Not applicable to passive services!

Household analogy

- In your house, you are free to arrange your furniture at will

- Flexible Spectrum Use Rights are expected to offer similar freedom in using the RF spectrum.



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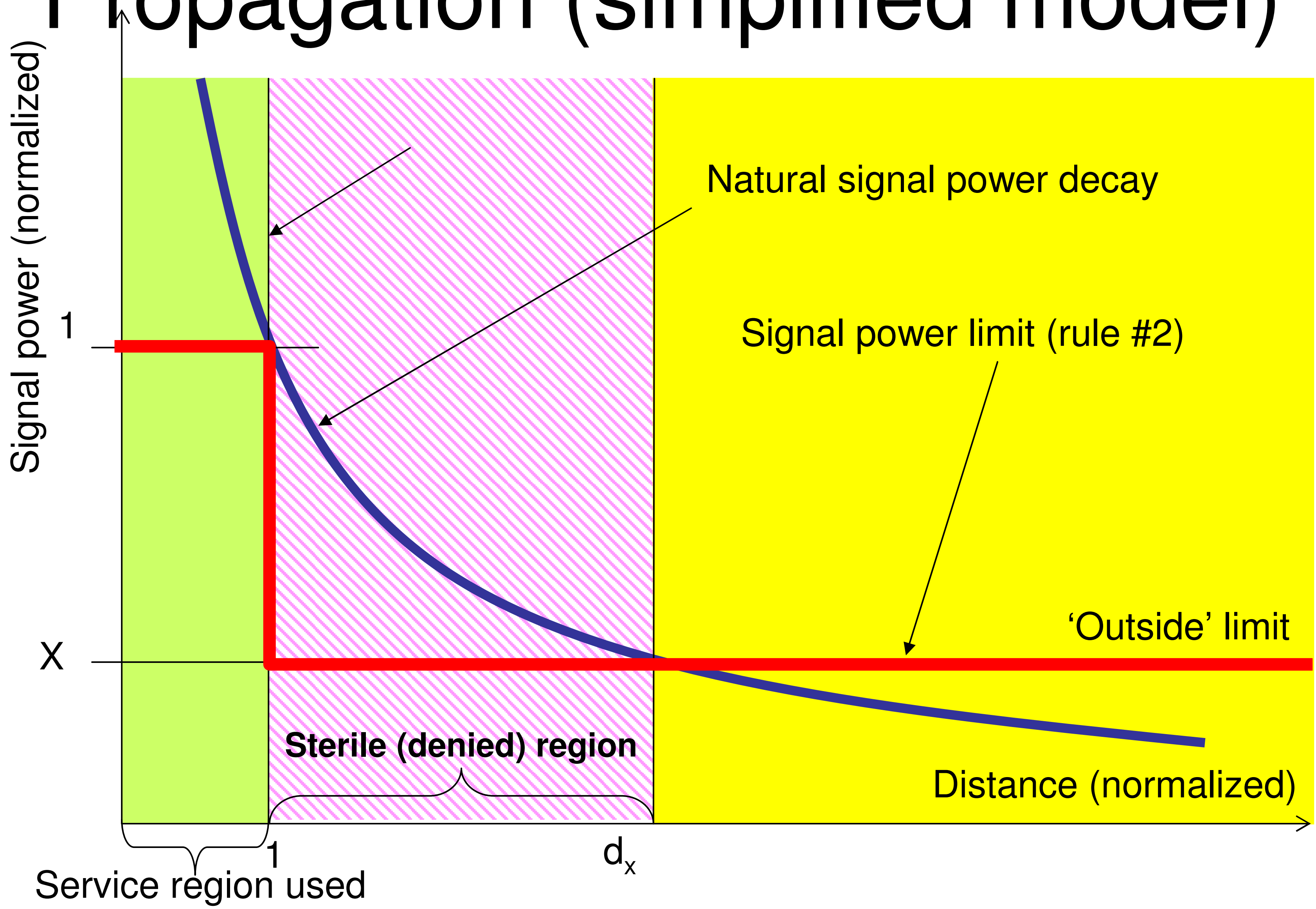
Radio wave propagation

- „Flexible use” rules
  - Inside the licensed region the signal must be strong as required by the service offered there
  - Outside the licensed region the signal must be weak - otherwise it disturbs services offered there
- imply the signal to change at the border

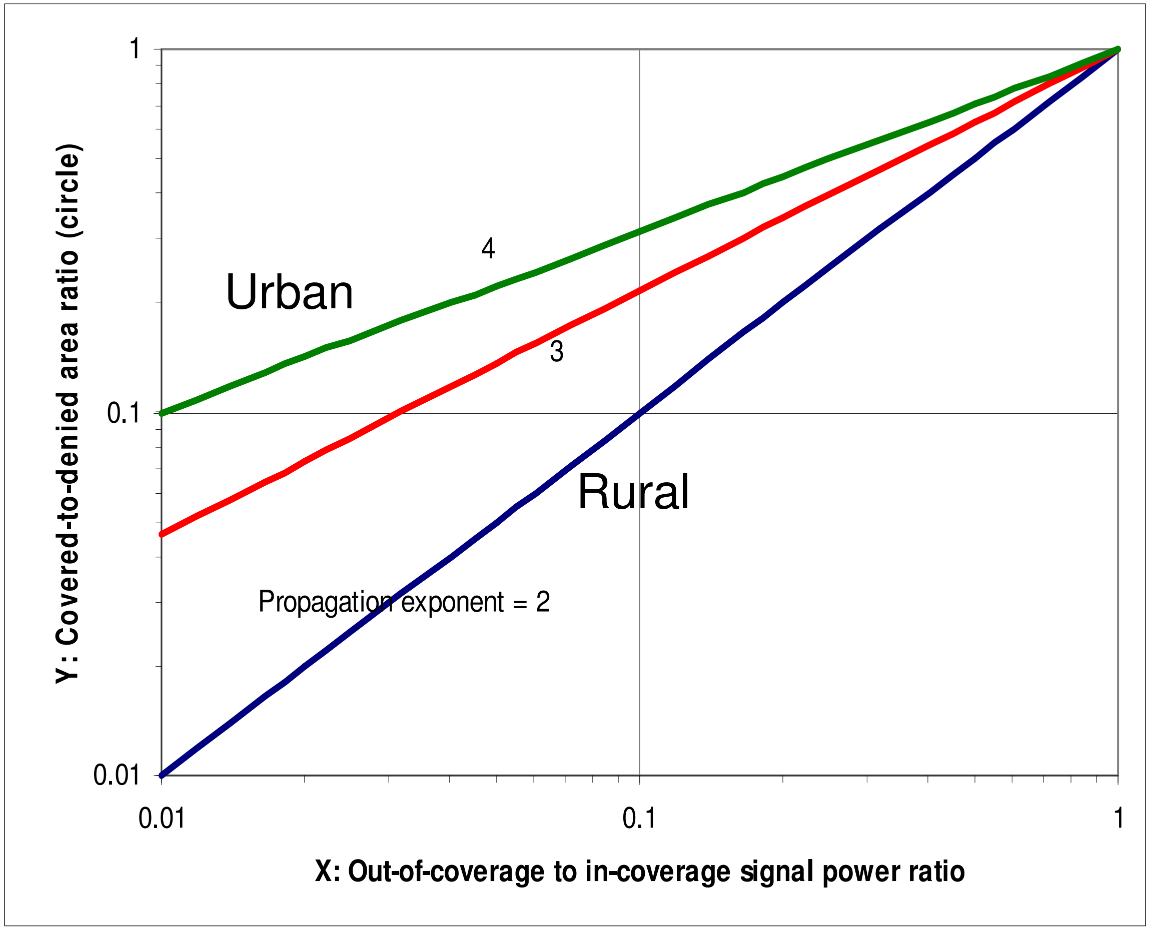
- *Problem*: radio wave in a continuous medium decays gradually – it cannot change abruptly

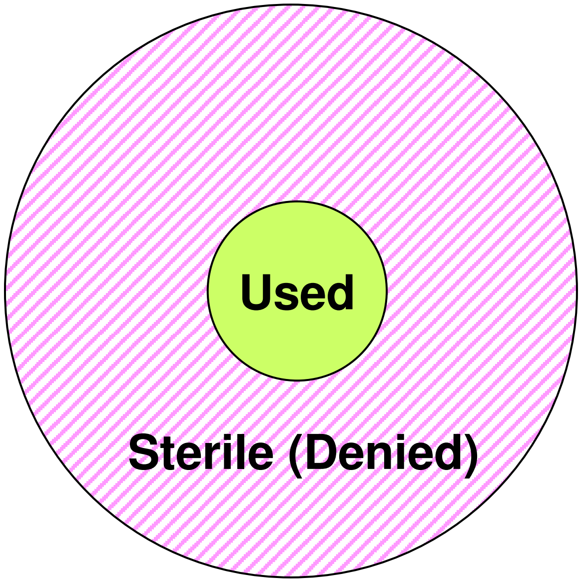
- The signal power can fall naturally to level ‘X’ only at a distance dx from the transmitter
- ‘dx’ determines sterile region where other systems cannot use the same frequency resources (compare „frequency reuse distance”)
- The flexible spectrum use doctrine disregards that fact.

Propagation (simplified model)



Covered-to-sterile area ratio





Omnidirectional antennas

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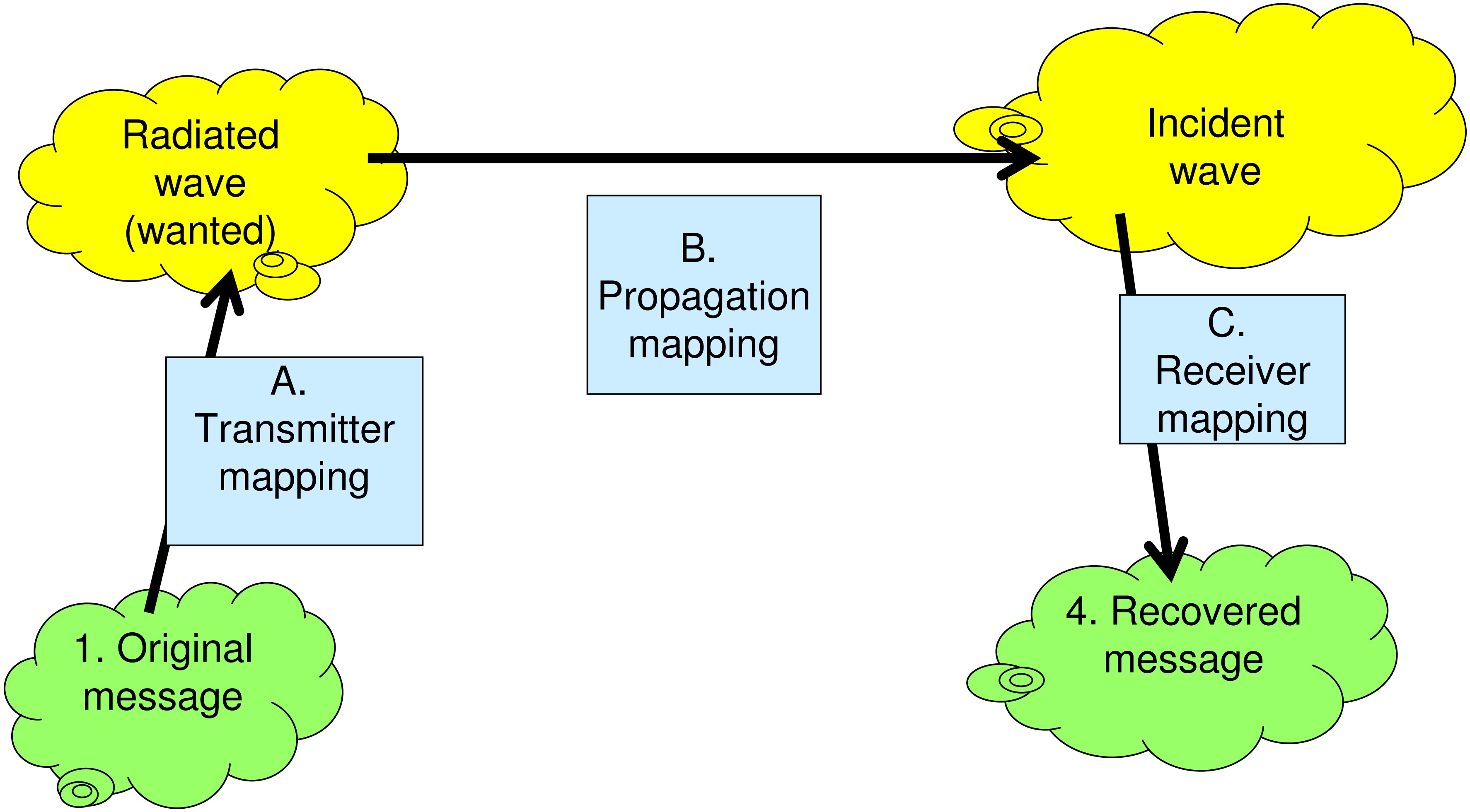
A new look at radio transmission

- A radio signal has a number of measurable characteristics (dimensions) that create a multidimesional space (hyperspace)
  - Signal hyperspace - a set of orthogonal variables by which one radio signal can be distinguished from another. Frequency, modulation, power, direction and coding are examples.
- Signals → solids in the hyperspace
- Radio transmission → a series of signal mappings

- *Transmitter*:
  - maps the original message (*mi*) into the radiated radio wave
- *Propagation process*:
  - maps it into the incident wave (*sij*) and introduces noise, reflections, latency, fading, Doppler Effect, etc. - many of these effects are uncontrollable!
- Receiver:
  - maps incident wave into the recovered message (*mij*) that (normally) is close to the original message

Radio transmission = mapping



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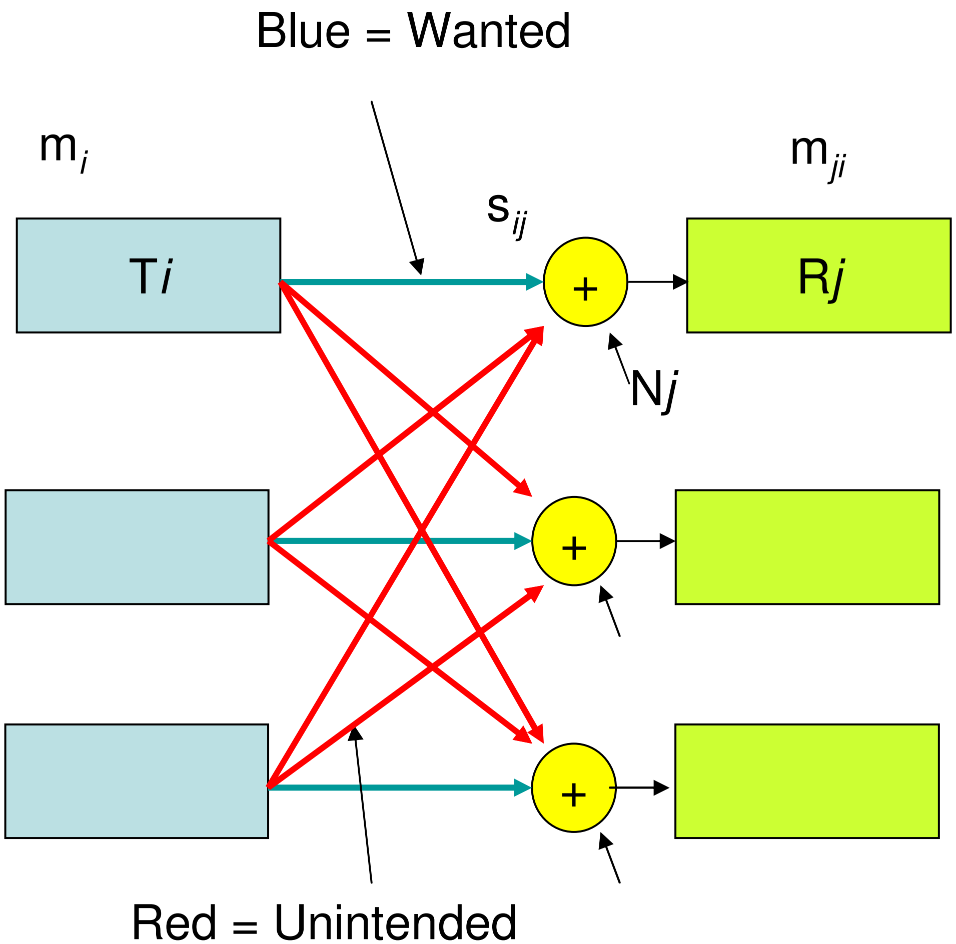
- The radiated wave reaches the intended receiver(s) ***and*** other receivers

- The incident wave at each receiver is a combination of the intended signal, noise and a number of unintended signals

- The service (quality, range, coverage, etc.) depend on the power ratio of the intended-to-unintended signals (congested environment)



- There is a multitude of radio transmitters (T_j) and receivers (R_j) in operation → congestion!

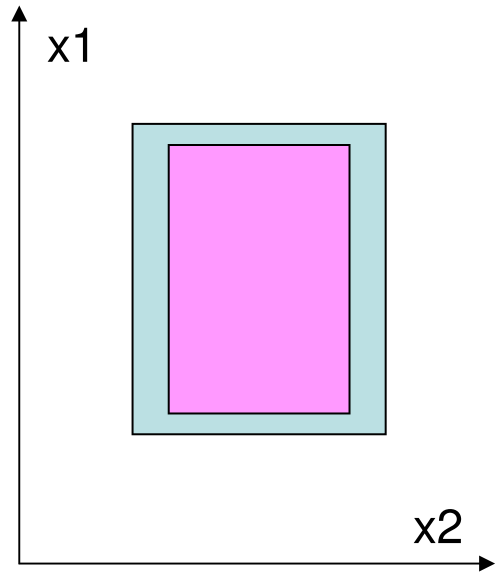
Successful transmission #1

- The intended signal must fit the receiver input „window" in all dimensions

Signal projection on (x1, x2)

1) x1=Time, x2 = Frequency
2) x1=Power. x2 = **Frequency**
3) x1=Frequency. x2 = Time

etc.



- Receiver responds only to the incident-wave components that fall into its „reaction window”
  – The intended signals must appear at correct time and frequency, from correct direction, with correct polarization and coding, etc.
- Receiver reaction window:
  – a single opening (analog systems) or
  – a set of non-contiguous openings (digital systems)

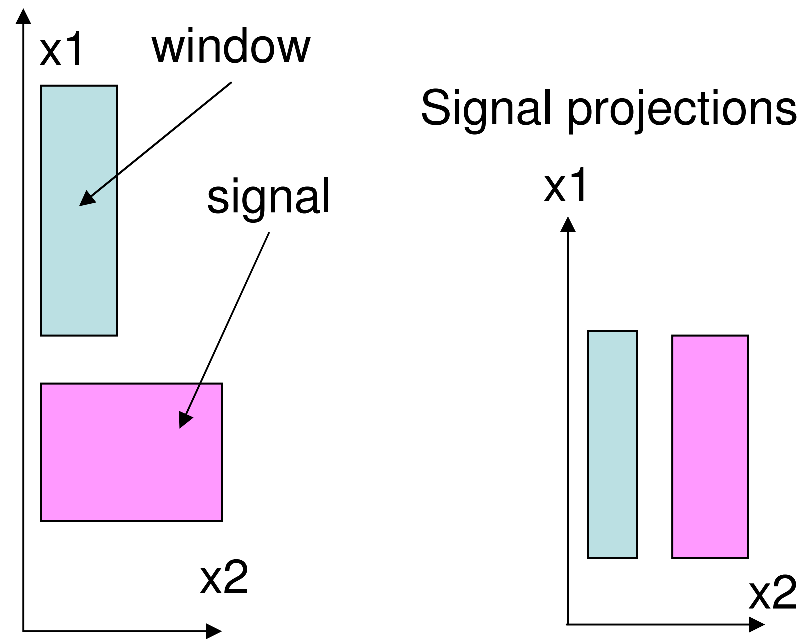
Successful transmission #2

- All unintended signals must be rejected
  - they must be outside the receiver reaction window

Signal projection on (x1, x2)

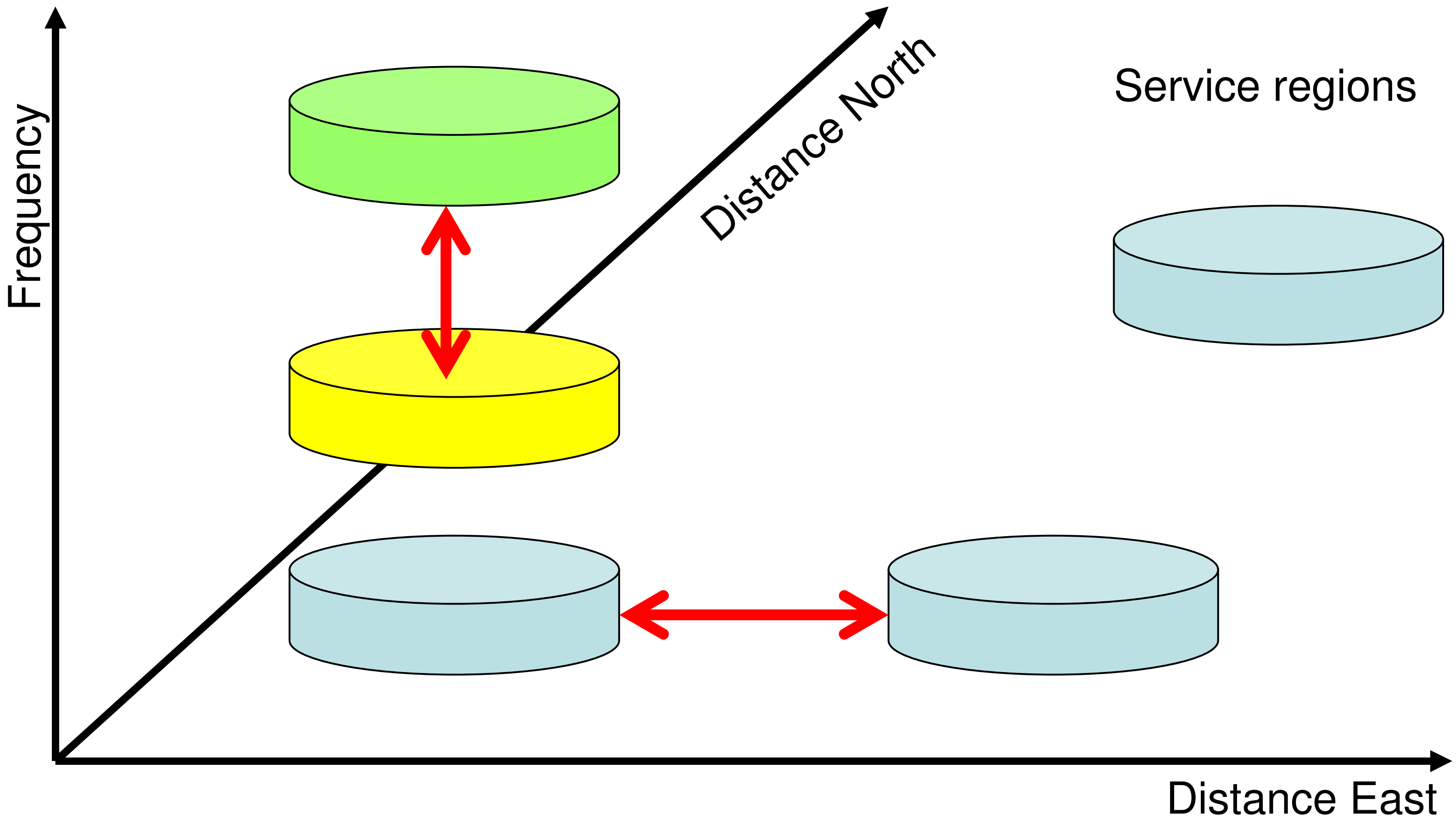
1) x1=Time, x2 = Frequency
2) x1=Power. x2 = Frequency
3) x1=Frequency. x2 = Time

etc.

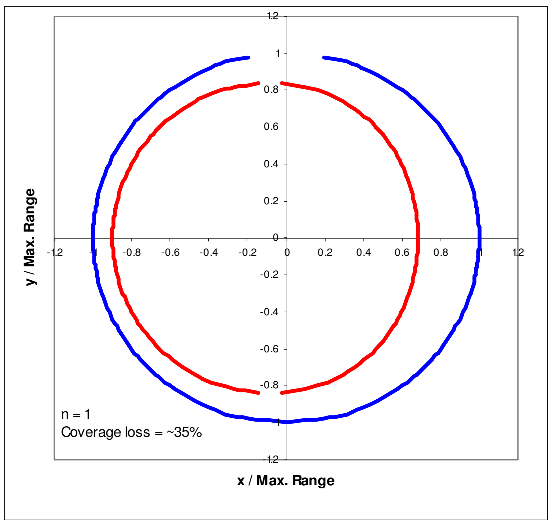


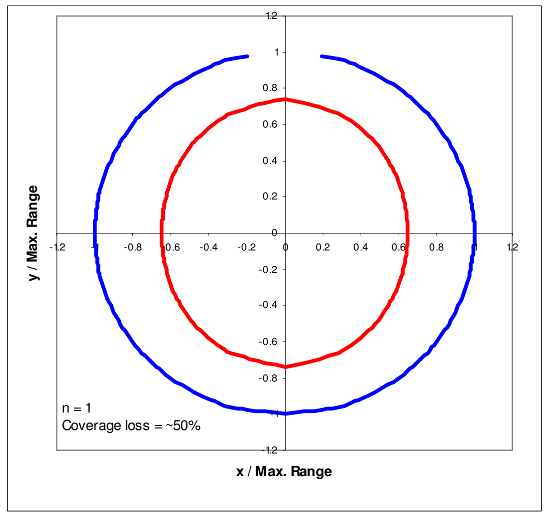
- To be rejected, an unintended signal must be sufficiently distant from the receiver’s reaction window in *at least one variable*
  - It must appear at wrong times, at wrong frequencies, wrongly coded etc.
- The “sufficient” distance is system dependent and might be defined in
    - geographical domain (e.g. frequ. re-use distances),
    - frequency domain (e.g. frequency plans),
    - power domain (as in ultra-wideband systems sharing frequencies with narrow-band systems),
    - time domain (e.g. TDMA systems)
    - coding/ spreading domain (as in spread-spectrum systems)
    - direction domain (antenna directivity)
    - etc., plus any combination

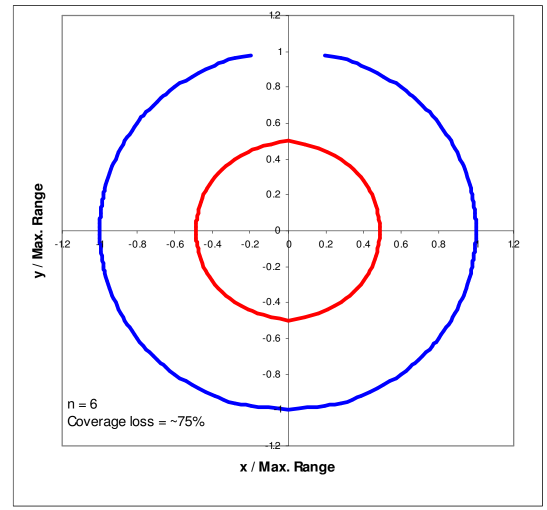
3D illustration



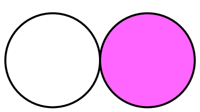
Unintended interactions: effects

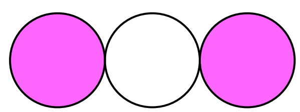


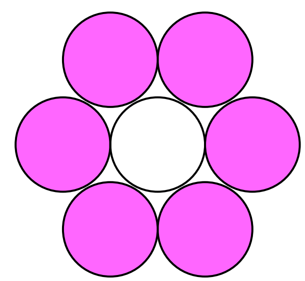




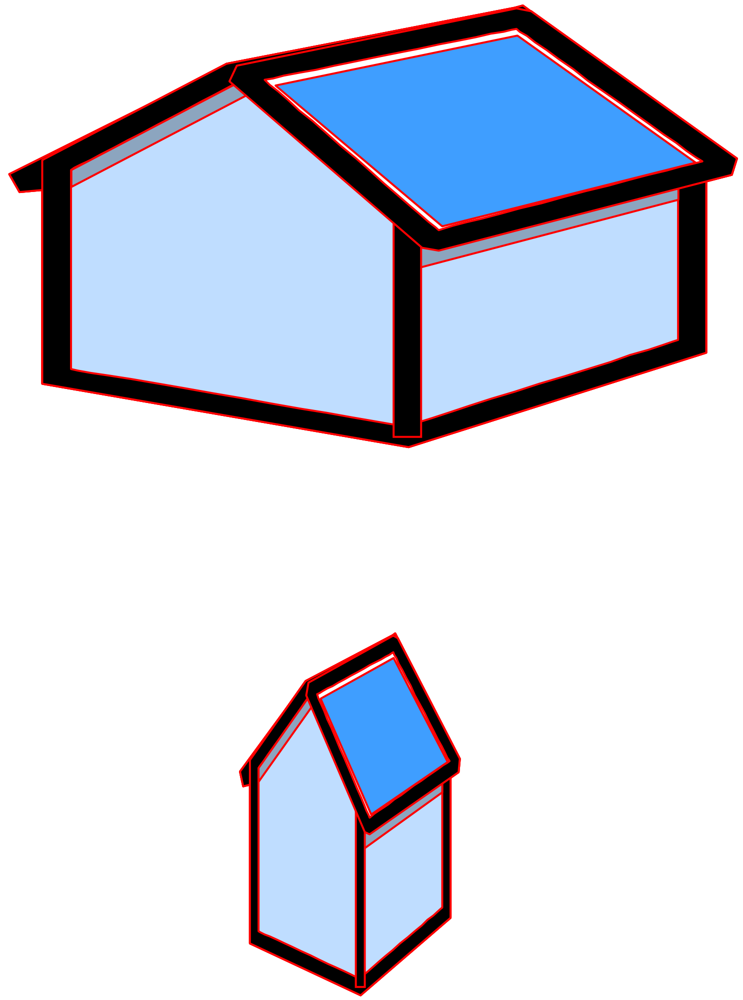
Loss: 35% 50% 75%







- Household analogy:
  - House walls made of a rubber membrane
  - under the neighbors' pressure, the house changes its size and form
  - no more flexibility in the furniture arrangement!



- Unintended interactions are critical factors

- Problems:
  - They depend not only on specific characteristics of individual systems, but also on their *number and spatial deployment* that are *out of control* (as a principle)
  - Their possible control reduces greatly the freedom in RF spectrum use
  - The doctrine of flexible use disregards that fact

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Open questions

- Due to unintended interactions, each new transmitter operating nearby reduces the service (range and/or quality) and so do profits
  - How does it influence the investment decisions?
  - How does it depreciate the business value?
  - Could it be compensated?

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Trends #1

- The more signal dimensions used by the system, the more degrees of freedom and more flexibility in the use of the RF spectrum resources
- There is *no limit* imposed *a priori* on signal dimensionality employed and additional dimensions (variables) are included as spectrum congestion increases, rational spectrum management evolves, and radio technology develops

Trends #2

- Static approach to spectrum use
→ dynamic approach
- Spectrum management rules and practices
→ built-in in the equipment hardware/ software and executed automatically (communication protocols, rules, strategies, policies)
- Competition in the spectrum use
→ collaborative approach
- Competition among the spectrum users
→ competition among equipment manufacturers

Self-organizing & learning systems operating like ants that assist each other in fulfilling their tasks - New business model

http://ant.edb.miyakyo-u.ac.jp/INTRODUCTION/Gakken79E/Page_04.html

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Concluding remarks

- Flexible spectrum use doctrine is an interesting concept deserving further exploration
- It is applicable to a wide range of active services but is not applicable to passive services.
- It disregards some physical constraints due to unintended interactions and radio propagation
- It requires „intelligent communication robots” -- self-organizing systems able to learn and adapt automatically/ dynamically to the environment

- With „Classic” radio technology, flexible-use spectrum rights can be exercised only when the system in hand is isolated, or when it does not require any protection against interference and it does not disturb other systems.

- New technologies of „intelligent communication robots” make practical the concept of flexible spectrum use rights

- Physical constraints do not depend on spectrum management regime (static or dynamic) and spectrum use rights
  - » They are the same when the spectrum resources are treated a private property or as an open commons, administratively regulated, or self-regulated through market forces
- Unintended interactions with other systems determine system performances to the same degree as intended ones
  - » Interacting systems behave as a network
  - » Operation of systems in the network must be harmonized/ coordinated

Selected references

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About the author

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Formerly, Prof. Struzak was employed as Acting Assistant Director & Head of Technical Department, CCIR-ITU; Visiting Professor, Institut National Polytechnique de Toulouse (F); Full Professor, University of Information Technology and Management, Rzeszow (PL); Professor, Wroclaw University of Technology (PL); Research Professor & Head of NIT's Wroclaw Branch (PL); Editor-in-Chief, Global Communications, (UK), as well as Consultant to ITU, OCHA, WB, IUCAF, PWC, and other entities. He co-founded and chaired International Wroclaw Symposium on EMC. He published some two hundred publications in radio science and engineering.

Prof. Struzak was active in international organizations: ITU-RRB; ITU-CCIR; URSI; IEC-CISPR, where he was elected to leading positions. Among others, he was elected (and then re-elected) a Member and then the Vice-Chair of the ITU Radio Regulations Board. He is a recipient of the ITU Silver Medal and two International Awards (Int'l Symposiums on EMC in Montreux and in Rotterdam), an IEEE EMCS "Acknowledgment of Gratitude" and numerous national awards and decorations. International Biographical Centre listed him among the "Leading Scientists of the World".

Prof. Struzak has been elected to the grade of a Fellow and then a Life Fellow of IEEE, a Member of the New York Academy of Science and an Academician of the International Telecommunication Academy.

Important notes

- Beware of misprints!!! These materials are preliminary notes for my lectures and may contain misprints. If you notice some, or if you have comments, please send these to r.struzak@ieee.org.

Thank you for your attention