Joint Multi-Channel Link Layer and Multi-Path Routing Design for Wireless Mesh Networks

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Outline

- Introduction
- JMM protocol
  - *-Multi-Channel Link Layer Part*
  - *-Multi-Path Routing Part*
- Performance evaluation
- Conclusion

Introduction

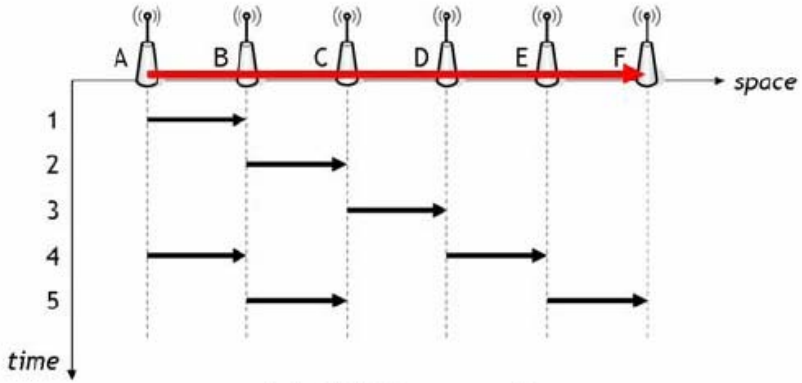
- Main reasons that end-to-end throughput of a flow may decrease rapidly as the number of hops increases is:

  -Half-duplex property of the radios

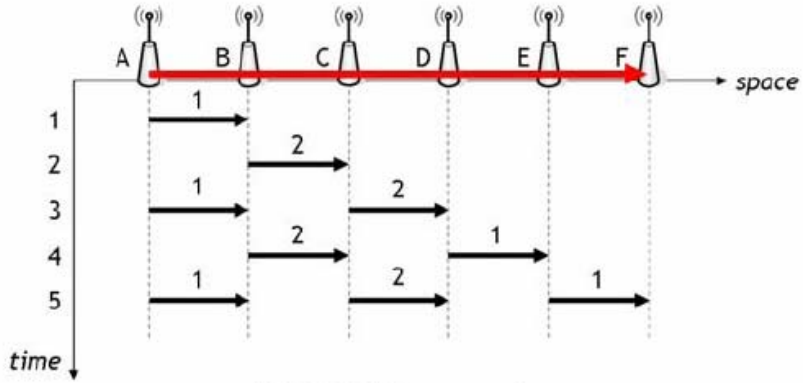
  -Broadcast nature of the wireless medium

  -Difficulty of collision avoidance

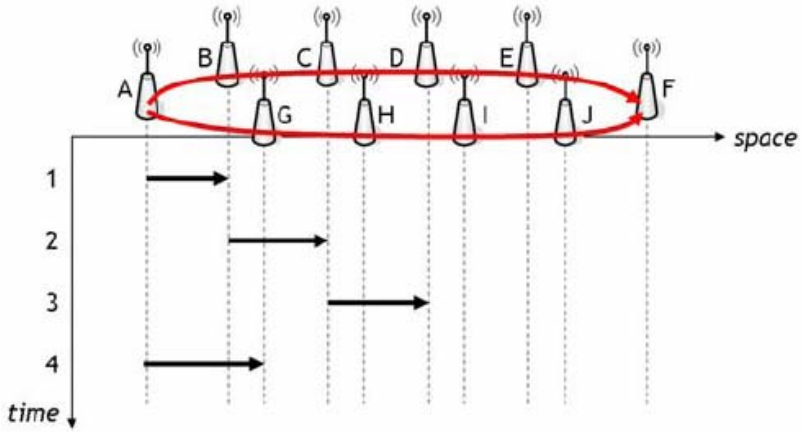
Ideal Packet Scheduling



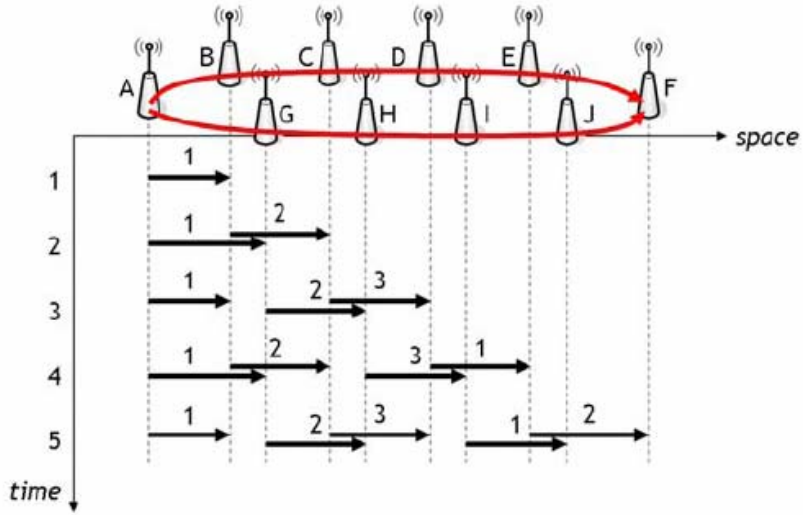
(a) SCSP scenario



(b) MCSP scenario



(c) SCMP scenario



(d) MCMP scenario

Related Work

- Multi-Channel MAC and Link Protocols
  - *-single-transceiver* schemes
  - *-multi-transceiver* schemes
- *Multi-Channel Routing Protocols*
- *Multi-Path Routing Protocols*

JMM Protocol

- A crosslayer design on top of the 802.11 MAC layer and does not require any change to the 802.11 MAC and hardware.
- Composed of a multi-channel link layer part and a multi-path routing part.

JMM Protocol

- It decides the receiving channel of each node based on neighborhood information.
- It constructs a dual path from each node to its gateway.
- It conducts slot assignment for each node’s superframes.
- It schedules and forwards packets and adjusts the ratio of transmitting slots to receiving slots for each node.

Multi-Channel Link Layer Part

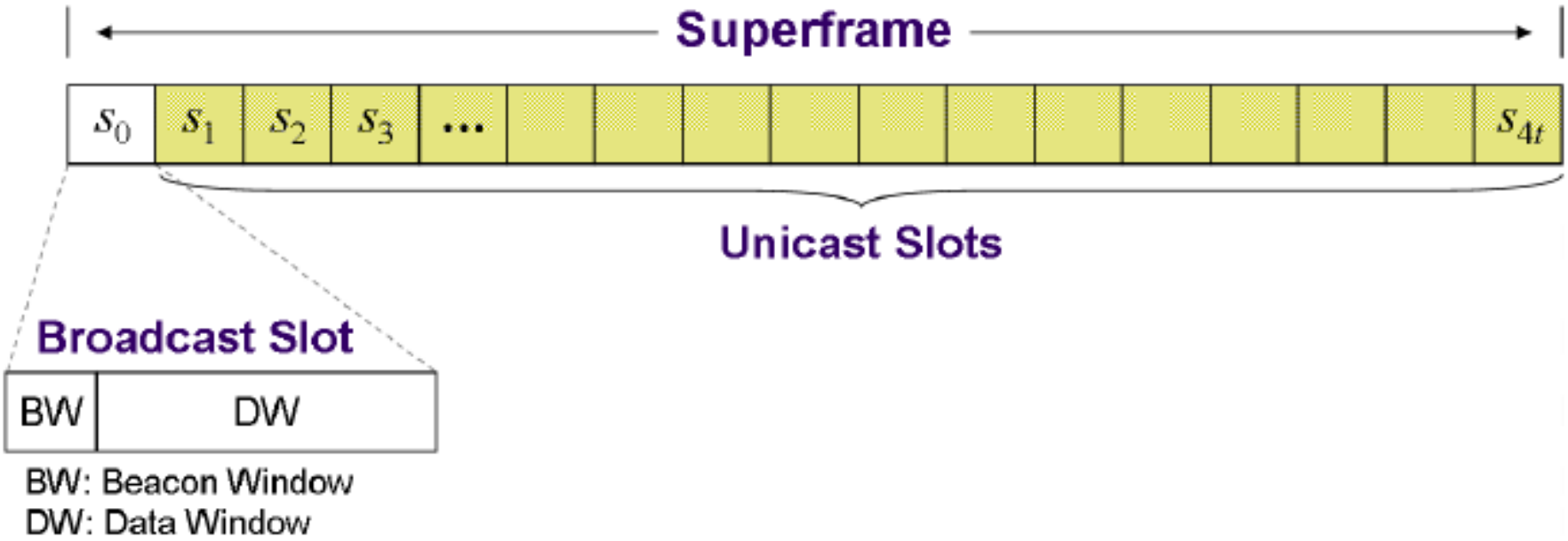
- *Channel Scheduling:*

  To control which channel the transceiver should stay on.

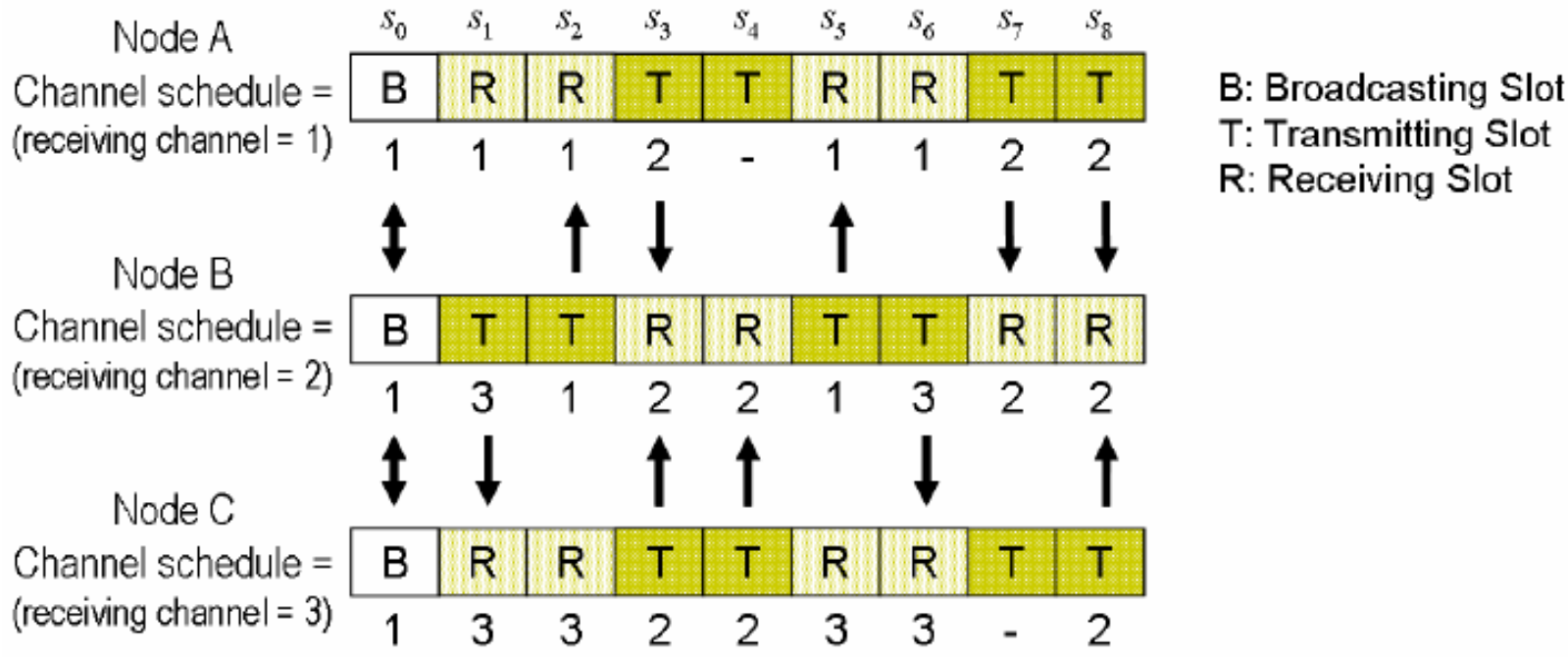
- *Packet Scheduling:*

  To schedule when a packet can be sent.

Superframe Structure

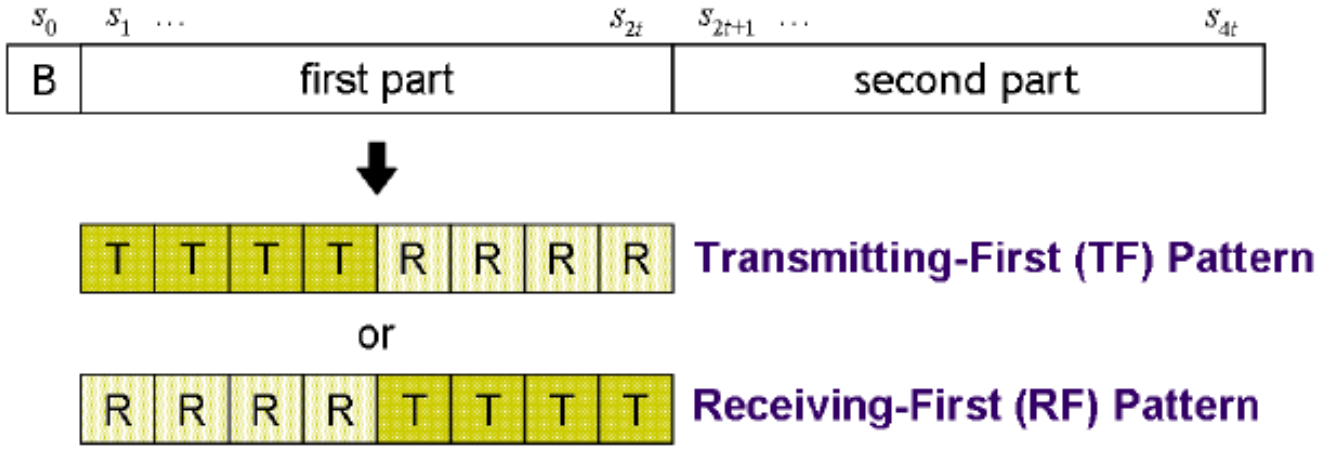


Example of Channel Schedule



- Two nodes can communicate only if one is in a transmitting slot and the other is in a receiving slot.

Transmitting and Receiving Patterns



Dynamic Adjustment of the T/R Ratio

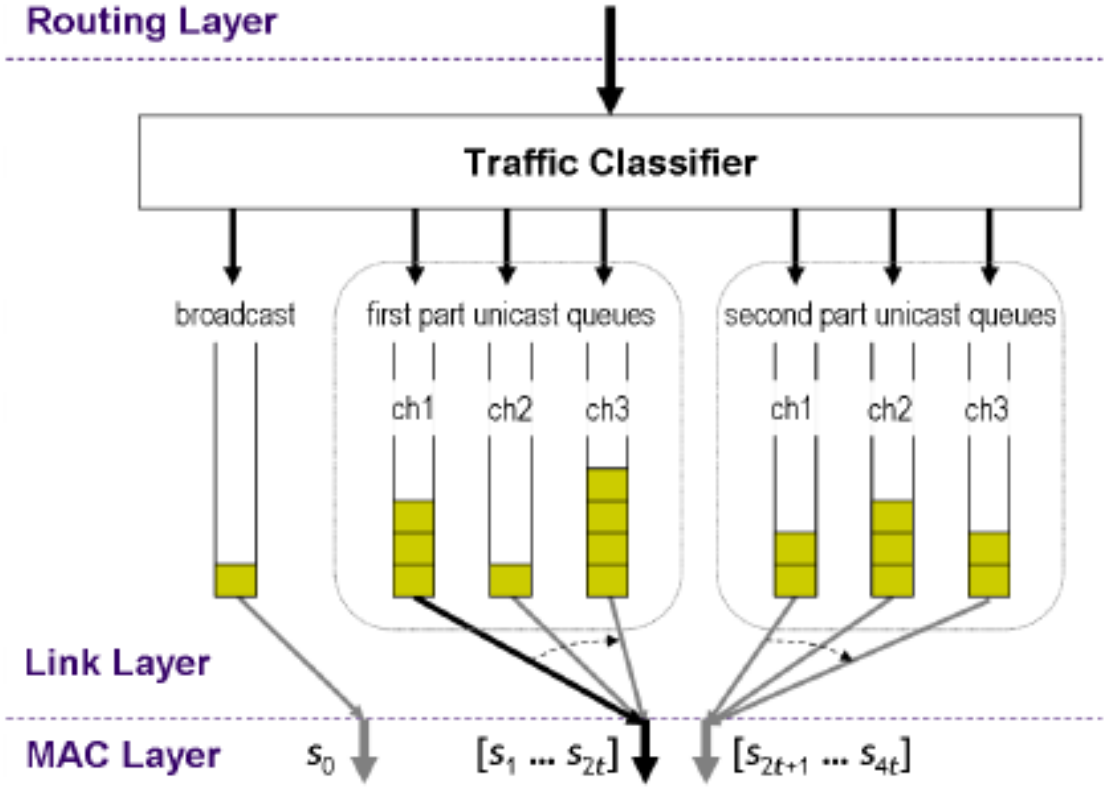
$$T_{smooth} \leftarrow \alpha * T_{actual} + (1 - \alpha) * T_{smooth};$$

$$R_{smooth} \leftarrow \alpha * R_{actual} + (1 - \alpha) * R_{smooth}.$$

if $(T_{smooth}/T)/(R_{smooth}/R) > Threshold_h$ and $R > 1$ **then**
    $T \leftarrow T+1$;
    $R \leftarrow R-1$;
endif

if $(T_{smooth}/T)/(R_{smooth}/R) < Threshold_l$ and $T > 1$ **then**
    $T \leftarrow T-1$;
    $R \leftarrow R+1$;
endif

Packet Queues

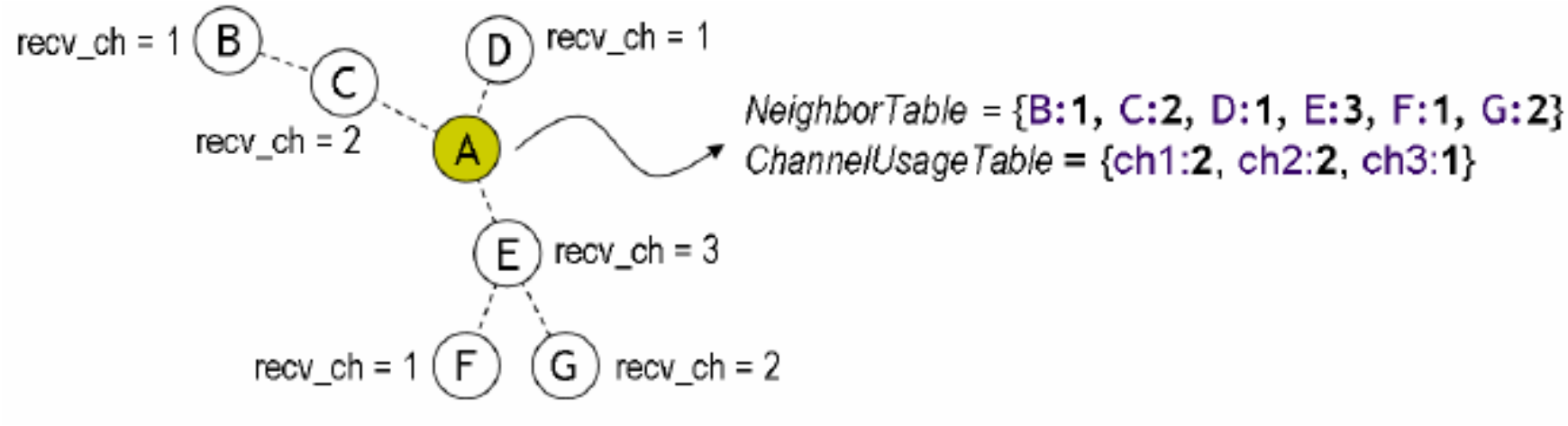


- The number of queues in each part is equal to the number of channels in the system.

Multi-Path Routing Part

- The goal of the routing part is to construct two paths to the gateway

Selection of Receiving Channels



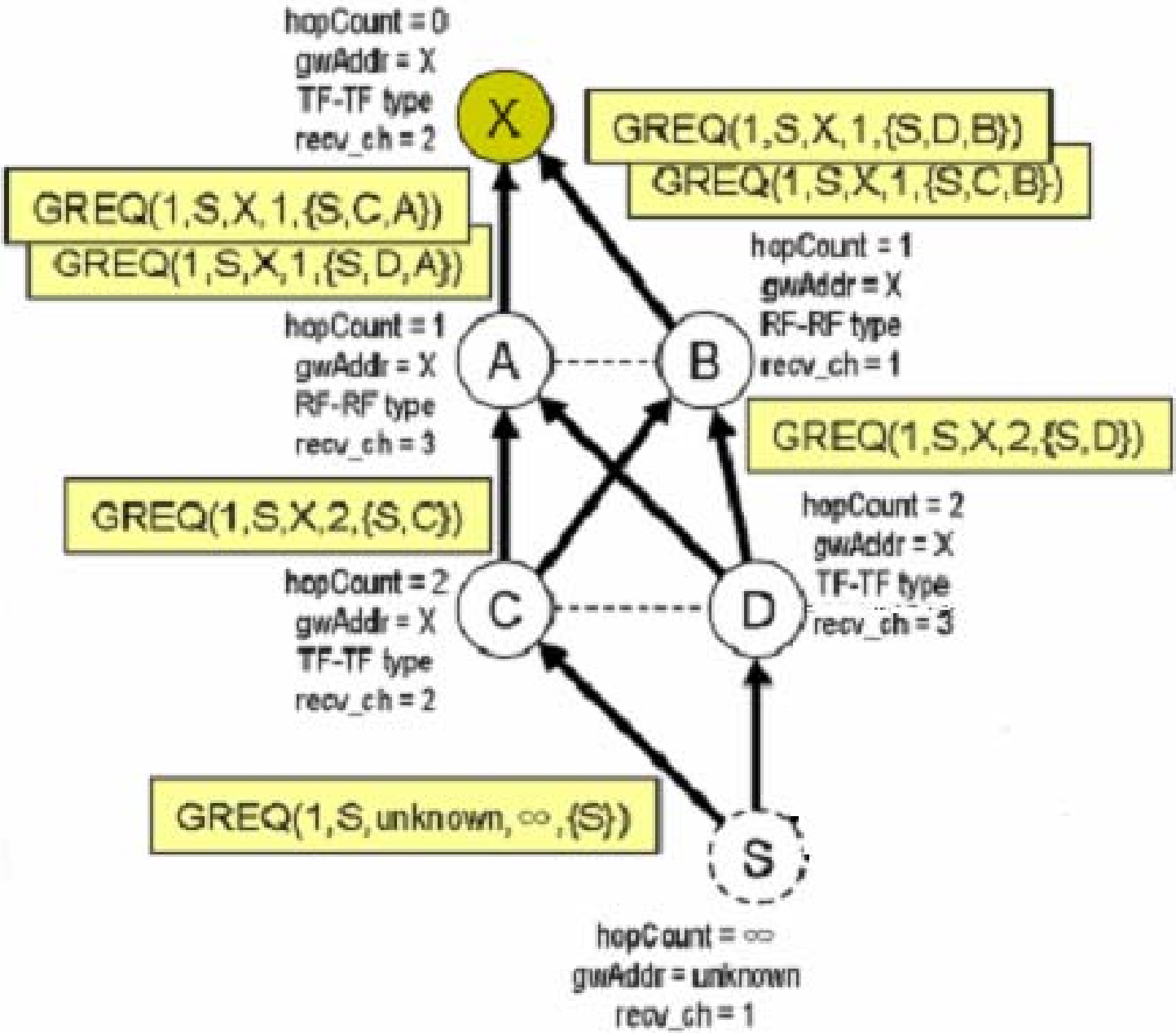
- A node will choose the least used channel as its receiving channel.

Dual-Path Route Discovery

- To avoid network-wide flooding of route search packets.
- Do not expect too many duplicate route search packets being discarded by intermediate nodes.

STRUCTURE OF THE GREQ MESSAGE (S IS THE SOURCE NODE).

Field	Initial value	Meanings
$seqNum$	seqNum at S	the sequence number
$srcAddr$	S	the source address
$gwAddr$	unknown	the gateway address of the mesh network
$hopCount$	∞	the smallest number of hops to the gateway
$pathRecord$	{S}	the list of node records on the path


hopCount = 0
gwAddr = X
TF-TF type
recv_ch = 2
X
GREQ(1,S,X,1,{S,D,B})
GREQ(1,S,X,1,{S,C,B})
GREQ(1,S,X,1,{S,C,A})
GREQ(1,S,X,1,{S,D,A})
hopCount = 1
gwAddr = X
RF-RF type
recv_ch = 1
hopCount = 1
gwAddr = X
RF-RF type
recv_ch = 3
A
B
GREQ(1,S,X,2,{S,D})
GREQ(1,S,X,2,{S,C})
hopCount = 2
gwAddr = X
TF-TF type
recv_ch = 3
hopCount = 2
gwAddr = X
TF-TF type
recv_ch = 2
C
D
GREQ(1,S,unknown,∞,{S})
S
hopCount = ∞
gwAddr = unknown
recv_ch = 1

Path Selection Metric

$$metric = w_{node}V_{node} + w_{chl}V_{chl} + w_{qlty}V_{qlty}$$

V_{node} = number of common nodes between *P*1 and *P*2 excluding the source node and the gateway.

$$V_{chl} = CN(P_1) + CN(P_2) + \delta(P_1, P_2)$$

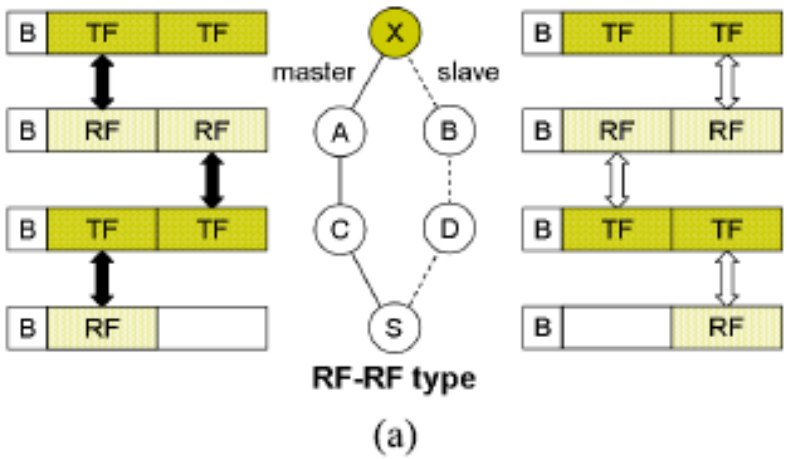
V_{qlty} is defined as $ETX(P_1) + ETX(P_2)$

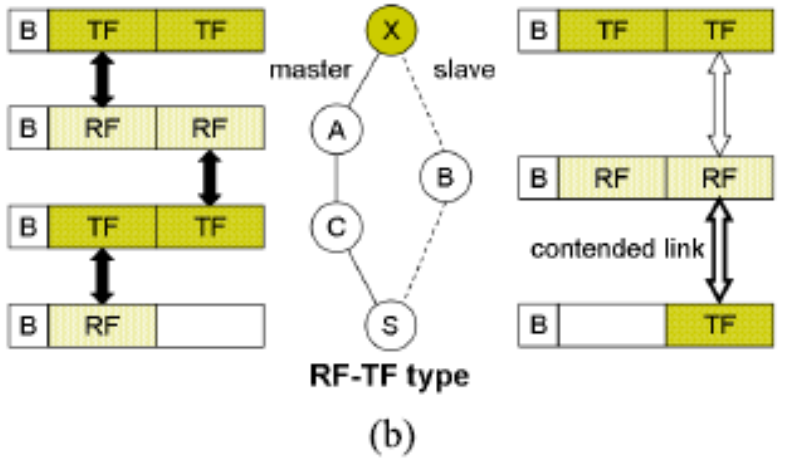
$$w_{node} + w_{chl} + w_{qlty} = 1$$

Determining Superframe Patterns

- The selection will be based on the result of the route discovery.
- Given any dual-path, the gateway will designates one path as the master path, and the other as the slave path.

The pattern selection of S





Packet Forwarding Rule

$$P = M \oplus E \oplus D \oplus C$$

$$M = \begin{cases} 0 & \text{if the pkt is to be sent along the master path;} \\ 1 & \text{if the pkt is to be sent along the slave path;} \end{cases}$$

$$E = \begin{cases} 0 & \text{if the hop count to gw along the intended path is even;} \\ 1 & \text{if the hop count to gw along the intended path is odd;} \end{cases} \quad (6)$$

$$D = \begin{cases} 0 & \text{if the pkt is issued by a gateway;} \\ 1 & \text{if the pkt is issued by a source;} \end{cases} \quad (7)$$

$$C = \begin{cases} 0 & \text{if the pkt is to be transmitted to a non-contended link;} \\ 1 & \text{if the pkt is to be transmitted to a contended link.} \end{cases} \quad (8)$$

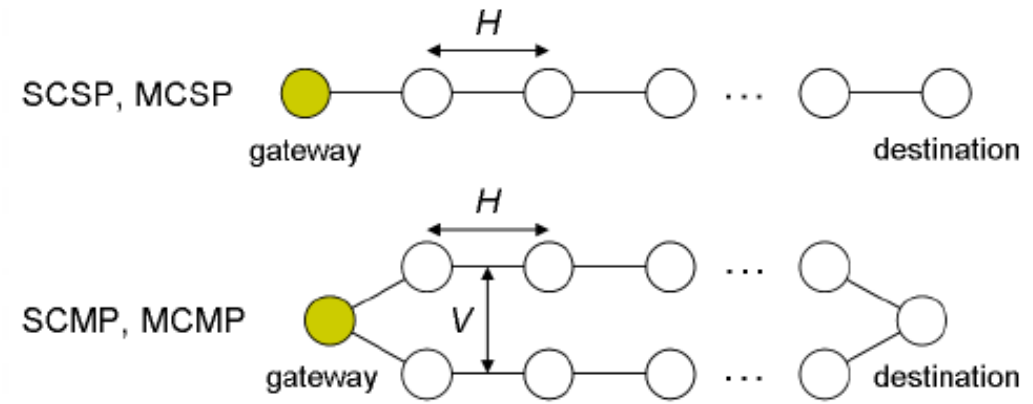
Route Maintenance

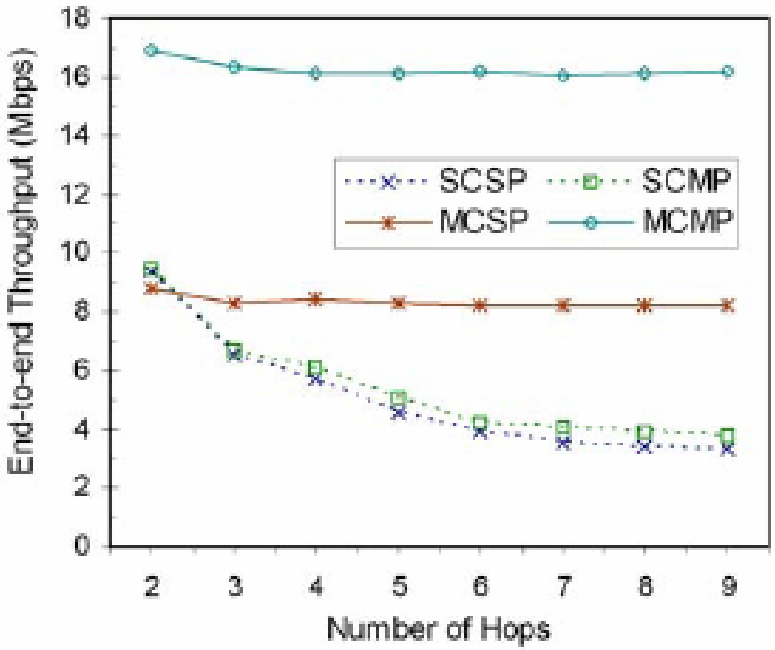
- Faulty links are detected by nodes' periodical HELLO messages.

- When a node discovers a faulty link, it will propagate a GERR message to all its successors which use this link.

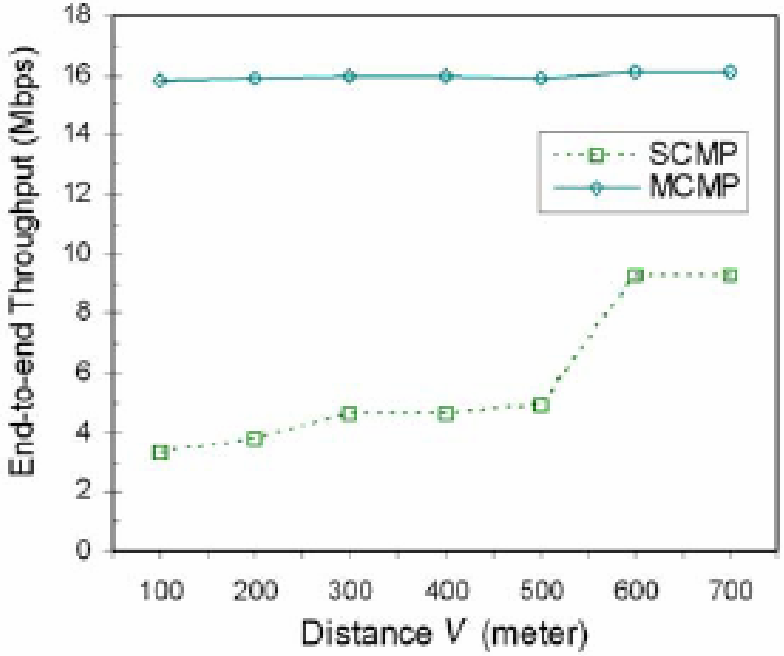
Performance Evaluation

Parameter	Default	Meanings
l	20 ms	the slot size
t	4	the number of slots in a quarter of a superfame
α	0.2	the weight between actual and smooth traffic
$Threshold_h$	2	the high threshold of adjusting the T/R ratio
$Threshold_l$	0.5	the low threshold of adjusting the T/R ratio
w_{node}	0.74	the weight of parameter V_{node}
w_{chl}	0.18	the weight of parameter V_{chl}
w_{qlty}	0.08	the weight of parameter V_{qlty}

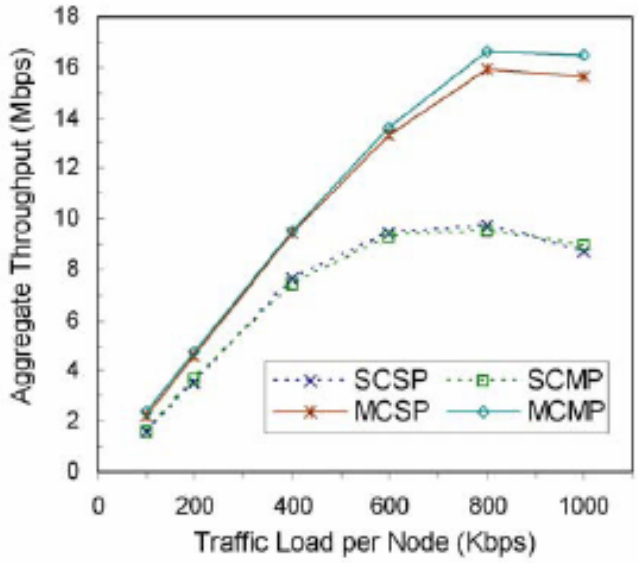



End-to-end Throughput (Mbps)
18
16
14
12
10
8
6
4
2
0
SCSP
SCMP
MCSP
MCMP
2
3
4
5
6
7
8
9
Number of Hops

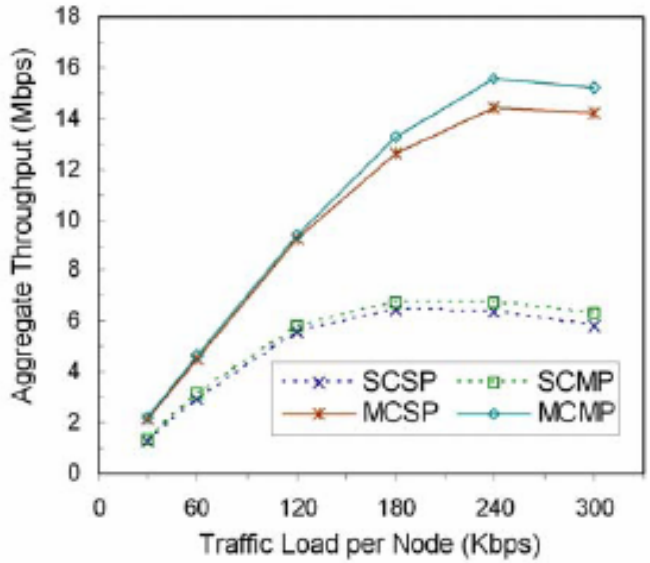
(a)


End-to-end Throughput (Mbps)
18
16
14
12
10
8
6
4
2
0
SCMP
MCMP
100
200
300
400
500
600
700
Distance V (meter)

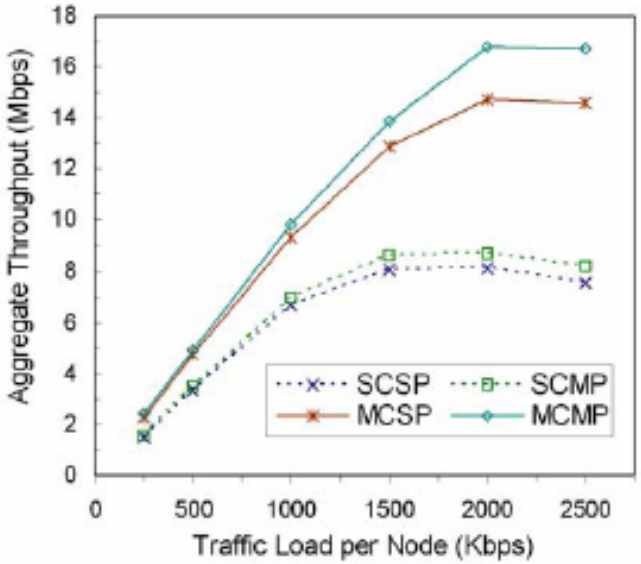
(b)



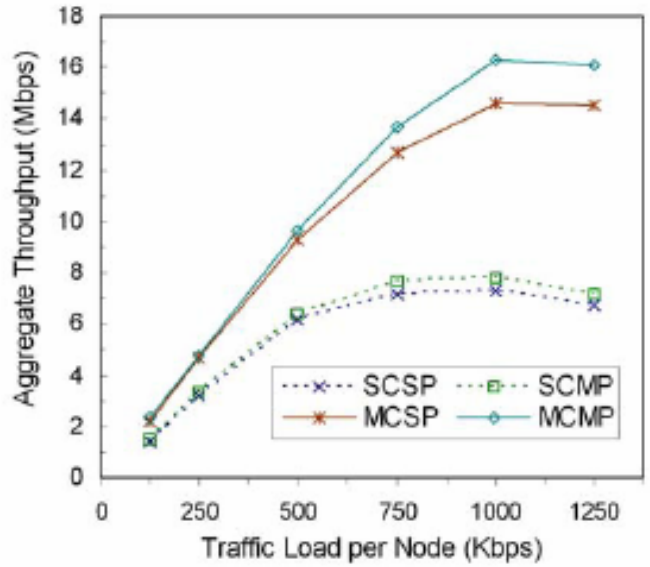
(a) dense load, 5x5 network



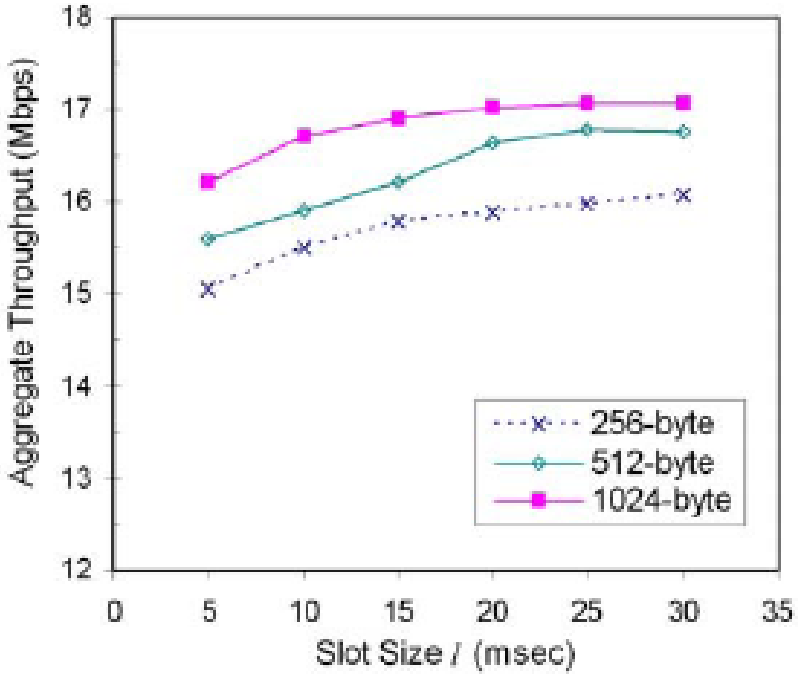
(b) dense load, 9x9 network



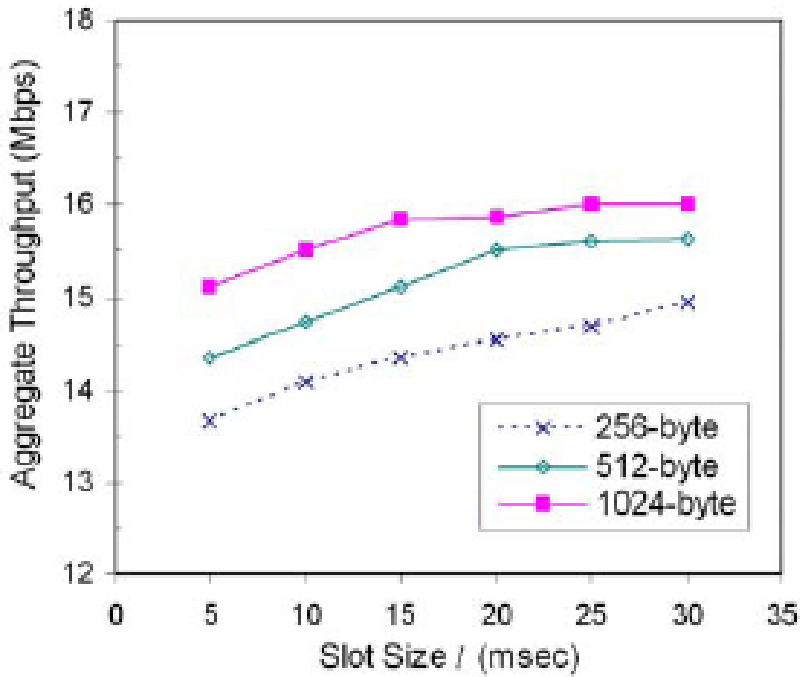
(c) 10 traffic-generating nodes, 9x9 network



(d) 20 traffic-generating nodes, 9x9 network



(a) 5x5 grid network



(b) 9x9 grid network

Conclusion

- WMNs inherit some scalability problems in terms of throughput, delay, and packet delivery ratio faced by all multihop wireless networks.
- JMM efficiently increases the performance by decomposing contending traffic over different channels, different time, and different paths.