Opportunistic Spectrum Access in Cognitive Radio Networks

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Outline

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Introduction

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  - Increasing demand
  - Limited and expensive resource (e.g. 4.7B for 22MHz)

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    - Increasing demand
    - Limited and expensive resource (e.g. 4.7B for 22MHz)
- Wasteful spectrum usage:
    - More than 70% of the licensed spectrum is under-utilized
- Cognitive radio permits the opportunistic access of secondary users to primary users' bands

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- . . .

QoS support for secondary users in a dynamically changing radio environment is very challenging!

Previews of Non-intrusive Opportunistic Spectrum Access

Non-intrusiveness:

- SU access generates insignificant interruption to PU
- PUs do not help

Major problems addressed:

- Quantification of the interruption to the PU
- Interplay between the PU behavior and the SU performance
- PHY/MAC protocol design

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Primary User Behavior

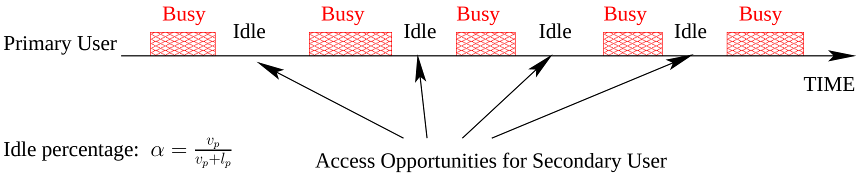
- Primary user behavior: alternating ON/OFF
- Transmits at will
- Exponential idle time distribution
- Un-slotted structure of busy-idle periods
- No synchronization between SU and PU

Average idle time: v_p

Average # of packets in a busy time: n_p

Average busy time: $l_p = n_p \cdot \Delta$

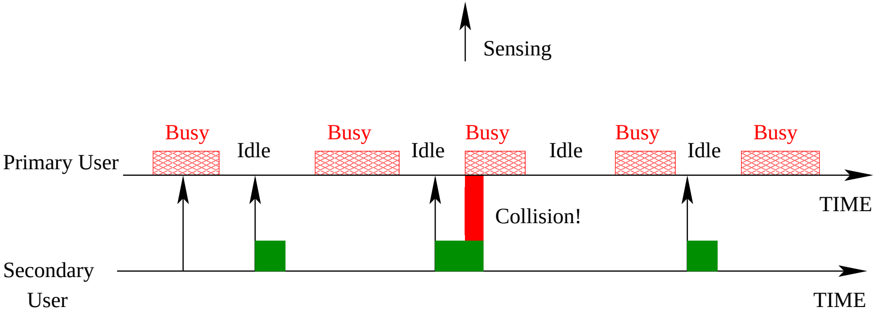
Packet Length: Δ



Idle percentage: $\alpha = \frac{v_p}{v_p + l_p}$

Secondary User Behavior

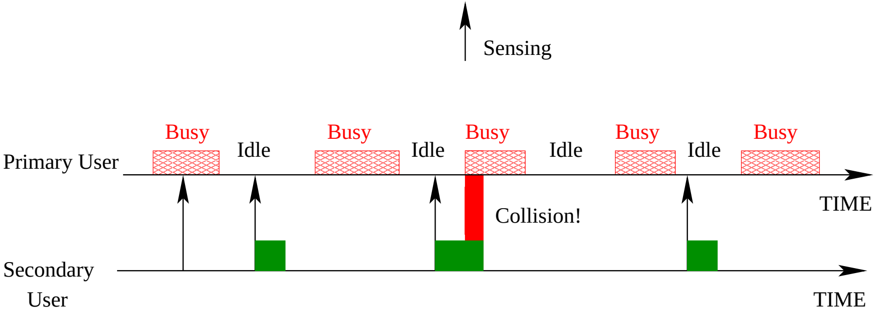
- Listen-before-talk spectrum access policy
- Spectrum sensor at SU: perfect sensing
- Knowledge about average idle/busy time
- Always has packets to send



Protection Metrics for the PU

Packet collision probability:

$$p_p^c = \lim_{T \to \infty} \frac{\text{\# of PU's collided packets in [0,T]}}{\text{\# of packets sent by PU in [0,T]}}$$



Performance Metric for the SU and Problem Formulation

Throughput: Percentage of successful transmission time

$$C_s = \lim_{T \to \infty} \frac{\text{Successful Xmission Time of SU in } [0, T]}{T}.$$

Constrained Optimization Problem:

$$\begin{aligned} &\text{maximize}\{C_s\} \\ &\text{subject to} \\ &p_p^c \leq \eta \end{aligned}$$

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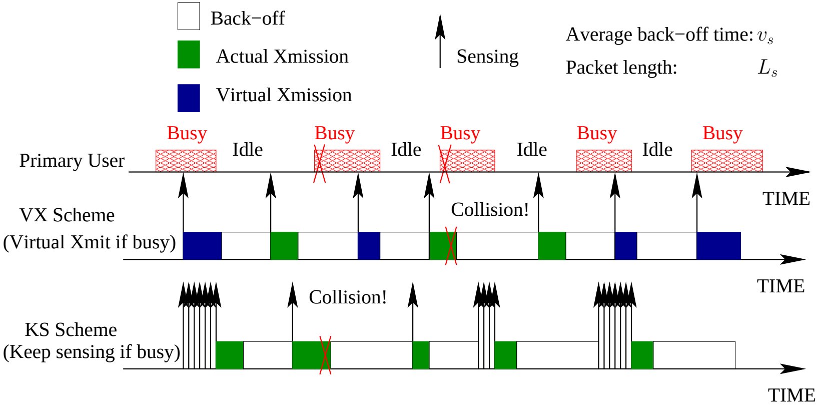
Spectrum Access Schemes: VX and KS



Design variables: v_s, $f_{L_s}(\cdot)$.

Throughput Performance for VX Scheme

Closed-form expressions ($n_p = 1$):

- General distribution: $f_{L_s}(\cdot)$:

$$C_s^{max} = \eta \cdot \alpha \cdot \frac{\int_0^\infty \frac{\tau}{v_p} e^{-\frac{\tau}{v_p}} f_{L_s}(\tau) d\tau}{\int_0^\infty (1 - e^{-\frac{\tau}{v_p}}) f_{L_s}(\tau) d\tau}.$$

- Fixed L_s:

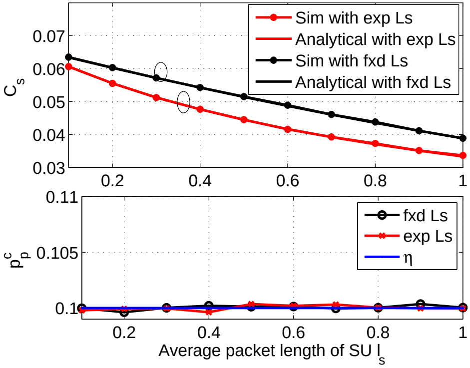
$$C_s^{max} = \eta \cdot \alpha \cdot \frac{l_s e^{-l_s/v_p}}{v_p(1 - e^{-l_s/v_p})}; \qquad p_p^c = (1 - e^{-\frac{l_s}{v_p}}) \frac{v_p}{v_s + l_s}$$

- Exponential L_s:

$$C_s^{max} = \eta \cdot \alpha \cdot \frac{v_p}{l_s + v_p}; \qquad p_p^c = \frac{v_p}{v_s + l_s} \cdot \frac{l_s}{l_s + v_p}$$

Observations for VX scheme

- Smaller packet length: larger throughput
- Optimal packet length: overhead
- Fixed length packet: achieves better performance (actually the best)



$$v_p = 1,\ \Delta = 0.5, n_p = 1,\ \eta = 0.1$$

Throughput Limit for VX scheme

Proposition

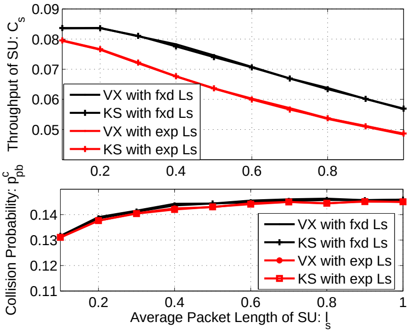
For a primary band of which the idle time V_p obeys the exponential distribution, suppose that the probability of channel being idle as α, under the collision probability constraint η, the achievable throughput of the SU with VX scheme is upper bounded:

$$C_s \leq n_p \cdot \eta \cdot \alpha.$$

- $0 < n_p \eta < 1$
- $n_p \eta \to 0$, $C_s \to 0$
- Deterministic idle time: $C_s \to \alpha$

Comparison between VX and KS schemes

Parameters: $v_p = 1$, $\Delta = 0.5$, $\alpha = 0.67$, $n_p = 1$
VX and KS schemes: indistinguishable throughput performance.



Conjecture: throughput limit for exponential idle time: $n_p \cdot \eta \cdot \alpha$.

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Assumptions

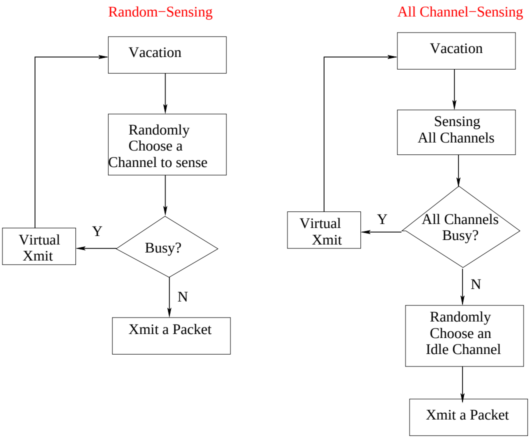
- No synchronization between SUs and PUs
- Homogeneous primary bands: same constraint, same channel statistics
- Perfect sensing: no collision among SUs
- Each SU uses VX scheme with the same parameters
- M SUs, N bands

Result: Multiple SU, One Band

- Closed-form expression for relationship between p_p^c and M, v_s, and l_s when $n_p = 1$
- Closed-form expression for aggregated C_s

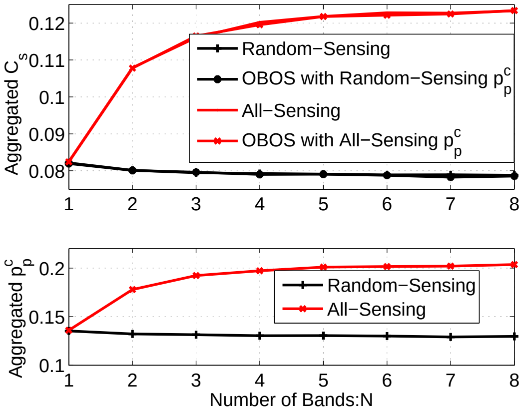
Multiple SUs, Multiple Primary Bands

Two sensing strategies:



Simulation Result for Multi-SU Multi-band Systems

- Simulation setting: $M = 3N$
- Sensing all bands: does not improve the total throughput.



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Conclusions

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- Throughput: limited by the collision probability constraint, n_p, and idle percentage of primary band
- Protection constraint: trade-off between protection and throughput
- Similar characteristics in multi-band systems

Extensions:

- Non-exponential idle time distribution
- Impacts of imperfect sensing

Results

- Optimal transmission policy for generic idle time distribution: a threshold-based strategy
- Exponential idle time distribution: one of the worst
- Random access schemes: achieve $n_p \cdot \eta \cdot \alpha$
- Imperfect sensing: degrades throughput performance
- Optimal operating point for spectrum sensor