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# Addressing the Hidden Incumbent Problem in 802.22 Networks

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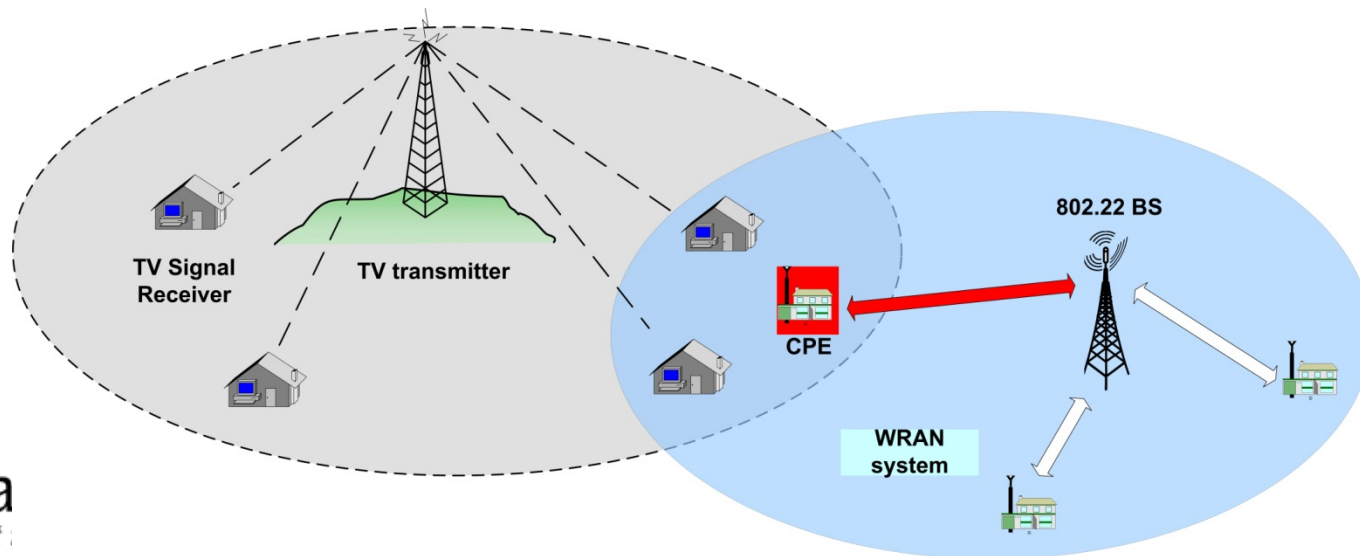
# Outline

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- Hidden Incumbent Problem
- Explicit Outband Signal Scheme
- A New Hidden Incumbent Detection Protocol
- Comparisons
- Conclusions

# Hidden Incumbent Problem

- Incumbent coexistence in 802.22 networks
  - Incumbent users: TV transmitter and TV signal receivers
  - Secondary users: 802.22 Base Station (BS) and Consumer Premise Equipments (CPEs)
- Hidden incumbent problem
  - A CPE within the protection region of an operating incumbent fails to report the existence of the incumbent; the BS transmits in the incumbent's band.
  - The CPE cannot decode signals of the BS; the BS's transmission will interfere with incumbent receiver.





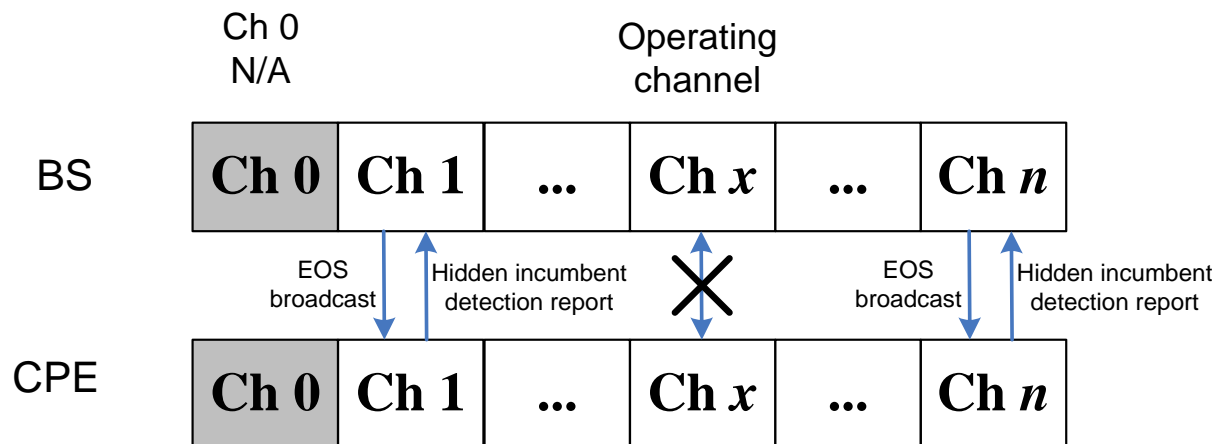
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# Explicit Outband Signal (EoS) Scheme

- The *candidate channel set* for an 802.22 entity: the set of *all* channels that are free of incumbent signals based on its local spectrum sensing results.
- Suppose that channel *X* between a BS and a CPE is unavailable
  - The BS broadcasts EoS on its candidate channels.
  - The CPE searches for EoS on its candidate channels.
  - If EoS is found by the CPE on channel *Y*, it will send hidden incumbent detection report to the BS via channel *Y*.



# Problems with Explicit Outband Signal

- EoS scheme

- BS has to broadcast EoS on its candidate channels (i.e., *all* channels free of incumbent signals).
- CPE has to search for EoS on its candidate channels (i.e., *all* channels free of incumbent signals).
- CPE is able to discover the BS's EoS on the *common* channels (i.e., intersection of the two candidate channel sets).

- Our objective is to reduce control overhead

- Number of channels in the candidate channel set can be reduced to reduce control overhead
- Need to guarantee that there is at least one *common* channel.



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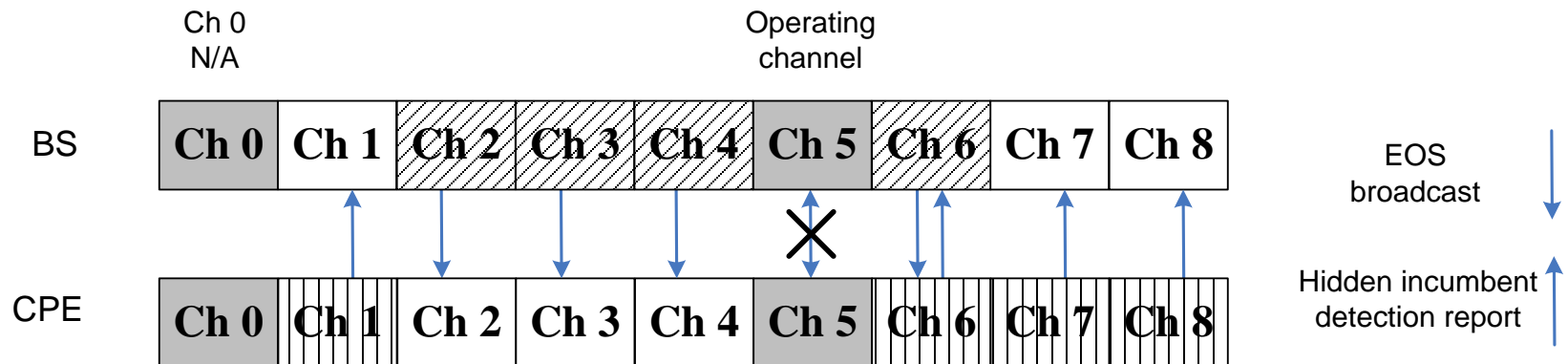
# The Quorum System

- **Main idea**: construct candidate channel sets using the quorum system
- A quorum system is a set of quorums.
  - Each quorum is a subset of a finite universal set,  $U = \{0, 1, \dots, n-1\}$ .
  - *Intersection property*: two quorums in a quorum system must have at least one common element.
  - Ex.  $Q = \{\{0, 1\}, \{1, 2\}, \{0, 2\}\}$  is a *majority* quorum system under  $U = \{0, 1, 2\}$ .
- The candidate channel set of a BS and the candidate channel set of a CPE must have a common channel
- → A quorum system in which two quorums have a non-empty intersection

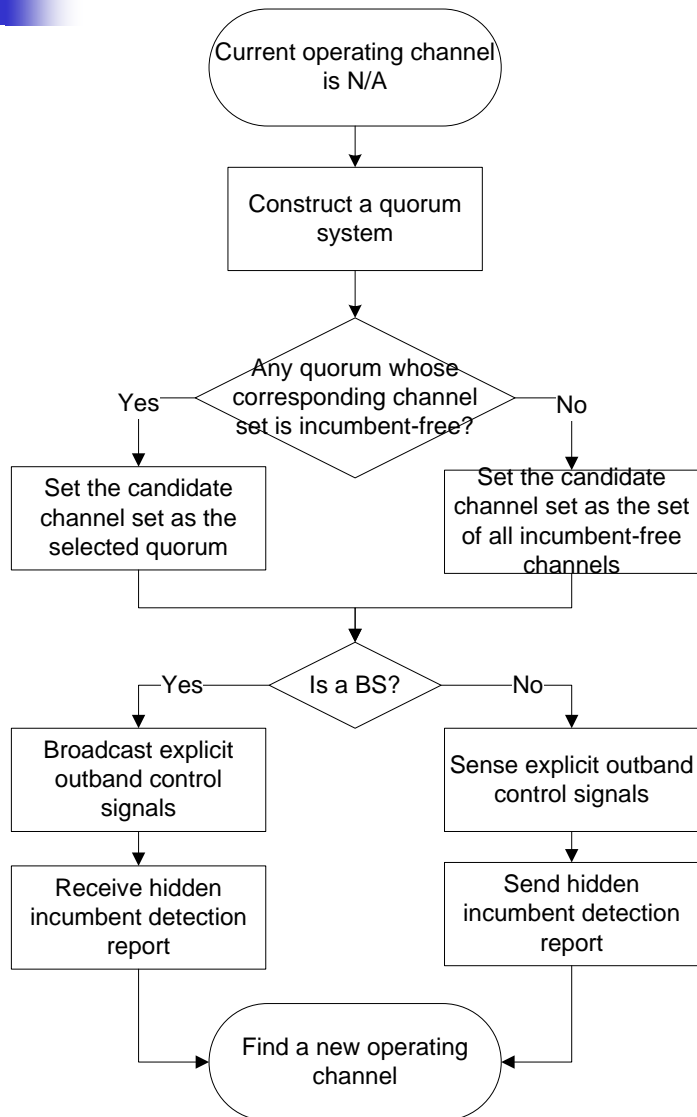


# The HID Protocol Based on A Cyclic Quorum System

- Given 9 channels, construct a quorum systems over  $\mathbf{Z}_9 = \{0, 1, \dots, 8\}$ .
  - $S = \{\{0,1,2,4\}, \{1,2,3,5\}, \{2,3,4,6\}, \{3,4,5,7\}, \{4,5,6,8\}, \{5,6,7,0\}, \{6,7,8,1\}, \{7,8,0,2\}, \{8,0,1,3\}\}$ .
  - The BS picks the quorum  $p = \{2,3,4,6\}$  as its candidate channel set.
  - The CPE picks the quorum  $q = \{6,7,8,1\}$  as its candidate channel set.
  - The BS and the CPE perform a two-way handshake on their common channel, viz Ch6, which is selected as the new operating channel.



# The Process of the HID Protocol



- Construct a quorum system
- Select a candidate channel set by picking a quorum
  - Broadcast EoS
  - Search for EoS
- Handshake on a new common channel
  - Tx/Rx hidden incumbent report
- Find a new operating channel



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# Comparisons

- Total of  $n$  available channels; the common operating channel  $X$  between a BS and a CPE is unavailable due to incumbent signals.
- EoS scheme
  - The BS broadcasts on  $(n-1)$  candidate channels.
  - The CPE scans for EoS on  $(n-1)$  candidate channels.
- HID protocol with a majority quorum system
  - The BS broadcasts on  $(n+1)/2$  candidate channels.
  - The CPE scans for EoS on  $(n+1)/2$  candidate channels.
- HID protocol with a cyclic quorum system
  - The BS broadcasts on  $\sqrt{n}$  candidate channels.
  - The CPE scans for EoS on  $\sqrt{n}$  candidate channels.



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## Conclusions

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- We proposed a quorum-based approach for constructing the candidate channel sets used for hidden incumbent detection in 802.22 networks.
  - The size of the candidate channel sets is reduced while ensuring a non-empty intersection between the two sets.
  - Size of the candidate channel sets depends on the type of quorum system used.
  - The control overhead in the 802.22 network is reduced.

Questions?

Thank you ☺