# Revising Buffering in Multihop CSMA/CA Wireless Networks

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林咨銘
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tmlin@itri.org.tw

# Outline

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# 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

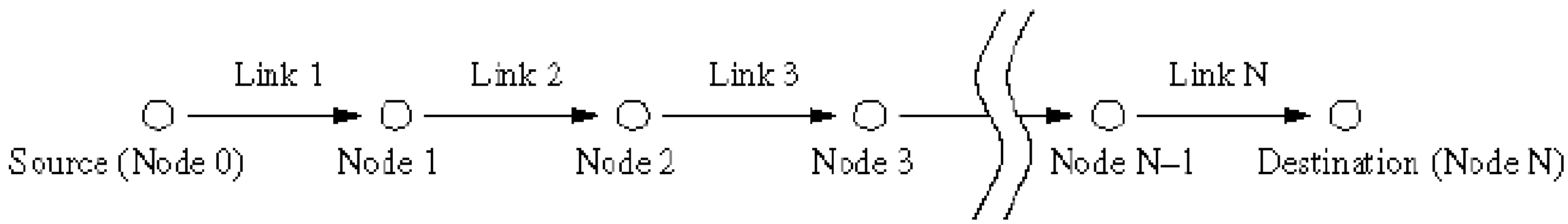
- Congestion problem
  - Nodes compete with each other for transmission
- Two solutions
  - Centralized scheduling
    - Unpredictable results when control messages are delayed or lost
  - Multiple wireless interfaces
    - Interferences between interfaces impact throughput and are evidenced in prior 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 throughout using completely decentralized MAC protocol
  - Resolve the contentions between neighboring nodes locally

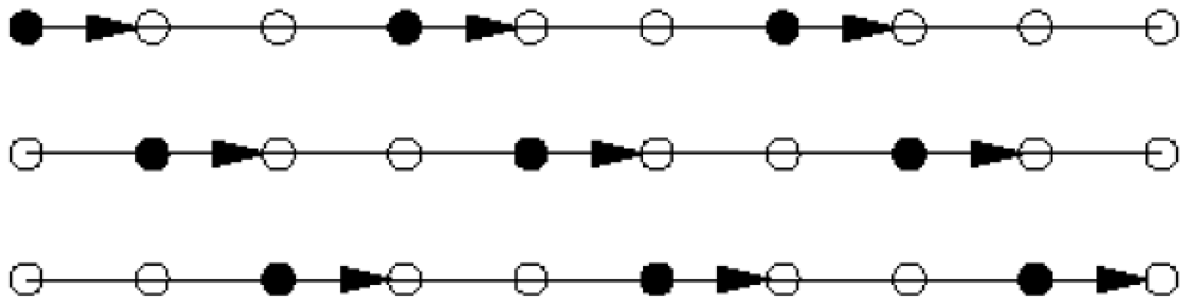
# Model

- 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*** / ≧ ***L***
  (Link ***i*** does not interfere with link ***j***)



Optimal operation of the network for $\ell = 3$

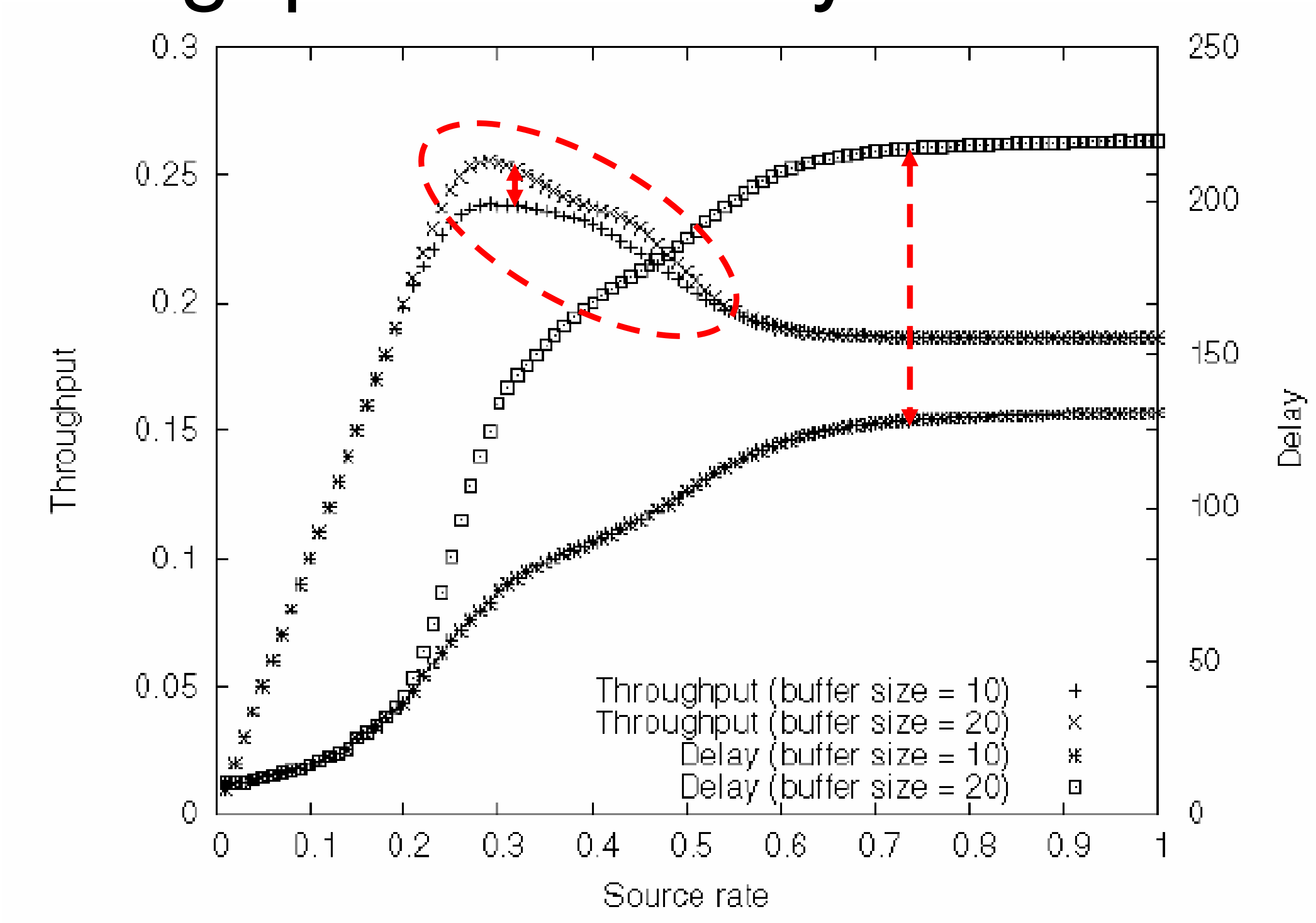
- This model has only ***1/L*** throughput of the multihop route

# The Current Situations

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

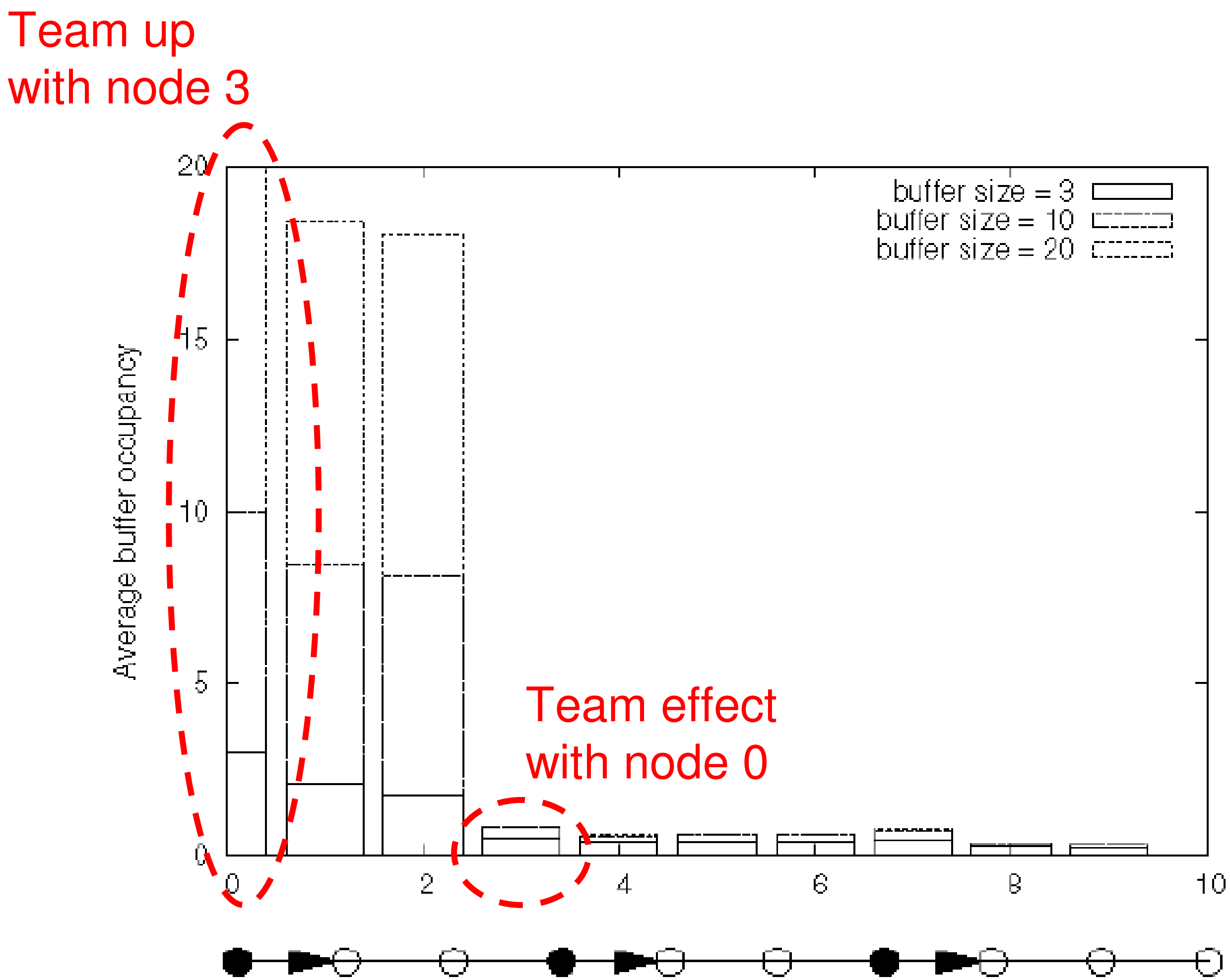
- Some observations are noted
  - Throughput decreases when network starts to drop packets
  - Increasing the buffer size does not increase asymptotic throughput
  - End-to-End delay increases if buffer size is enlarged

# Observation 1 – Throughput and Delay Performance




The lost of throughput is not due to undersized buffers

# Observation 2 – Average Occupancy of Buffer



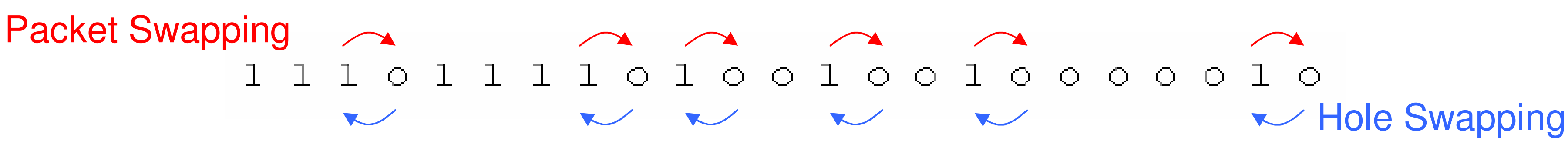
# Proposed Scheme

- 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

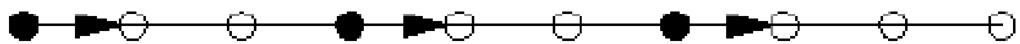
# Proposed Scheme

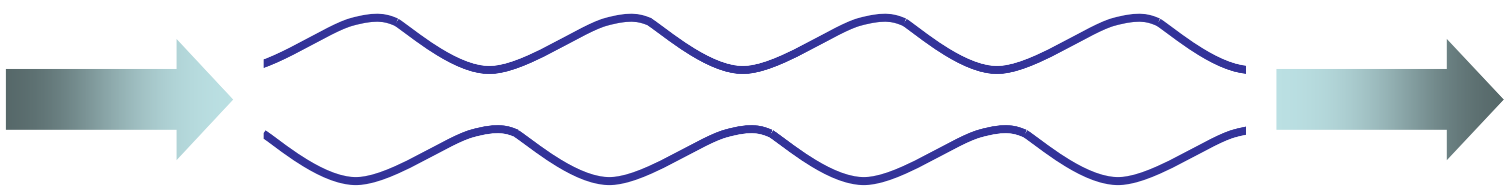
- Packet/hole duality
  - Because of R1 and R2, a transmission can only take place between
    - A node that has one packet in its buffer
    - A node that has no packet
  - Packet swapping is implying Hole swapping between the source and destination nodes



# 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

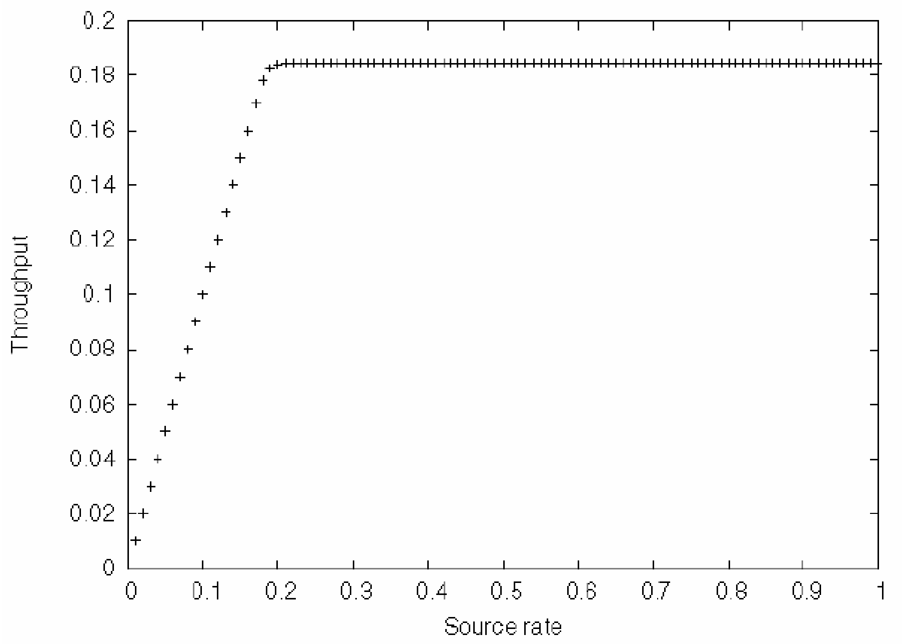




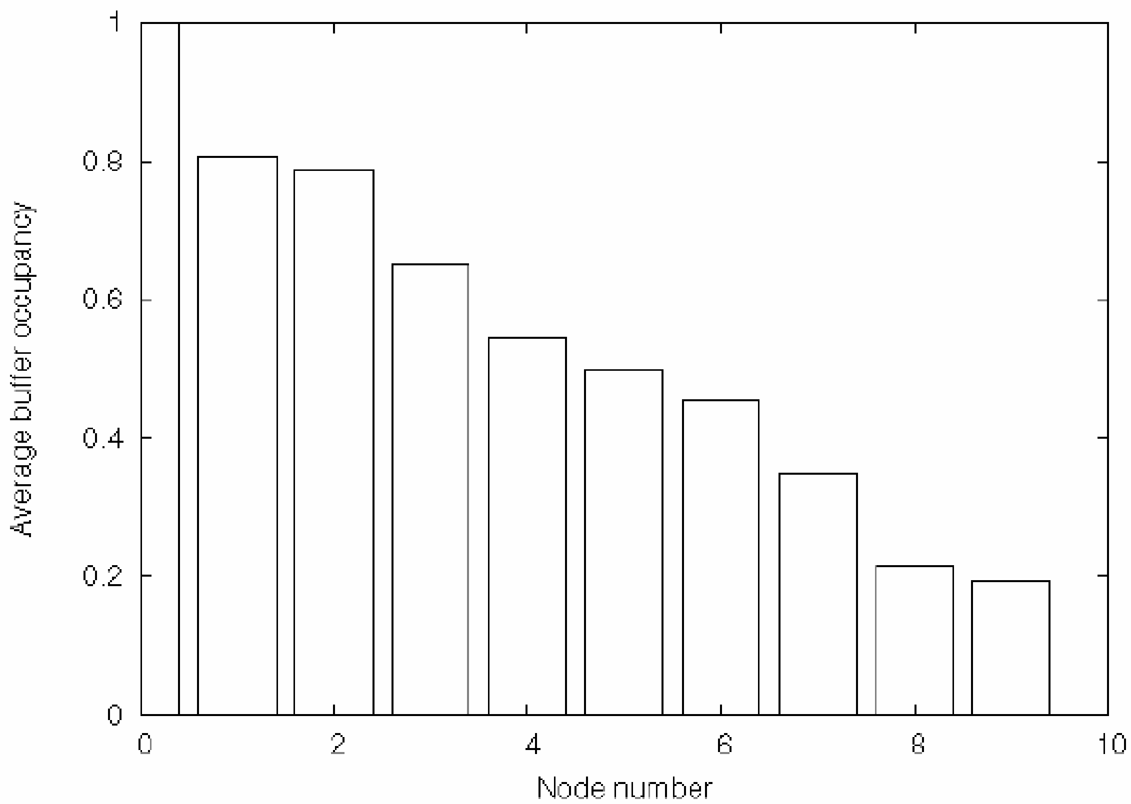
# Proposed Scheme

- 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



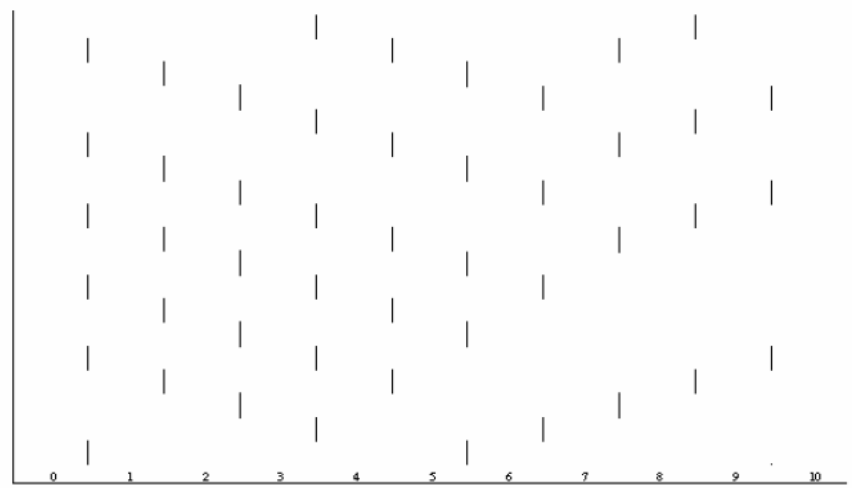
# Proposed Scheme




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



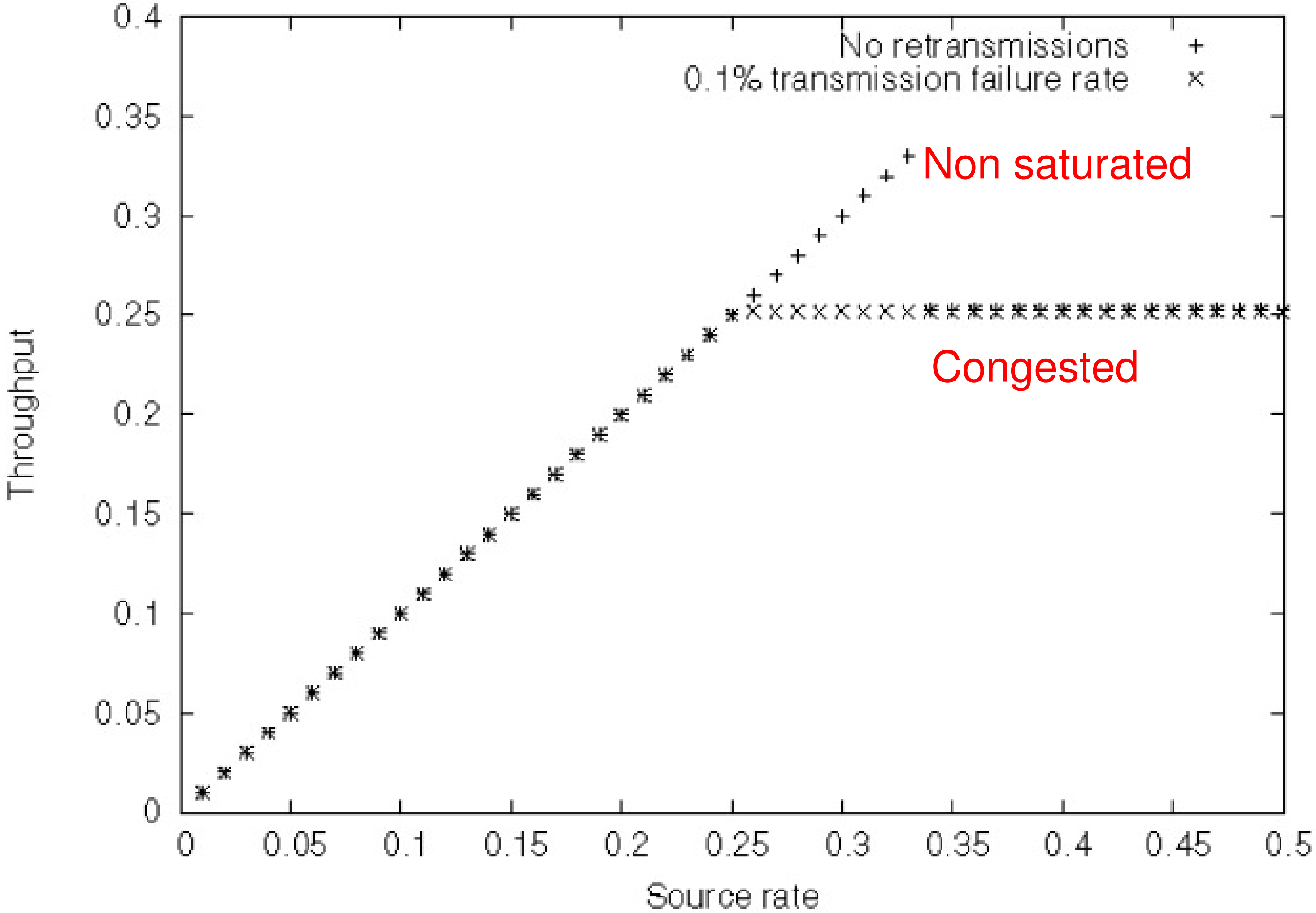

The evolution of the link activity vector with constant packet size

# 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

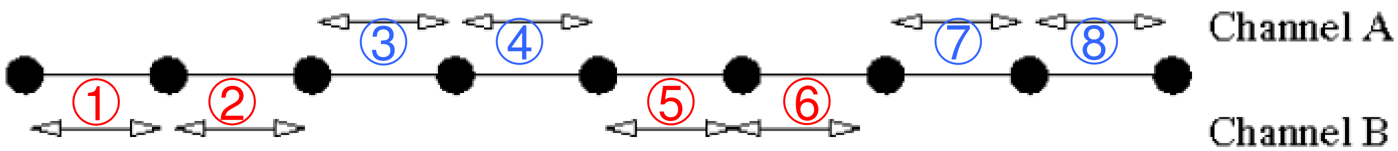
```
B(0) = [ 1 o 1 1 1 o o o o 1 o 1 o o o ]
B(1) = [ 1 1 1 1 s 1 o o o s 1 1 o o o ]
B(2) = [ 1 1 1 1 s s 1 o o s 1 s 1 o o ]
B(3) = [ 1 1 1 s 1 s s 1 o o 1 s s 1 o ]
B(4) = [ 1 1 1 s s 1 s s 1 o s 1 s s o ]
B(5) = [ 1 1 s 1 s s 1 s s 1 s s 1 s o ]
B(6) = [ 1 1 s s 1 s s 1 s s 1 s s 1 o ]
B(7) = [ 1 s 1 s s 1 s s 1 s s 1 s s o ]
B(8) = [ 1 s s 1 s s 1 s s 1 s s 1 s o ]
B(9) = [ 1 1 s s 1 s s 1 s s 1 s s 1 o ]
```

Stable and Recurrent

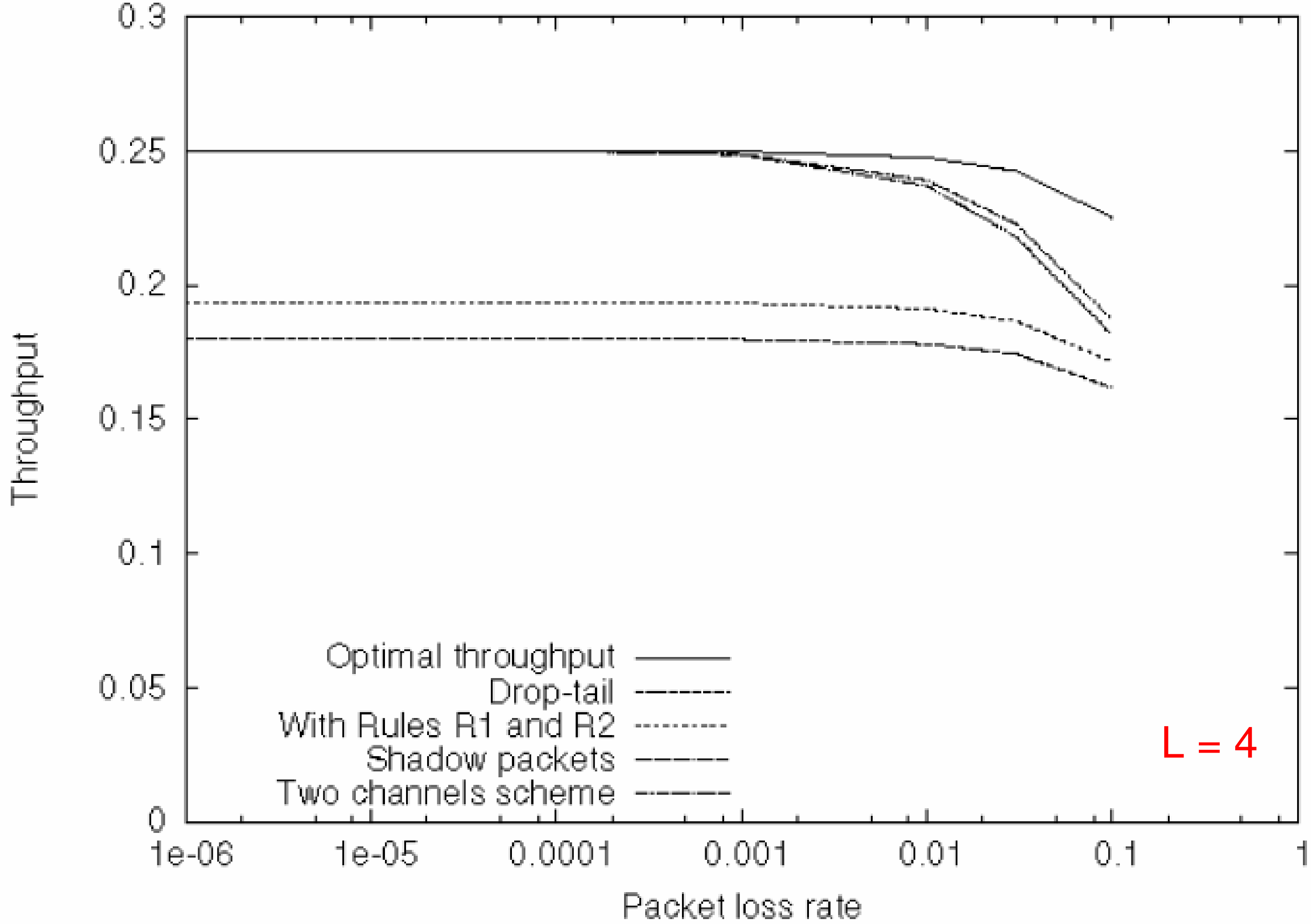
  - Because of packet/hole duality, a sufficient spacing between holes rather than between packets

# 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

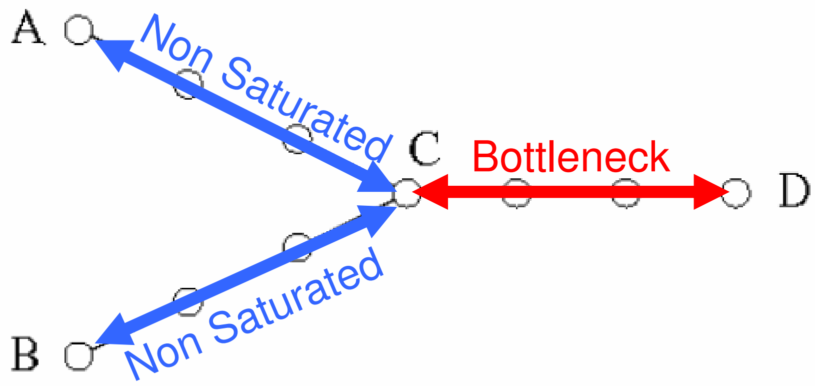


# Simulation – Against Packet Loss



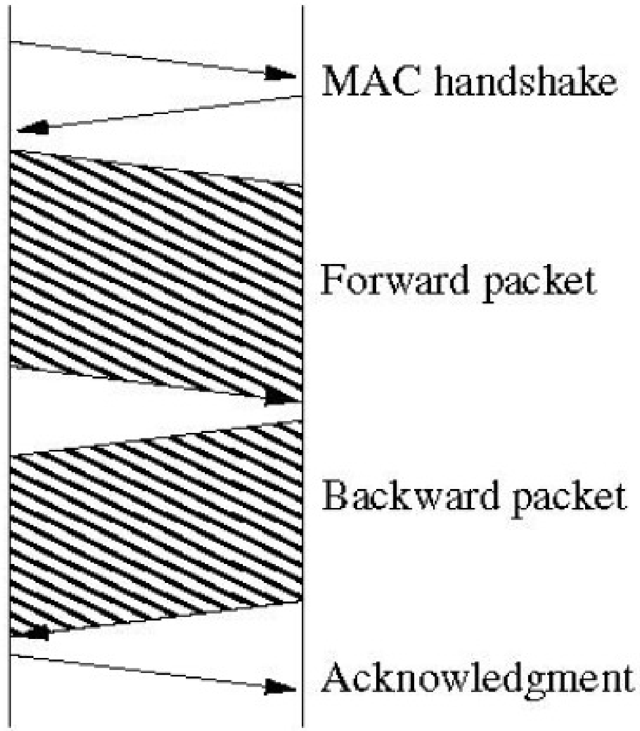
# Possible Extensions

- 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 form 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