In defense of Wireless Carrier Sense

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Wireless medium is *semi*-shared

- Sometimes networks are largely independent
  - Can transmit concurrently: “spatial reuse” of medium

- Sometimes they are in conflict
  - Throughput will be nearly zero under concurrent transmission; should time-multiplex

- Someone must make the decision. How?
Solution: Carrier sense?

- **Mechanism: Interferer power vs. threshold**
  - Defer transmissions when competing packets above threshold
  - Transmit freely when below
  - Used by MACs to answer “Can I talk now?”,
- **Strikes balance between interference protection and spatial reuse**
  - Attempts to use spectrum efficiently while preserving fairness
- **Simple – and simple is good!**
Reasons to be suspicious...

• Wrong measurement!
  – Power at *receivers* is what matters [Karn ’90]
• Classic example: “hidden terminal”

• How can this make sense?
Life’s not so simple, either

Desired result: concurrency

Desired result: time-multiplexing

Desired result: ???
Our question: How well does CS work?

• Are collisions and horrible failures the right way to think about carrier sense?
• How common are mistakes? (sub-optimal decisions)
• How much do they cost in throughput?
• How does carrier sense compare to “optimal”?  
  – Key metric: Mean expected throughput  
  – Also, starvation and similar misbehavior?
• (Also, might things have changed since earlier work?)
Why CS might work: Limiting cases

• “Far” interference:
  – Small distance variation: $\Delta r_1 \approx \Delta r_2$

• “Near” interference:
  – Nobody wants concurrency; $\text{SINR}_{\text{concurrent}} \ll \text{SNR}_{\text{multiplexing}}$

• In both cases, all receivers agree on preferring either multiplexing or concurrency
  – “Agreement” means CS can perform well
• Intermediate distance will be the hard case
• Also, shadows and obstacles?
Let's explore with a simple model

• Simplifications & limitations
  – Only two contending transmitters
  – Transmitters have same power, omni antennas
  – Focus on fundamentals, rather than on a particular implementation
    • No framing, ACKs, slotting, etc.
    • Not modeling capture effects

• Building blocks: Network layout + radio propagation + estimated throughput

• Output: Predictions for average throughput under concurrency, multiplexing, carrier sense, and optimal
Model: layout and averaging

• Place senders at fixed locations
• Assume receivers uniformly distributed within some $R_{\text{max}}$
• Compute mean throughput over both sets of receivers ($S_1$’s & $S_2$’s)
• Will investigate effect of varying sender-sender distance $D$, given an $R_{\text{max}}$
Model: radio propagation

Standard textbook model (e.g. Akaiwa ‘97):

• Path loss: $r^{-\alpha}$
• Environmental shadowing: $\pm \sigma$ dB
• Multipath fading: Rayleigh variation
  - Wideband channels average this away (mostly)
Model: throughput

• Need a way to model throughput as a function of SINR (Signal to Interference + Noise Ratio)
• Adaptive bitrate (ABR) is pervasive nowadays
  – And will turn out to be crucial
• Shannon capacity is a half-decent approximation model for ABR (with nice analytical properties)
  – Capacity / Bandwidth(Hz) ≈ log(1 + SINR)
What we’re going to look at

• First, for individual receiver configurations, which choice gives better throughput, concurrency or multiplexing?

• Next, average throughput across the ensemble of different possible receiver configurations
  – Compare CS to concurrency, multiplexing, optimal

• Finally, vary $R_{\text{max}}$ (network size) to show that good efficiency holds across the space of possibilities
A first look: individual receivers

D = 55

- Prefers concurrency
- Prefers multiplexing
- Starved w/o multiplexing
In detail...

Receiver preference vs. position:

- Excellent agreement on multiplexing
- Disagreement??
- Excellent agreement on concurrency

- D = 20
- D = 55
- D = 120

- Prefers concurrency
- Prefers multiplexing
- Starved w/o multiplexing
ABR prevents disaster!

• Intermediate distance can mean poor agreement! But...
• Does “mistaken” multiplexing mean 50%-reduced throughput? No. Adapts with higher bitrate.
• “Exposed” and “hidden” terminals are not very useful concepts with ABR
Obstacles aren’t fatal

• Most obstacles are not opaque!
• Most configurations have alternate propagation paths
• ±4dB - 12dB variation from path loss is typical
  – (See e.g. COST 231 and other model reviews)
• If shadowing were much greater, CS would be no better than random. But it’s not.
• (ABR also helps here)
Average throughput: CS works!

Inefficiency is small

\( (R_{\text{max}} = 55) \)
The larger parameter space

- Of course, one example isn’t enough
- Need to explore full relevant span of parameters
  - Fortunately, interferer distance and network size capture most of the important features

Fraction of optimal throughput vs. D and $R_{\text{max}}$

- Long range is worse overall
- Intermediate interferer distance is less efficient
- Throughput efficiency is always good
Intuitions summary

• Distant interferers affect receivers uniformly
  – Short range networks switch to multiplexing while interferer still distant

• Nearby interferers don’t – but they’re loud so everybody prefers multiplexing anyway

• So long as most receivers agree, CS performs well

• Rate adaptation smoothes rough edges in between

• Shadowing matters but isn’t big enough to drown out distance
Experiments (brief)

• Experimental hypothesis: We’re not crazy
• Result: We aren’t!
  – Carrier sense mean throughput is close to optimal
  – Short range is excellent
  – Long range is OK
• 802.11a testbed, random pairs of sender-receiver pairs
• Broadcast packets for 15 seconds, try different bitrates, measure throughput under concurrency and multiplexing
• Short range and long range scenarios
One experiment: short range
Implications for future research

• Don’t forget bitrate!
  – Much work critical of carrier sense doesn’t consider ABR
    and so for ABR hardware is pessimistic about CS and
    optimistic about claimed gains

• Hidden terminals can be a reliability problem but aren’t
  common and don’t matter much for average
  performance
  – “Expensive” solutions like RTS/CTS wouldn’t hurt
    throughput if they were only used when needed

• Exposed terminals cost these kinds of networks very
  little, given ABR

• (Paper argues these three points in more detail)
Conclusions

• Carrier sense *does* work, in a large, important class of networks
  – See paper for discussion of other issues like threshold robustness

• Room for improvement in corner cases, but not much in overall performance

• A fresh look at modeling can help us balance out the idiosyncrasies in experimental wireless work