Revising Buffering in Multihop CSMA/CA Wireless Networks

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Outline

• Introduction
• Related Works
• Model
• The Current Situations
• Proposed Scheme
• Solutions to Congestion
• Possible Extensions
• Conclusions
Introduction

• Multihop wireless networks can provide
  – Small amount of data in an energy efficient way
  – Broadband services

• IEEE 802.11 is the leading protocol for broadband ad hoc networks
  – Poor throughput over multiple hops is provided

• The disappointing throughput is caused by
  – Fundamental limitation due to spatial reuse

• The measured throughput is still much smaller than the theoretical value
  – Additional loss is due to a poor coordination between transmissions
Introduction

• Congestion problem
  – Nodes compete with each other for transmission

• Two solutions
  – Centralized scheduling
    • Unpredictable results when control messages are delayed or lost
  – Multiple wireless interfaces
    • Interferences between interfaces impact throughput and are evidenced in prior studies

• This study considers a single multihop path and focus on buffering and packet dynamics to solve the congestion problem
Related Works

• Many works have been developed for mesh networks to maximize spatial reuse of channel assignment
  – Optimal centralized assignment has been shown to be a NP hard problem

• Interactions between TCP and MAC layer in multihop can increase throughput
  – Optimal the TCP window size
  – Adaptive MAC protocols

• The goal of this study is to maximize throughput using completely decentralized MAC protocol
  – Resolve the contentions between neighboring nodes locally
Model

- This study considers the route across a multihop wireless networks

- Node 0 : the source node
- Node N : the destination
- Node 1 ~ N-1 : the intermediate node
Model

- $L$: smallest integer such that $|i-j| \geq L$
  (Link $i$ does not interfere with link $j$)

- This model has only $1/L$ throughput of the multihop route
The Current Situations

• Potential waste of bandwidth due to buffer overflow
  – Buffer overflow => Drop packet => Waste resource

• Some observations are noted
  – Throughput decreases when network starts to drop packets
  – Increasing the buffer size does not increase asymptotic throughput
  – End-to-End delay increases if buffer size is enlarged
Observation 1 – Throughput and Delay Performance

The lost of throughput is not due to undersized buffers
Observation 2 –
Average Occupancy of Buffer

Team up with node 3

Team effect with node 0
Proposed Scheme

• Two rules
  – R1: Incoming data transmission are not accepted by the nodes if their buffers are already full
  – R2: Relay nodes’ buffers may contain no more than one packet

• The second rule is to keep delay in short
• Using small buffers will not lead to any additional packet drop
Proposed Scheme

• Packet/hole duality
  – Because of R1 and R2, a transmission can only take place between
    • A node that has one packet in its buffer
    • A node that has no packet
  – Packet swapping is implying Hole swapping between the source and destination nodes
Proposed Scheme

• Throughput and Congestion
  – The network behaves like a pipe with single buffer at its entrance because all the buffering is done at the source node
    • The configuration is particularly suitable for TCP
Proposed Scheme

• The throughput is still far from the optimal throughput of $1/L$
  – Transmission interfere with each other when packets are close from each other

• Traffic jam problem
Proposed Scheme

Average buffer occupancy for a protocol complying with R1 and R2 and interference parameter $L = 3$
Solutions to Congestion

- Constant packet size
  - Setting the size of all MAC data frames to the same value can establish a well coordinated behavior
    - All the transmission in the network synchronized
    - Slotted protocol

The evolution of the link activity vector with constant packet size
Solutions to Congestion

• Saturated mode (source rate > \(1/L\))
  – \(B(n)\), status of node \(n\), is a discrete time Markov chain
    • \(B(n+1)\) is independent of all values \(B(m)\) for \(m<n\)
    • Unique recurrent positive class

• Non saturated mode (source rate < \(1/L\))
  – Transmission rate = source rate
    • the transmission between two consecutive packets do not interfere each other
  – The fluid is unstable
    • Transmission delay for some reason leads the network to congested regime
      – e.g. packet loss
Throughput with interference parameter $L = 3$
Solutions to Congestion

• Shadow packets
  – Nodes refuse incoming packets for a certain duration
    • Making the fluid regime stable

\[
\begin{align*}
B(0) &= [1 \circ 1 \ 1 \ 1 \ 1 \circ \circ \circ \circ \ 1 \circ 1 \circ \circ \circ] \\
B(1) &= [1 \ 1 \ 1 \ 1 \ 1 \ 1 \circ \circ \circ \circ \circ \circ \circ \circ \circ] \\
B(2) &= [1 \ 1 \ 1 \ 1 \ 1 \ 1 \circ \circ \circ \circ \circ \circ \circ \circ \circ] \\
B(3) &= [1 \ 1 \ 1 \ 1 \ 1 \ 1 \circ \circ \circ \circ \circ \circ \circ \circ \circ] \\
B(4) &= [1 \ 1 \ 1 \ 1 \ 1 \ 1 \circ \circ \circ \circ \circ \circ \circ \circ \circ] \\
B(5) &= [1 \ 1 \ 1 \ 1 \ 1 \ 1 \circ \circ \circ \circ \circ \circ \circ \circ \circ] \\
B(6) &= [1 \ 1 \ 1 \ 1 \ 1 \ 1 \circ \circ \circ \circ \circ \circ \circ \circ \circ] \\
B(7) &= [1 \ 1 \ 1 \ 1 \ 1 \ 1 \circ \circ \circ \circ \circ \circ \circ \circ \circ] \\
B(8) &= [1 \ 1 \ 1 \ 1 \ 1 \ 1 \circ \circ \circ \circ \circ \circ \circ \circ \circ] \\
B(9) &= [1 \ 1 \ 1 \ 1 \ 1 \ 1 \circ \circ \circ \circ \circ \circ \circ \circ \circ]
\end{align*}
\]

– Because of packet/hole duality, a sufficient spacing between holes rather than between packets
Solutions to Congestion

- **Two channel scheme**
  - No explicit scheduling is necessary
  - Two states for each node:
    - Occupied
    - Vacant
  - Simple channel assignment rule to reduce the inter-channel interference
    - Links 1, 2, 5, 6,…, 4K +1, 4K + 2 use the first channel while others use the other channel
    - No contention between links at all
Simulation – Against Packet Loss

Throughput vs. Packet loss rate

- Optimal throughput
- Drop-tail
- With Rules R1 and R2
- Shadow packets
- Two channels scheme

$L = 4$
Possible Extensions

• **Mesh Networks**
  – Multihop wireless network may have much more complex topologies
  – A case where a flow splits into two branches is addressed
    • DC would not be in a congested regime
      – Packet/hole duality

• Bandwidth allocation for AD and BD depends on the contention scheme between two links accessing node C
Possible Extensions

• Opposite traffic
  – Backward traffic can be also applied along the same route by adopting packet/hole duality
    • Replace swapping hole with a backward packet
    • Sum of the forward and backward packets shall be constant to keep the rule of slot transmission
  – Throughput is identical as in the unidirectional case
    • However, some amount of packets must be carried in both directions
Conclusions

• Multihop transmissions suffer from intrinsic performance problems due to
  – Long transmission path
  – Congestion
  – Packet loss

• A simple policy is proposed to solve the problems by
  – Reducing buffer size to one packet
  – Refusing incoming transmissions when buffers are already occupied

• Interesting property that packets and holes have dual roles is acquired for extending the scheme
  – Carrying traffic in both directions with same performance as in the unidirectional case