Carnegie Mellon

Relieving Spectrum Scarcity Through Real-Time Secondary Markets

Jon M. Peha

***Carnegie Mellon University*, Professor and**
Assoc. Director, Center for Wireless & Broadband Networks

***Cyphermint*, Chief Technical Officer**

www.jpeha.com peha@stanfordalumni.org

Carnegie Mellon

"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

Carnegie Mellon

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.***

3

Carnegie Mellon

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.**

4

Carnegie Mellon

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.

5

Carnegie Mellon

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.

6

Carnegie Mellon

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.

Carnegie Mellon

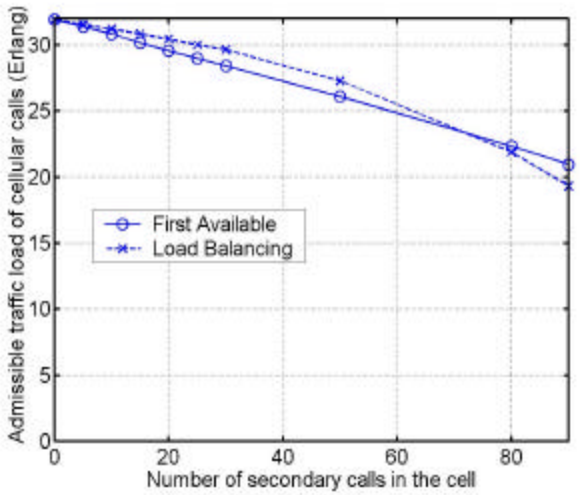
Further Assumptions to simplify analysis in this example

- **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.**

Carnegie Mellon

Impact of Secondary Users on the Cellular Network

Load from cellular calls (Erlangs)



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

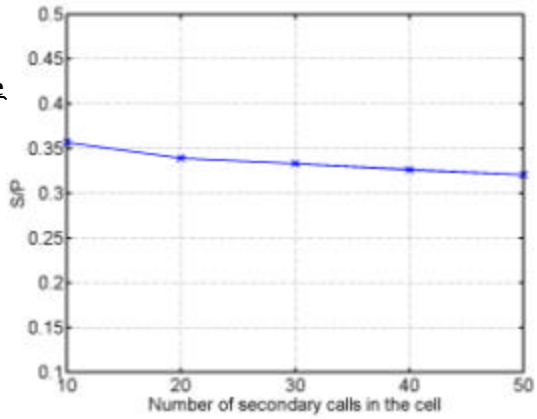
- Admitting secondary calls decreases cellular capacity, but not much.

9

Carnegie Mellon

Break-Even Price vs. Number of Secondary Calls

$\frac{\text{secondary price per minute}}{\text{primary price per minute}}$



cell radius 2 km
basestation power <= 30W
41 200-kHz GSM channels
Secondary devices transmit
at 100 mW over 200 KHz
for 500m
SIR 15 dB required

- 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

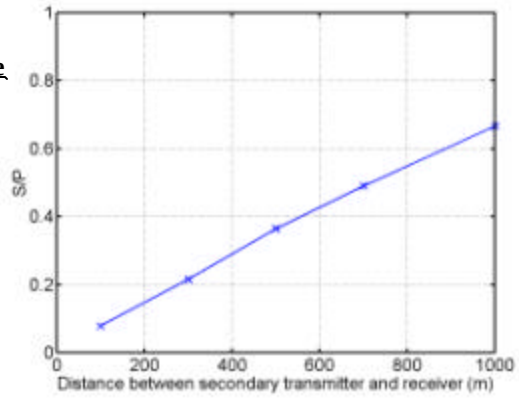
10

Carnegie Mellon

Break-Even Price vs. Distance

secondary price per minute
primary price per minute

cell radius 2 km
basestation power <= 30W
41 200-kHz GSM channels
Secondary devices transmit over 200 KHz
SIR 15 dB required



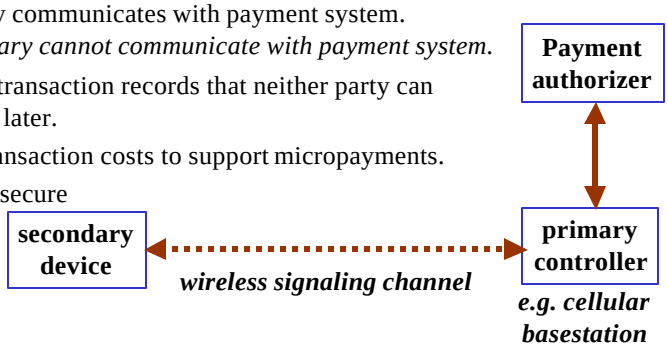
- A carrier can offer a secondary access service inexpensively at any transmission distance
- The normalized minimum break even rate increases roughly linearly with distance, even though affected area increases with distance^2 (since analysis assumed omnidirectional transmitters)

11

Carnegie Mellon

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. *Secondary cannot communicate with payment system.*
  - Create transaction records that neither party can dispute later.
  - Low transaction costs to support micropayments.
  - Highly secure



12

Carnegie Mellon

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.

Carnegie Mellon

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 on 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.**