Effective Carrier Sensing in CSMA Networks under Cumulative Interference

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Introduction

- Broadcast nature of wireless media → interference
- Interference-safe (collision free) transmission
- CSMA protocol: coordinate with carrier sensing
  - Sense before transmit

- Operate interference-safe transmissions in CSMA networks?
Overview

- Requirement of Interference Safe in CSMA Network
  - Real Interference in Practice: Cumulative interference
  - safe carrier-sensing range

- Implementation: IPCS
  - Incremental-Power Carrier Sense
  - Incremental Power range concept

- IPCS can improve spatial reuse and network throughput
Safe carrier-sensing range

- Under pair-wise interference model [1]
  - The interferences are considered one by one
  - No collision between any pair \( \Rightarrow \) No collision overall
  - Safe carrier sensing range requirement

\[
\text{Safe} - \text{CSR}_{\text{pairwise}} = (\gamma^\alpha + 2)d_{\text{max}}
\]

- For example, if \( \gamma = 8 \) and \( \alpha = 3 \),
then \( \text{Safe} - \text{CSR}_{\text{pairwise}} = 4d_{\text{max}} \)

Safe carrier-sensing range

- However, in practice
  - Interference is cumulative
  - $\textit{Safe - CSR}_{\text{pairwise}} = (\gamma^\alpha + 2)d_{\text{max}}$ is too optimistic

\[
\begin{align*}
\gamma &= 8, \quad \alpha = 3, \\
\text{Safe - CSR}_{\text{pairwise}} &= 4d_{\text{max}}
\end{align*}
\]

- Not sufficient to prevent collisions under cumulative interference

\[
\text{SIR}(R_1) = \frac{P_t(d_{\text{max}})^{-5}}{P_t(6d_{\text{max}})^{-5} + P_t(2d_{\text{max}})^{-5}} = 7.714 < \gamma
\]
Under cumulative interference model

- **Theorem:** Setting the carrier sensing range as
  \[ Safe - CSR_{\text{cumulative}} = (K + 2)d_{\text{max}}, \text{ where } K = \left( 6\gamma \left( 1 + \left( \frac{2}{\sqrt{3}} \right)^{\alpha} \frac{1}{\alpha - 2} \right) \right)^{\frac{1}{\alpha}} \]
  is sufficient to ensure interference-safe transmissions in CSMA networks under cumulative interference model.
  - Worst-case interference in an infinite large network
  - The safe carrier sensing range need to be increased
  \[ \gamma = 8 \quad \alpha = 3, \]

- **Not amendable with current carrier sensing in 802.11**
  - Detect a power \( P^{CS} \) compare with a power threshold \( P_{th} \)
  - \( P^{CS} \) is an absolute power: consists of the sum total powers
  - Does not contain enough information for all the required distances

\[ \begin{align*}
& Safe - CSR_{\text{pairwise}} = 4d_{\text{max}} \\
& Safe - CSR_{\text{cumulative}} = 6.96d_{\text{max}}
\end{align*} \]
Implementation: IPCS

- **IPCS (Incremental-Power Carrier Sense)**
  - The detected power is a function of time
  - Key idea: incremental power ↔ required distance information
  - Check every increment with a power threshold $P_{CS}(t)$
  - Separate the interference one by one
  - Interference safe:
    \[ P_{th} = P_t \cdot (Safe - CSR_{cumulative})^{-\alpha} \]
Comparison

- **current carrier sensing in 802.11 v.s. IPCS**
  - Absolute power v.s. incremental power
  - Current carrier sensing reduces spatial reuse
    - The location of the third concurrent link

**Current CS**

\[
P_{CS}(T_i) = P_i d(T_i, T_i)^{-\alpha} + P_{th} d(T_i, T_i)^{-\alpha}
\]

\[
= 2P_{th} d(T_i, T_i)^{-\alpha} \leq P_{th}
\]

\[\rightarrow l_3\]

**IPCS**

\[
\Delta P_{CS}^1(t_1) = P_i \cdot d(T_i', T_i)^{-\alpha} \leq P_{th}
\]

\[
\Delta P_{CS}^2(t_2) = P_i \cdot d(T_2, T_2)^{-\alpha} \leq P_{th}
\]

\[\rightarrow l_3'\]

The separation between transmitters increases progressively.

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Conclusion

- Propose the concept of the safe carrier sensing range under the cumulative interference model
- Propose a new carrier sensing mechanism, IPCS, to implement accurately
- IPCS is the bridge between theoretical analysis and the real protocol in practice
- IPCS can improve spatial reuse and network throughput.

<table>
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<th>Interference Models</th>
<th>Pairwise Interference Model</th>
<th>Cumulative Interference Model</th>
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<tbody>
<tr>
<td>Absolute power carrier sensing</td>
<td>many (e.g., [8], [10])</td>
<td>[15], [16]</td>
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<tr>
<td>Incremental power carrier sensing</td>
<td>This paper</td>
<td>This paper</td>
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Thanks!