Relieving Spectrum Scarcity Through Real-Time Secondary Markets

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“Spectrum Scarcity”

- Some claim that there is a spectrum shortage.
  - Much of the spectrum is idle at any given time.
- Exclusive access through licensing leads to idle spectrum.
  - The price of interference protection.
- There are alternatives to exclusive access, including
  - Unlicensed spectrum
  - Secondary access
Unlicensed Spectrum

- **Benefits**
  - Allows spectrum sharing.
  - Makes mobile wireless systems possible:
    - Mobile LANs, PBXs, etc.
  - No lengthy licensing process required.
    - Promotes experimentation and innovation.
    - Important when licensing cost would dominate.
  - We need sufficient unlicensed spectrum

- **Limitations**
  - Mutual interference is hard to avoid.
  - Little incentive to conserve spectrum.
  - There is no limit to the number of devices contending for spectrum.
    - No performance guarantees.
    - User expectations may not be met.
  - Unlicensed spectrum is not a panacea, especially where QOS is required.

Secondary Access

- License holders are guaranteed access on demand without interference.
- Secondary devices transmit when and only when interference to license-holder would be tolerable.
- Models of secondary access
  - No explicit coordination
    - Secondary spectrum-user requests permission from the FCC
    - Example: ultrawideband requires this approach.
  - Explicit coordination
    - Secondary user requests permission from the license-holder before each call.
    - License-holder may ask for payment.
    - A real-time secondary market.
Supporting Technology

- **Challenges**
  - Requires a signaling protocol through which secondary users make requests
  - Could use license-holder’s spectrum or unlicensed spectrum.
  - Requires an admission control mechanism, through which a license holder can accept or reject requests.
  - Must guarantee adequate quality of service for both primary and secondary users.
  - Requires frequency assignment algorithm
  - Requires a payment system, to allow efficient funds transfer

- **Some enabling technologies** (useful but not required)
  - Software defined radios
    - Secondary devices can jump from one band to another until finding available spectrum.
  - Global positioning systems (GPS)
    - Devices can provide location information to better predict interference levels if sharing is allowed.

Our Work Summarized In This Presentation

- **Analysis of one specific example of real-time secondary access to determine**
  - whether it is possible.
  - whether the benefits make up for any negative impact on the license-holder and its customers.
  - This portion of the work done with Sooksan Panichpapiboon, graduate student at CMU.

- **Design and implementation of viable payment system**
  - to enable funds transfers and create indisputable transaction records.
Example Model

- Primary user
  - A GSM-based cellular carrier
  - Base station uses power control.
  - Cellular network can locate all handsets (FCC’s E911 requirement)
  - No coordination among base stations. (a conservative assumption)

- Secondary user
  - Can be any point-to-point link that requires quality of service, e.g. a broadband middle-mile or last-mile internet access.
  - Secondary devices have GPS receiver

- Admission of Cellular Calls
  - Two conditions must be satisfied to admit cellular call.
    - Signal/interference ratio (SIR) of primary call must be adequate
    - SIR of the secondary calls already underway must be adequate
  - It is often possible for a secondary device and primary device to share a spectrum band, depending on their location in the cell.
    - Algorithm that assigns frequency to new calls is important.

Further Assumptions to simplify analysis in this example

- A secondary device is stationary during the period when it is using the spectrum
- Call holding time of a secondary user is much longer than that of the cellular call
- Primary and secondary devices are stochastically uniformly distributed throughout the cell
- Call arrivals of the primaries follow a Poisson process
- Call holding time of the primaries are exponentially distributed
- A primary call can be moved from one channel to another.
Impact of Secondary Users on the Cellular Network

Load from cellular calls (Erlangs)

- 2% call blocking
- cell radius 2 km
- base station power <= 30W
- 41 200-kHz GSM channels
- Secondary devices transmit at 100 mW over 200 KHz
- SIR 15 dB required

Admitting secondary calls decreases cellular capacity, but not much.

Break-Even Price vs. Number of Secondary Calls

- Even at peak hour, cellular carrier makes a profit by charging just a third the rate of a cellular call or more.
- Break-even price insensitive to number of secondary calls, so a carrier does not need many secondary customers to break even.
Break-Even Price vs. Distance

- A carrier can offer a secondary access service inexpensively at any transmission distance
- The normalized minimum break even rate increases roughly linearly with distance, even though affected area increases with distance\(^2\) (since analysis assumed omnidirectional transmitters)

Micropayment System for Real-Time Markets

- Requirements
  - Payment system must support many license-holders of different types and many secondary users. Uniformity and scalability are important.
  - Secondary devices communicate with primary. Primary communicates with payment system. \textit{Secondary cannot communicate with payment system.}
  - Create transaction records that neither party can dispute later.
  - Low transaction costs to support micropayments.
  - Highly secure
The “PayCash” System

- **Minting electronic cash**, instead of typical centralized approach
  - Central authorizer applies $1 digital signature to base serial number to create a token worth $1.
  - Different signatures represent different denominations.
  - Authorizer applies signature $n$ times to the same base to be worth $n$.
- **Transaction**
  - Secondary device sends payment token to primary
  - Primary sends token to authorizer, which makes sure that authorizing signatures are valid, and token was not already spent.
  - Authorizer informs primary that payment is valid.
  - Strong encryption and authentication on all messages.
  - Automatically creates tamper-proof records of all transactions.

Conclusions

- **Dynamic secondary access** will increase spectrum utilization, decrease spectrum scarcity.
- **When primary is a GSM cellular carrier,**
  - A cellular carrier can profit from offering a secondary device access to spectrum even at a low price.
  - Economically viable with large or small number of secondary devices.
  - Secondary device also benefits.
- **GSM is just one example, and not necessarily the best.**
- **PayCash is an effective payment system for this purpose.**
  - Secondary devices communicate only with primary controller.
  - Same payment system works for multiple license-holders.
  - Low transaction costs.
  - Secure.
  - Tamper-proof records of all transactions to resolve any billing dispute or attempt at fraud.
- **PayCash has been implemented.** Could be used commercially for this if/when there is interest.