Distributed Coordination with Deaf Neighbors: Efficient Medium Access for 60 GHz Mesh Networks

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The 60 GHz millimeter (mm) wave band

• Unlicensed short range transmissions
• Oxygen absorption band (~ 16dB/Km)
• Low-cost mm wave transceivers feasible

A lot going on in industry

WiGig Alliance, WirelessHD, IEEE 802.15.3c, IEEE 802.11ad, ECMA
60 GHz outdoor mesh networks
Mm wave communication is fundamentally different!

- Omnidirectional links are not an option
  - Path loss, power, transceiver complexity

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\frac{P_r}{P_t} \propto \frac{1}{f^2}
\]
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• Directional transmission and reception essential
  – Highly directional circuit board antenna arrays are feasible

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Mm wave links are inherently directional

=> new challenges in system design!
Link budget

- 2 Gbps (QPSK)
- 100 m
- Tx power: 10dBm
- Bandwidth: 1.5 GHz
- SNR: 15 dB
- Oxygen absorption: 15 dB/Km
- Noise figure: 6 dB
- Link margin: 10 dB
“Omni-steerable” directional mesh nodes

- 2.4 GHz Wi-Fi antenna
  - D = 5dBi
  - ~15cm

- Circular array antenna for a 60 GHz mesh network
  - D = 30dBi
  - ~15cm
  - <10°

Reconfigurable circular array
- Total 10 angular slots; 5 slots installed
What about medium access control?

• No *omnidirectional* mode
What about medium access control?

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• Can no longer rely on carrier sensing (*deafness*)
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• What about interference?
  
  – *wire-like* characteristics [1]

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• What about interference?
  
  – *wire-like* characteristics [1]

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MAC challenge: transmit-receive coordination in a deaf network

Memory-guided Directional MAC (MDMAC)

- Implicit coordination via *persistence* on successful Tx/Rx slots
  - Unsuccessful slots on a *per-neighbor blacklist*
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MDMAC – key idea

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Frame 1

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<tr>
<td>C</td>
<td></td>
<td></td>
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Failed transmission
Successful tx/rx
Blacklisted slot
MDMAC – key idea

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Overall schedule evolution
A naive approach
A naive approach
A naive approach

SUCCESS!

B C

SUCCESS!
A naive approach
A naive approach

Node A gets locked out!
Starvation with a naive approach

How to avoid locking into undesirable schedules?
Probabilistic state reset
Probabilistic state reset
Probabilistic state reset

- Randomization of persistence and blacklist lifetimes

Probabilistic state reset avoids locking into undesirable schedules
Explicit state reset

Total committed slots > T% => state reset for neighbor with highest share of resources
Explicit state reset
Explicit state reset

- Randomization of persistence and blacklist lifetimes
- Leave *enough room* in the schedules

Explicit state reset facilitates quick adaptation to changing demands
Effect of parameter choices

- Markov chain fixed point analysis for an outgoing link
- Understand the effect of persistence and blocked slot lifetimes, listening probability $p_I$
Effect of parameter choices

- Markov chain fixed point analysis for an outgoing link
- Understand the effect of persistence and blocked slot lifetimes, listening probability $p_l$

State diagram for an outgoing link

$$P = F(P)$$

- Iterative algorithm to find steady state probabilities
Effect of parameter choices

- **2-node case**

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• 4 neighbors per node

Average state lifetimes: throughput loss from churn versus dynamic schedule adaptability
Listening probability: performance relatively insensitive within a range
MDMAC performance: saturated traffic

Aggregate network throughput

MDMAC: higher throughput than Directional Slotted Aloha, comparable to Greedy Maximal Scheduling
Missed transmit opportunities

MDMAC schedules within 7% of the corresponding largest cardinality maximal matchings
Mesh network multihop traffic model

MDMAC: higher throughput, lower delay and jitter than DSA
Adapting to changes in traffic

MDMAC facilitates quick adaptation to changing traffic demands
Summary

• 60 GHz mesh networks: need for a novel design approach
  – Pseudo-wired link abstraction
  – MAC focus on coordination rather than interference management

• Memory-guided Directional MAC
  – TDM-like schedules in a deaf network by using memory
  – Random *churn* for quick schedule adaptation
  – Exploits interference reduction, deals with deafness

• A lot more to do!
  – Lightweight protocols for synchronization, network discovery
  – Omni coverage yet highly directional nodes: hardware challenges
  – Channel modeling: effect of reflections and obstacles
  – Routing, congestion control, ...
Thank you

For further information

Visit: http://www.ece.ucsb.edu/wcsl/mmwcsresearch/

Sumit Singh
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Related publications:


MAC level fairness

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<tr>
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<tr>
<td>MDMAC</td>
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<td>0.88</td>
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<tr>
<td>DSA</td>
<td>0.39</td>
<td>0.20</td>
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MAC fairness index

MDMAC has good MAC level fairness properties