A Policy–driven Trading Framework for Market–based Spectrum Assignment

Patroklos Argyroudis Tim Forde Linda Doyle
Donal O'Mahony

Centre for Telecommunications Value-chain Research
University of Dublin, Trinity College
{Firstname.Lastname}@tcd.ie

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Outline

1. Motivation
   - Extract the maximum benefit from the available spectrum
   - Address the increased complexity of new spectrum management strategies
2. Spectrum markets
   - Traded commodities
   - Complexities
3. Policy–driven spectrum trading
   - Design rationale
   - Market entities
   - Auction models
   - Prototype implementation

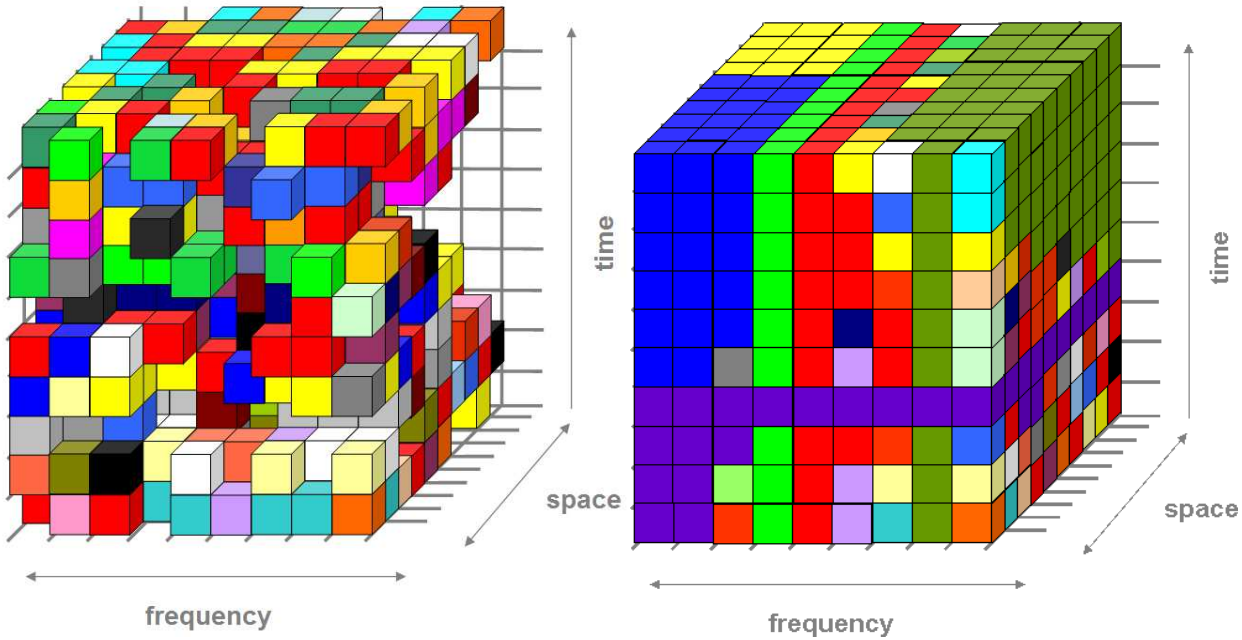
Dynamic spectrum access

- Methods for spectrum management that move away from the traditional *command and control* regulation
- Greater spectral efficiency, wider access to spectrum
- Promotes technological innovation and economically efficient uses
- Approaches:
  - Opportunistic usage regimes
  - Commons models
  - Exclusive usage rights schemes
- The FCC has proposed the removal of regulatory barriers to allow secondary markets in exclusive spectrum usage rights

Traded commodities

- Exclusive usage rights
  - The spectrum *itself* is not bought and sold, but rather the rights to its exclusive use
- Many attempts in the literature to define a *packet/bundle/block* of spectrum
- Our approach is to visualise what we term the *radio spectrum rights continuum* as a three dimensional model: space, time and frequency
- Each block represents a unique assignment of spectrum rights at a particular place, for a particular frequency and at a fixed time

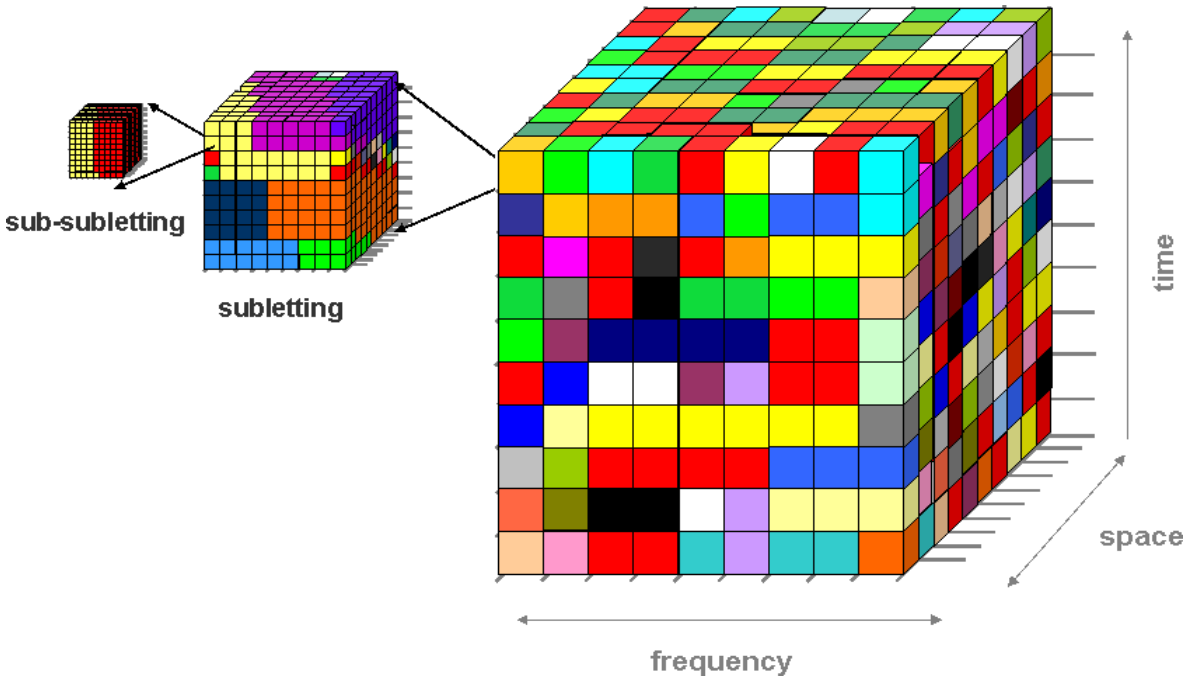
{Dis}Aggregated market–based assignments



- The Rubik's cube–like construct represents an area of the spectrum rights continuum
- Each block represents a unique spectrum assignment and each colour a unique *spectrum consumer*

ctvr

Subletting



- Any consumer of a block may deem to divide and sublet that block

Complexities

- Additional usage terms and conditions may be attached to particular spectrum blocks as they are traded on different markets
- Economic issues
  - Aggregation caps to limit monopolistic behaviour and promote competition
- Social issues
  - Clauses to meet universal service requirements
- Technical issues
  - A WiFi hot–spot provider and a UMTS network operator will be looking for different types of spectrum
- Context issues
  - In emergency situations precedence may have to be given to a different entity

Design rationale

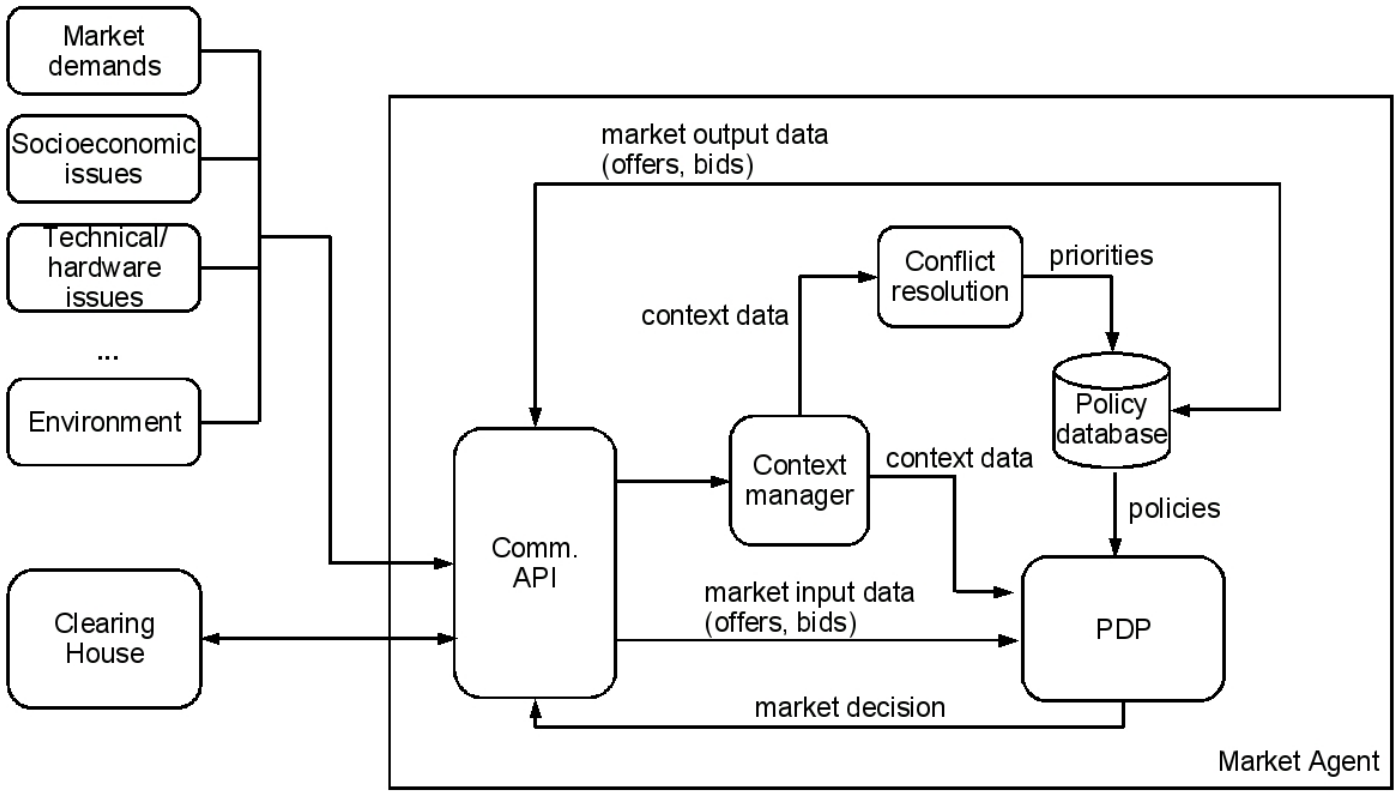
- Main objective is to design a framework that is able to address the complexities of spectrum markets
- We use the IETF Policy Core Information Model (PCIM)
  - Rich and robust model able to describe the requirements and the identified issues (technical, socioeconomic, etc.)
  - Allows the assignment of roles to policies, therefore we can define different spectrum blocks for the needs of different markets
  - Conflict resolution is handled by assigning priorities to policies

Market entities

- Clearing house: hosts offerings facilitating trading
  - Can also operate in a distributed way
- Spectrum consumer: makes offerings and purchases on the market
  - Plays the roles of buyer and seller in different transactions
  - Depending on the granularity of the traded spectrum blocks may range from wireless operators to end users
- Bank: has *off–line* monetary relationships with the previous entities

Market agents

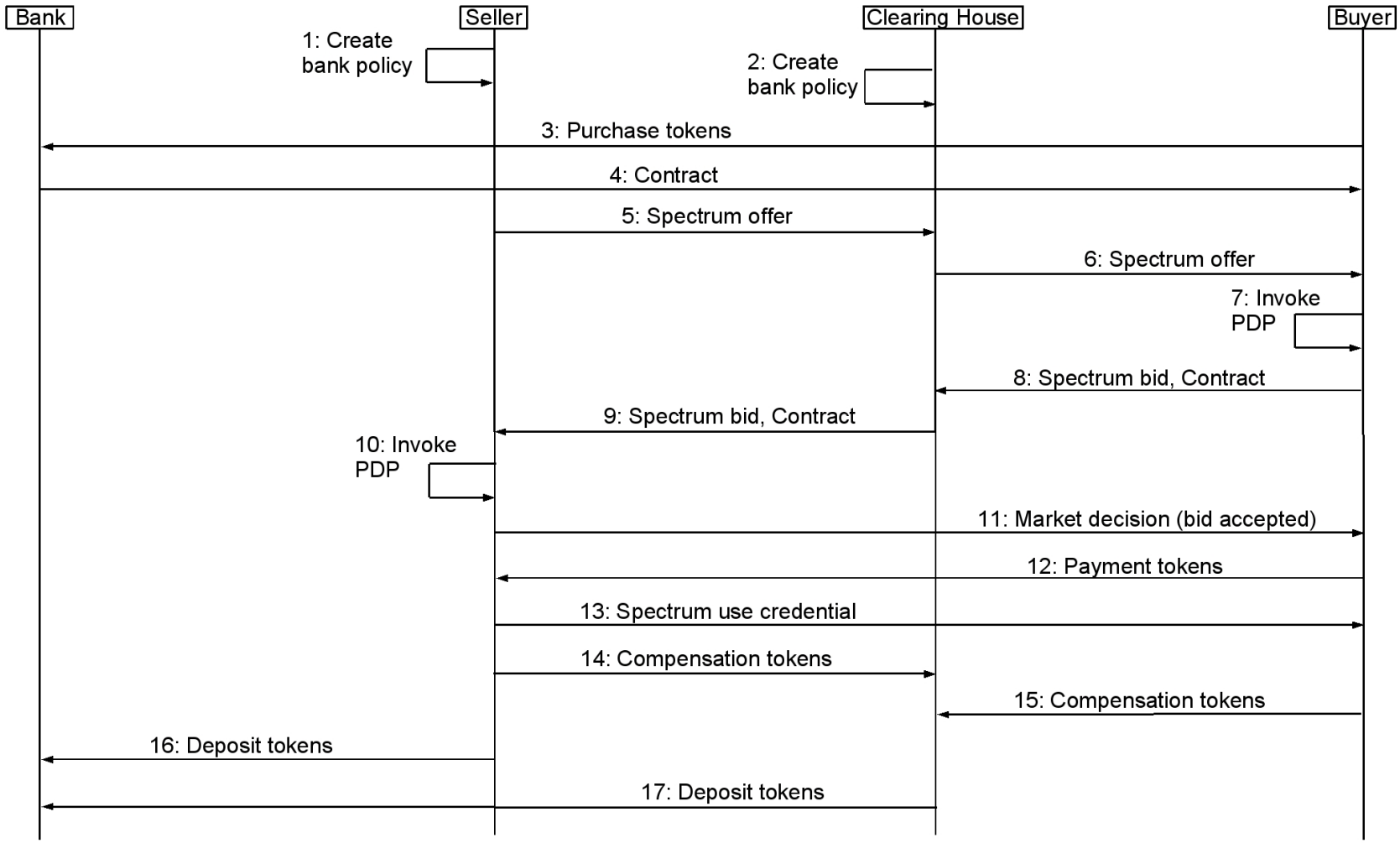
- The clearing house and the spectrum consumers run *market agents* that implement policy management functions



Auction models

- Open–cry
  - Public bids for offers found at the clearing house
  - Rival buyers have limited time to respond with higher counter–bids
  - Seller collects bids, invokes PDP and reaches a market decision
- Sealed bid
  - Clearing house keeps all bids secret for a given offer
  - The bids are evaluated against the offer at the clearing house's PDP
- Monetary compensations are handled by electronic payments

Open–cry auction model



Prototype implementation

- Addresses markets on which small spectrum blocks are traded
  - Micropayments since we have frequent low–valued exchanges
  - Macropayments and/or money transfers for the trading of larger spectrum blocks
- KeyNote to implement a subset of the IETF policy model
- KeyNote credentials to manage hash chain micropayments
- Our context manager is responsible for creating the *action attribute set* that the KeyNote PDP uses to describe policy requests

Example (open–cry)

- A spectrum `seller` needs to define a policy statement with the trusted banks (`bank_1` and `bank_2`)

```
authorizer: "POLICY"
local-constants:
    seller = "rsa-hex:3048024100cc02..."
    bank_1 = "rsa-hex:3048024100bf78..."
    bank_2 = "rsa-hex:3048024100da71..."
licensees: (bank_1 || bank_2) && seller
conditions: app_domain == "spectrum market" -> "true";
```

Example (open–cry)

continued

- Contract between `buyer` and `bank_1`

```
local-constants:
    buyer = "rsa-hex:3048024100aa88..."
    bank_1 = "rsa-hex:3048024100bf78.."
authorizer: bank_1
licensees: buyer
conditions: app_domain == "spectrum market" &&
    @date <= 20070912 &&
    amount == "0.1" && @number <= 100 -> "true";
signature: "sig-rsa-sha1-hex:26d7da6725..."
```

Example (open–cry)

continued

- Spectrum offer that binds the `seller` to the specified terms

```
local-constants: seller = "rsa-hex:3048024100cc02..."
authorizer: seller
conditions: app_domain == "spectrum market" &&
    &frequency <= 236.0 && &frequency >= 232.0 &&
    frequency_unit = "MHz" &&
    channel_bw == "1.75" && channel_bw_unit == "MHz" &&
    &transmit_power <= 1.0 && power_unit == "W" &&
    &latitude <= 51.15656 && &latitude >= 51.14949 &&
    &longitude >= 2.99228 && &longitude <= 3.01011 &&
    @date >= 20070417 && @date <= 20070418 &&
    @time >= 100000 && @time <= 220000 &&
    &amount * &number >= 3.0 -> "true";
signature: "sig-rsa-sha1-hex:81a0e2520f..."
```

Example (open–cry)

continued

- Policy that includes the anchor of the hash chain that the `buyer` commits to the bid

```
local-constants: buyer = "rsa-hex:3048024100aa88..."
      seller = "rsa-hex:3048024100cc02..."
authorizer: buyer
licensees: seller
conditions: app_domain == "spectrum market" &&
      &frequency <= 236.0 && &frequency >= 232.0 &&
      frequency_unit = "MHz" &&
      channel_bw == "1.75" && channel_bw_unit == "MHz" &&
      &transmit_power <= 1.0 && power_unit == "W" &&
      &latitude <= 51.15656 && &latitude >= 51.14949 &&
      &longitude >= 2.99228 && &longitude <= 3.01011 &&
      @date >= 20070417 && @date <= 20070418 &&
      @time >= 100000 && @time <= 220000 &&
      commitment == "b80e336f22b733e4692e270" &&
      amount == "0.1" && number == "30" -> "true";

signature: "sig-rsa-sha1-hex:59295c356d..."
```

Example (open–cry)

continued

- If the `buyer` has a valid contract with a bank that the `seller` trusts, and
- The offer's terms are met by the proposed bid
- Then the `seller's` PDP authorises the transaction, the `buyer` is informed and releases tokens to the `seller`
- The `seller` issues a signed KeyNote policy statement to the `buyer` with the purchased spectrum usage rights as specified in the initial offer
  - *Spectrum use credential*
- The `seller` periodically contacts the bank to translate tokens into monetary units (and deposit them)

Summary

- We aim to find an alternative to static assignment mechanisms for the operation of spectrum markets
- While our policy–driven prototype is far from complete it demonstrates several attractive features

- Future work
  - Context manager
  - IETF PCIM
  - Experimental evaluation (spectral efficiency, increased complexity)

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