Enabling Decentralized Peer-to-Peer Secondary Spectrum Marketplaces

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Introduction

- Dynamic spectrum access aims to address the spectrum scarcity issue by using the following approaches:
  - Exclusive usage rights schemes,
  - Commons model,
  - Opportunistic usage regimes.
- Current state of the art in secondary spectrum trading directly involves the governmental agencies resulting in considerable cost, overhead and delay.
- Need to enable *decentralized secondary spectrum trading* in a flexible way to increase efficiency of spectrum use.

Problem Statement

- Two Step Approach:
  1. Enable *trading of exclusive access rights* to a portion of spectrum (specified by frequency, location and time period) through payment of fee in a *decentralized* manner without directly involving the governmental agencies.
  2. Regulate radio device transmission using exclusive spectrum access rights to provide *proactive enforcement of spectrum usage policies* and to *deter unauthorized transmissions*.

What are the requirements of such a Secondary Spectrum Marketplace?

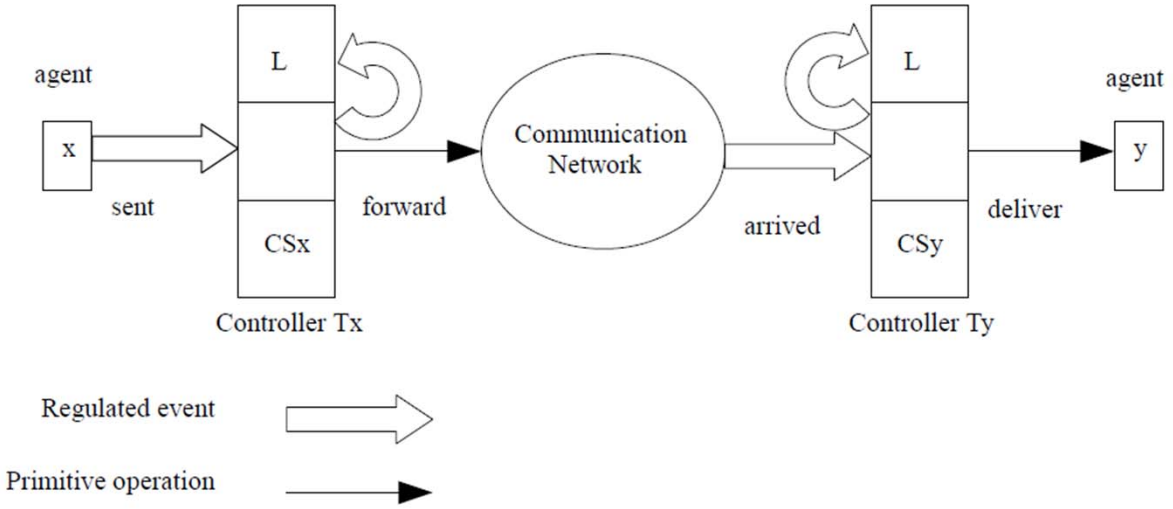
- Must allow spectrum consumers to sell, lease or transfer access rights to a chunk of spectrum in their possession.
- Must support disaggregation, partitioning or time-sharing of spectrum.
- Auditing must be supported to provide the governmental agencies with necessary information for monitoring spectrum usage, and to facilitate the collection of taxes.
- To be practical and effective, it is imperative that such trading is in compliance with rules set up by the government.
- Overall requirements can be met only by a generic "policy mechanism" that can enforce communal polices, while being stateful, proactive, highly decentralized, and safe/secure.

The Concept of Law Governed Interaction (LGI) ([1], [2])

- LGI is a message exchange mechanism that enables a community of distributed agents to interact under an explicit and strictly enforced policy, called the "law" of this community.
- Some characteristics of LGI:
  - Laws are about ***interaction*** between agents—it is a generalized access control mechanism.
  - Laws are about local behavior, but they have ***global, communal implications,*** because everybody in the given community is subject to the same law.
  - High expressive power, including ***stateful*** and ***proactive*** laws.
  - Laws can be written either in ***Java***, or in Prolog.
  - A single system may have a multitude of interrelated laws, which may interoperate, and be ***hierarchically*** organized.
  - **Enforcement is decentralized to achieve scalability.**

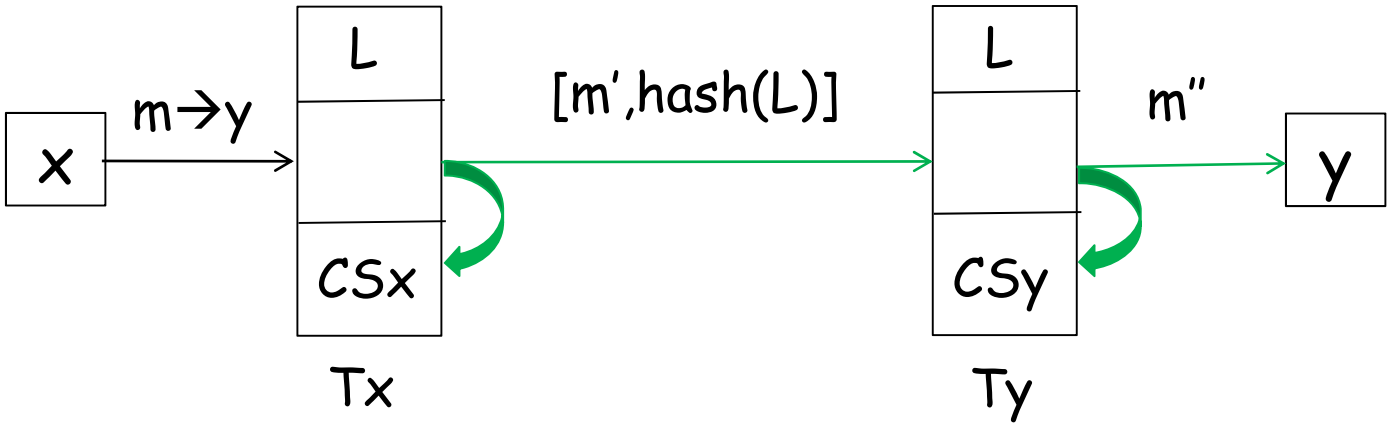
Distributed Law Enforcement under LGI ([1], [2])

- Laws are defined locally, at each agent:
  - they deal explicitly only with local events—such as ***sending*** or ***arrival*** of a message,
  - the ruling of a law for an event *e* at agent *x* is a function of *e*, and of the local control state CS_X of *x*,
  - a ruling can mandate only local operations at *x*.
- Local laws can have powerful global consequences—because of their global purview.



On the basis for trust between members of a community ([1], [2])

- For a member of an L-community to trust its interlocutors to comply with the same law, one needs to ensure:
  - that the exchange of L-messages is mediated by correctly implemented controllers,
  - that interacting controllers operate under the same law L,
  - messages are securely transmitted over the network.
- Such assurances are provided via certification of controllers, and the exchange of the hash of the law.



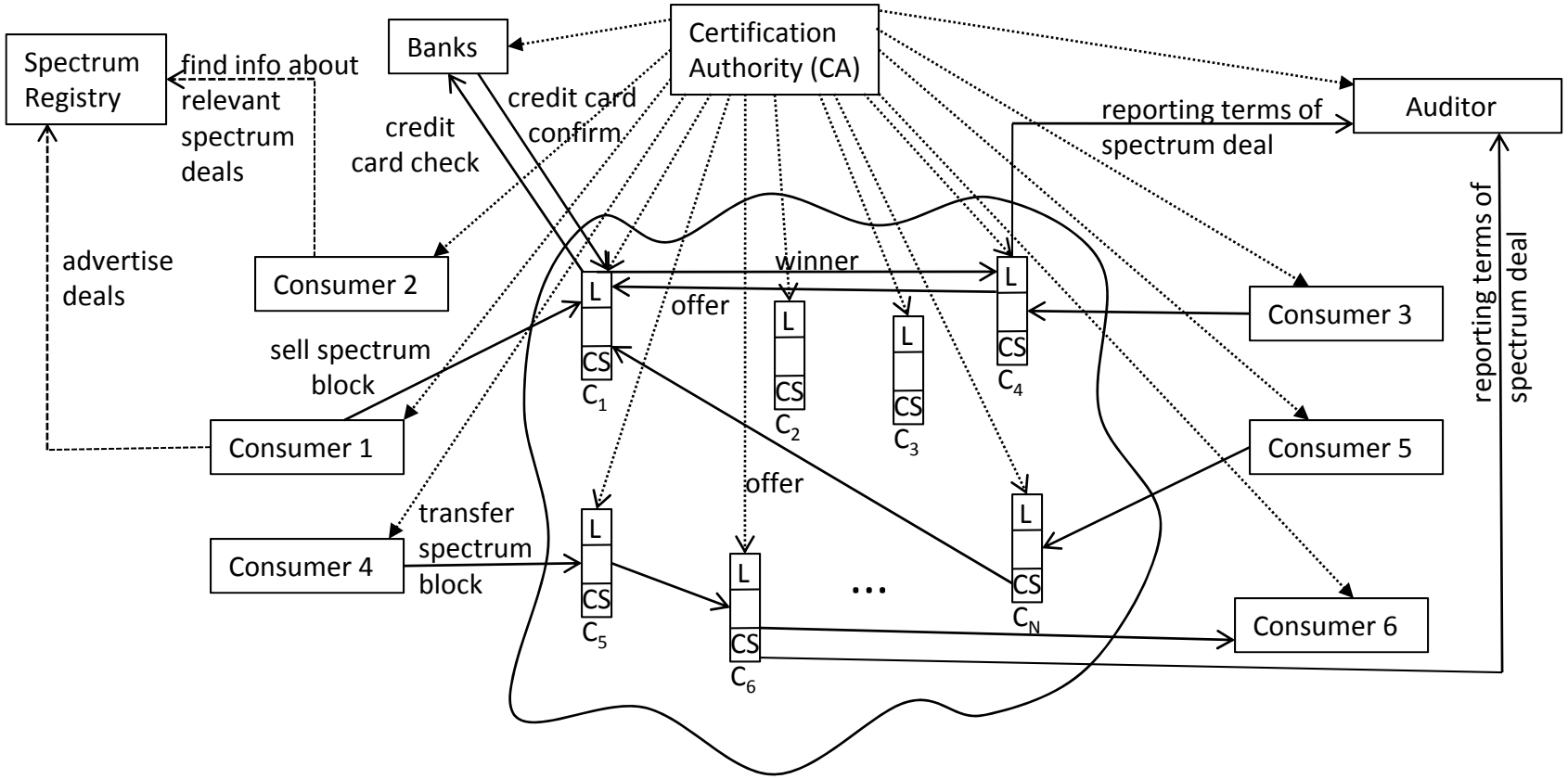
Fundamentals

- We use the *terminology* of Argyroudis et al. [3] regarding *spectrum consumers*, *spectrum blocks*, etc.
- Spectrum blocks are sold w/o any restrictions or rules about what services can be offered, what blocks can be neighbors, what technologies can be used, etc.
- Spectrum is *liberalized* with constraint only on the max level of interference that can be caused to neighboring spectrum consumers.
- Spectrum consumers can *divide and sell*, *transfer or lease* spectrum access rights they possess along one of the *frequency/space/time* dimensions or their combinations.

A Motivating Example

- *Entities:* spectrum consumers, banks, auditor, certification authority.
- Assume that a *spectrum registry* is used for advertising and searching information about spectrum block sales/auctions.
- *Controller Service* (operated and maintained by FCC) provides a reliable and secure set of controllers.
- *Government Policy* (P_G) case study deals with following issues:
  - authentication of participants and of spectrum access rights acquired in primary market via FCC;
  - allows consumers to sell or transfer spectrum blocks by dividing spectrum along frequency/space/time dimensions for a fixed price or under some kind of auctions (e.g., open-cry, Dutch, etc.);
  - banks handle monetary exchange via credit cards;
  - ensures reporting of transactions to a special auditor.

Snapshot of interaction taking place in a peer-to-peer Secondary Spectrum Marketplace



Implementation

- Access rights to a portion of spectrum *S* can be represented by the list [frequency(392,396,MHz), time(110000,190000), . . .].
- *S* can be divided along frequency/space/time dimensions in the following manner:
  - *Channel Disaggregation:*

    S_1-*[frequency(392,394,MHz)*, time(110000,190000), . . .];
    S_2-*[frequency(394,396,MHz)*, time(110000,190000), . . .].
  - *Time-sharing:*

    S_1-[frequency(392,396,MHz), *time(110000,150000)*, . . .];
    S_2-[frequency(392,396,MHz), *time(150000,170000)*, . . .];
    S_3-[frequency(392,396,MHz), *time(170000,190000)*, . . .].
- Similarly, spectrum blocks can be formed by geographic partitioning of *S* or by dividing *S* along a combination of frequency/space/time dimensions.

Discussion

- Current model involves bank to handle monetary exchange, but it is possible to make all interactions completely decentralized by incorporate payments via *digital cash*.
- Digital cash would further increase applicability of our scheme by making it suitable for both micropayment and macropayment deals.
- Model can be extended to support certificate expiration and revocation.
- Communication faults can be handled through the *exception* facility of LGI to avoid loss of spectrum goods.

Architecture

- *Assume:*
  - Radio devices have a secure clock and a secure GPS.
  - Existence of a secure mechanism to transfer tokens (i.e., exclusive spectrum access rights) from the controllers to the trusted kernel of the user device.
- Kernel approves transmission requests *iff* it satisfies frequency, space, timing and other constraints mentioned in token.
- *Advantage:* Enables proactive enforcement of spectrum usage policies and deters unauthorized transmissions.
- *Limitation:* Approach does not work if radio devices have been tampered or can be operated w/o complying to such tokens.
- *Proof of concept:* Regulation of wireless communication in ad hoc networks [3], which controls the application level messaging.

Related Work: Argyroudis et al. [4]

- Describes a policy-driven trading framework that allows spectrum consumers to trade exclusive access rights to spectrum blocks for electronic payments.
- Uses *Keynote* trust management system along with real-time hash chain micropayment scheme to handle monetary exchange.
- Cons:
  - Deals only with trading of exclusive access rights, but does not address how these credentials are to be used for policing spectrum use.
  - Cannot support delegation by transfer of privileges.
  - Auditing requirements (such as reporting of transactions to specified authorities, which is essential for monitoring) cannot be directly supported because keys do not reveal identity.

Related Work: SpecEx.com [5]

- *Centralized* online marketplace for secondary spectrum trading.
- Provides a platform for spectrum holders and buyers to sell, lease or exchange spectrum.
- Allows for disaggregation, partitioning and time-sharing of spectrum along one or any combination of the frequency/ space/time dimensions.
- FCC directly approves corresponding transactions once buyers and sellers agree to some common terms of the sale.
- Could be used as a *spectrum registry* for our model, where sellers advertise their spectrum goods and buyers search to find out about the deals they are interested in.

Conclusion

- Proposed an *innovative secondary spectrum marketplace*, where consumers can trade exclusive access rights to a portion of spectrum (specified by geographic location, frequency band and time period) for the payment of a fee in a *decentralized peer-to-peer fashion* w/o directly involving the governmental agencies.
- Outlined an architecture to regulate the transmission of radio devices based on exclusive access rights to spectrum.
- Advantages:
  - *Reduces overhead, delay and cost* of secondary spectrum trading.
  - Increases *spectrum efficiency*.
  - Simplifies task of spectrum management.

On-going Work

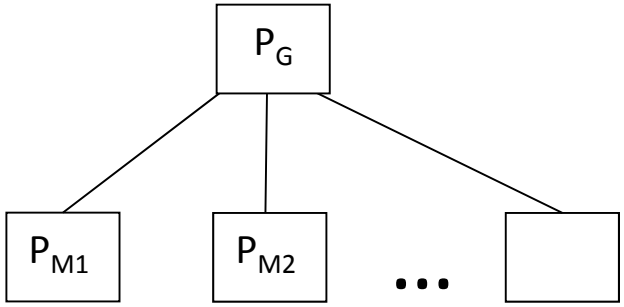


Fig. The superior/subordinate hierarchy of Secondary Spectrum Marketplace Policies

- Extend current model to support *hierarchical organization of secondary spectrum marketplace polices*:
  - Authorities involved in defining the rules are inherently hierarchical (federal government, state government, local authorities, etc.).
  - Individual spectrum marketplaces may be granted the freedom to define their own rules regarding negotiations, how spectrum goods are to be sold (e.g., fixed price deals or auctions), etc.

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[4] P. Argyroudis, T. Forde, L. Doyle, and D. O’Mahony, “A policy-driven trading framework for market-based spectrum assignment,” in Policies for Distributed Systems and Networks, 2007. POLICY ’07. Eighth IEEE International Workshop on, Jun. 2007, pp. 246–250.

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Thank you

Questions?