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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?

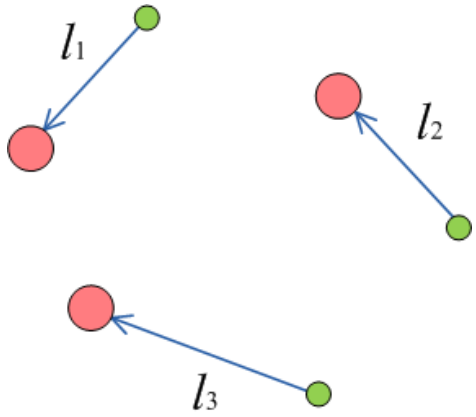
Overview

- 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 ⟹ No collision overall
  - Safe carrier sensing range requirement

$$Safe - CSR_{pairwise} = (\gamma^{\frac{1}{\alpha}} + 2)d_{\max}$$



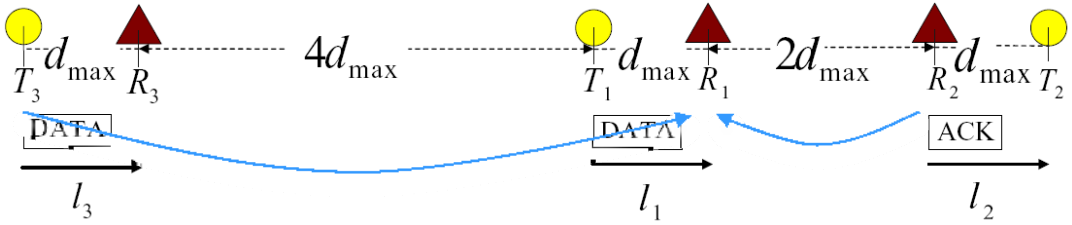
    - For example, if $\gamma = 8$ and $\alpha = 3$,

      then $Safe - CSR_{pairwise} = 4d_{\max}$

[1] L.B. Jiang and S.C. Liew, "Hidden-node Removal and Its Application in Cellular WiFi Networks" IEEE Trans. Veh. Technol. Vol. 56. no. 5, Sep. 2007

Safe carrier-sensing range

- However, in practice
  - Interference is cumulative
  - $Safe-CSR_{pairwise}=(\gamma^{\frac{1}{\alpha}}+2)d_{\max}$ is too optimistic



$$\begin{cases}\gamma=8,\ \ \alpha=3\\ Safe-CSR_{pairwise}=4d_{\max}\end{cases}$$

$$\mathrm{SIR}(R_1)=\frac{P_t\left(d_{\max}\right)^{-3}}{P_t\left(6d_{\max}\right)^{-3}+P_t\left(2d_{\max}\right)^{-3}}=7.714<\gamma$$

  - Not sufficient to prevent collisions under cumulative interference

Under cumulative interference model

- Theorem: Setting the carrier sensing range as $Safe - CSR_{cumulative} = (K+2)d_{\max}$, 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

$\gamma = 8 \quad \alpha = 3,$

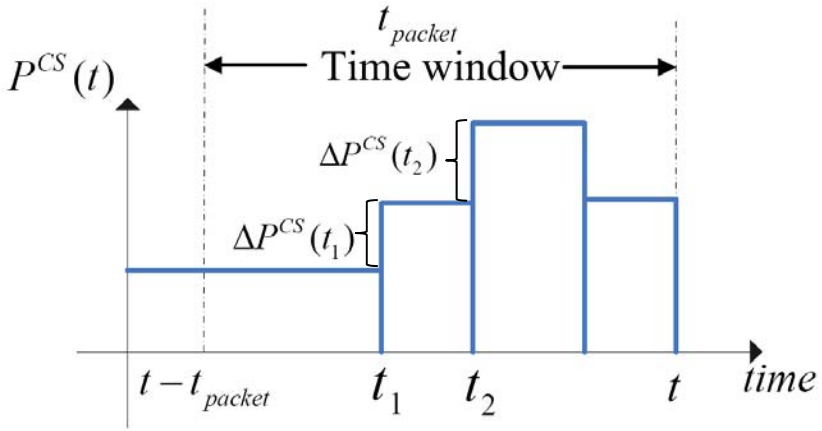
$$\begin{cases} Safe - CSR_{pairwise} = 4d_{\max} \\ Safe - CSR_{cumulative} = 6.96d_{\max} \end{cases}$$

- 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

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 :

$$P_{th} = P_t \cdot \left(Safe - CSR_{cumulative} \right)^{-\alpha}$$



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

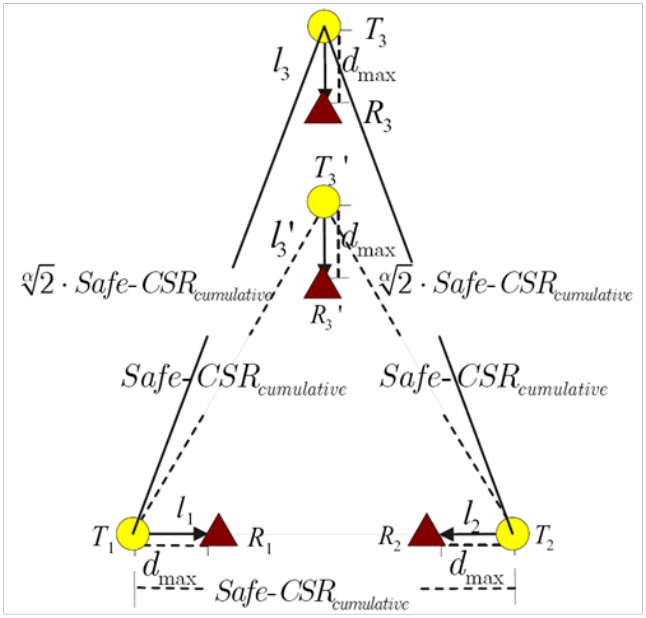
$$P^{CS}(T_3) = P_t d(T_3,T_1)^{-\alpha} + P_t d(T_3,T_2)^{-\alpha} = 2P_t d(T_3,T_1)^{-\alpha} \le P_{th}$$

$\Rightarrow l_3$

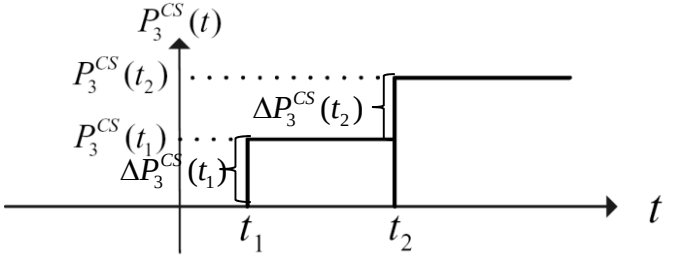
IPCS

$$\begin{cases} \Delta P_3^{CS}(t_1) = P_t \cdot d(T_3',T_1)^{-\alpha} \le P_{th} \\ \Delta P_3^{CS}(t_2) = P_t \cdot d(T_3',T_2)^{-\alpha} \le P_{th} \end{cases}$$

$\Rightarrow l_3'$

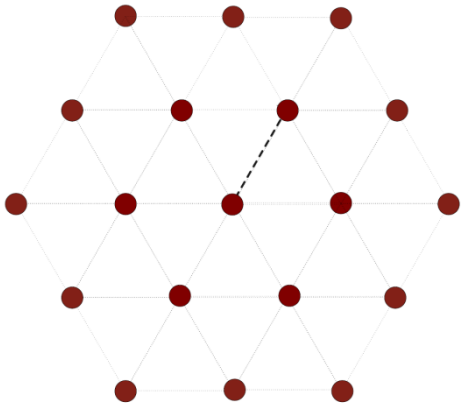


The separation between transmitters increases progressively

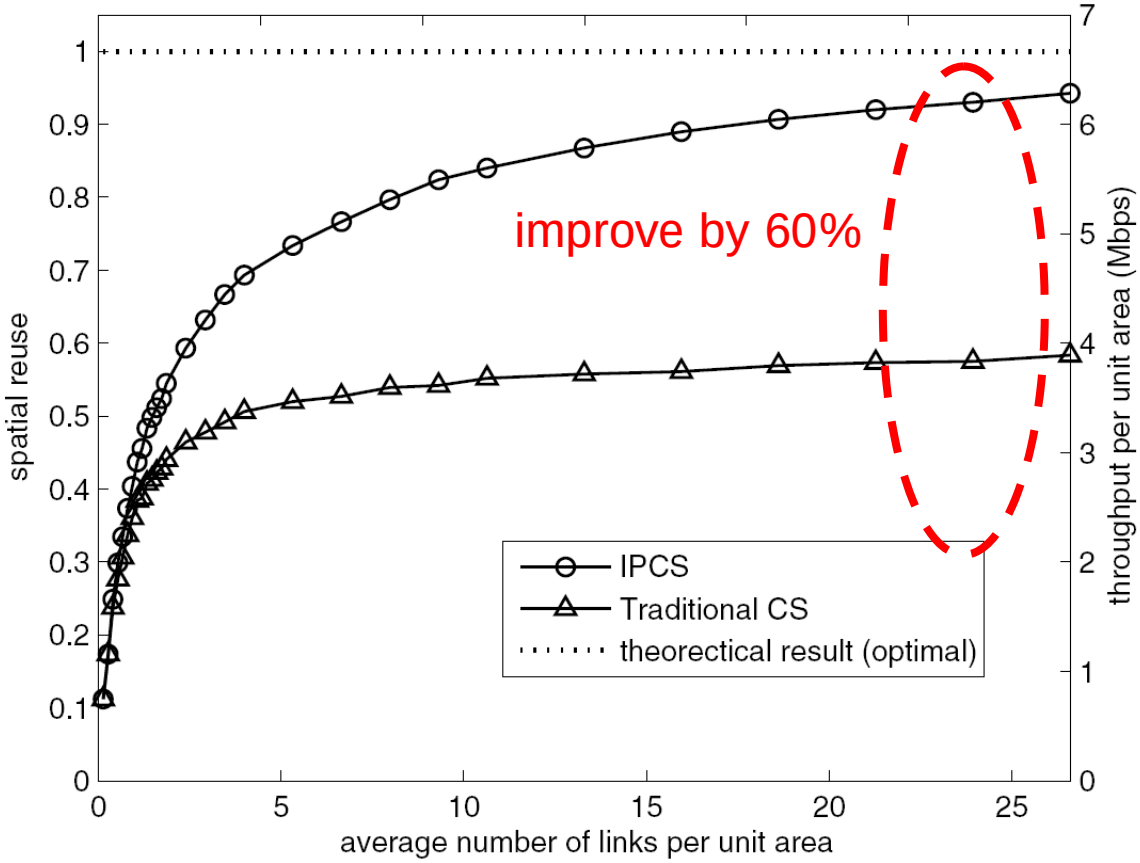


Throughput Improvement

Ideal packing of transmitters:



unit area: $\frac{\sqrt{3}}{2}\left(Safe - CSR_{cumulative}\right)^2$



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.

Interference Models	Pairwise Interference Model	Cumulative Interference Model
Absolute power carrier sensing	many (e.g., [8], [10])	[15], [16]
Incremental power carrier sensing	**This paper**	**This paper**

Thanks!