Future Channel Reservation Medium Access Control (FCR-MAC) for Multi-Radio Multi-Channel Wireless Mesh Networks

Marco Di Felice **Luciano Bononi**

Department of Computer Science

University of Bologna, Italy

{difelice, bononi}@cs.unibo.it

Guomei Zhu

School of Telecommunications Engeneering

Beijing University of Posts and Telecom., China

guomei@ece.gatech.edu

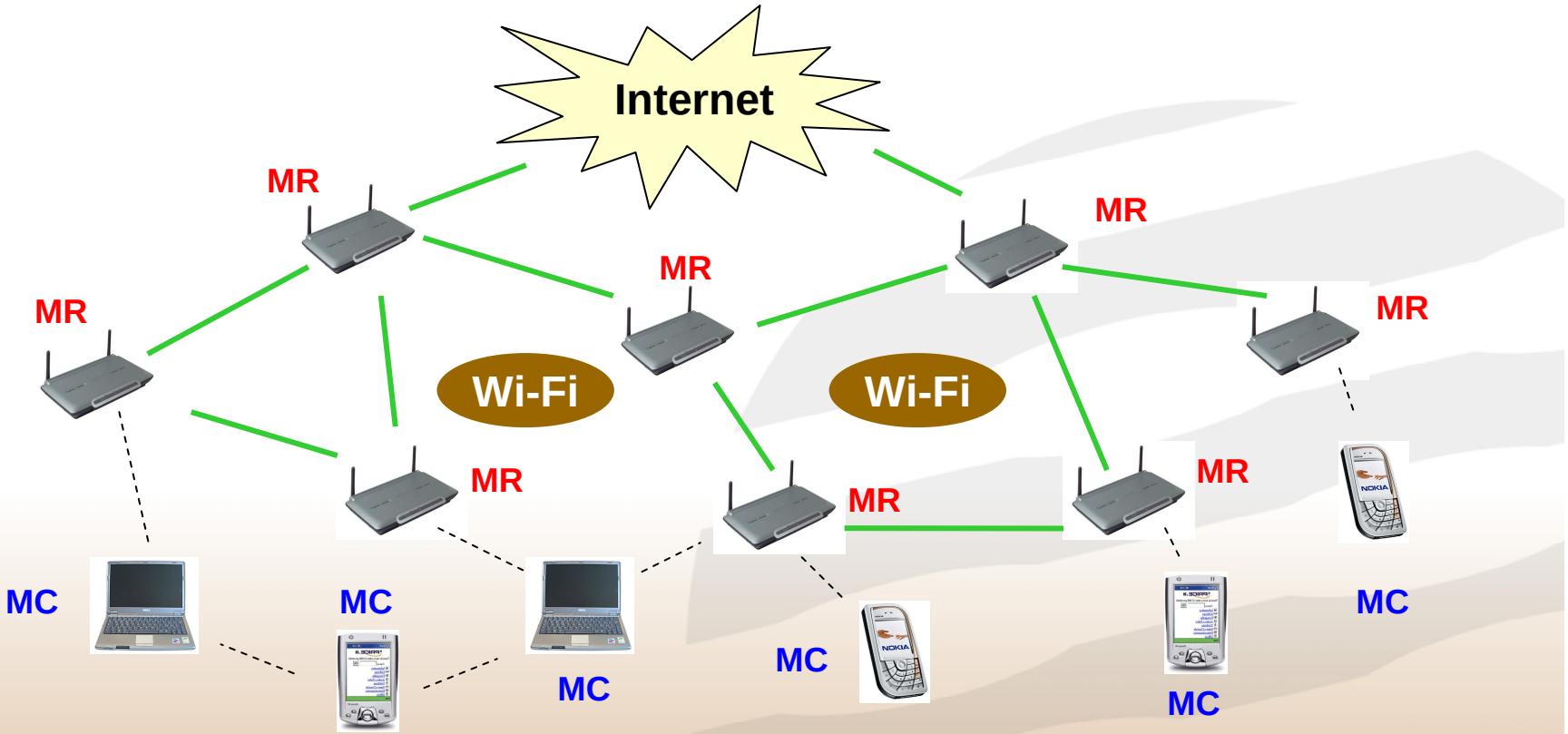
ACM PE-WASUN 2008

October 28th, Vancouver, Canada

Outline

1. Introduction
2. MAC Protocols for Wireless Mesh Networks
3. **FCR-MAC** Protocol
   - FCR-MAC: Channel Allocation
   - FCR-MAC: Channel Differentiation Support
   - FCR-MAC: Multi-Hop Communication Support
4. Performance Evaluation
5. Conclusions and Future Works

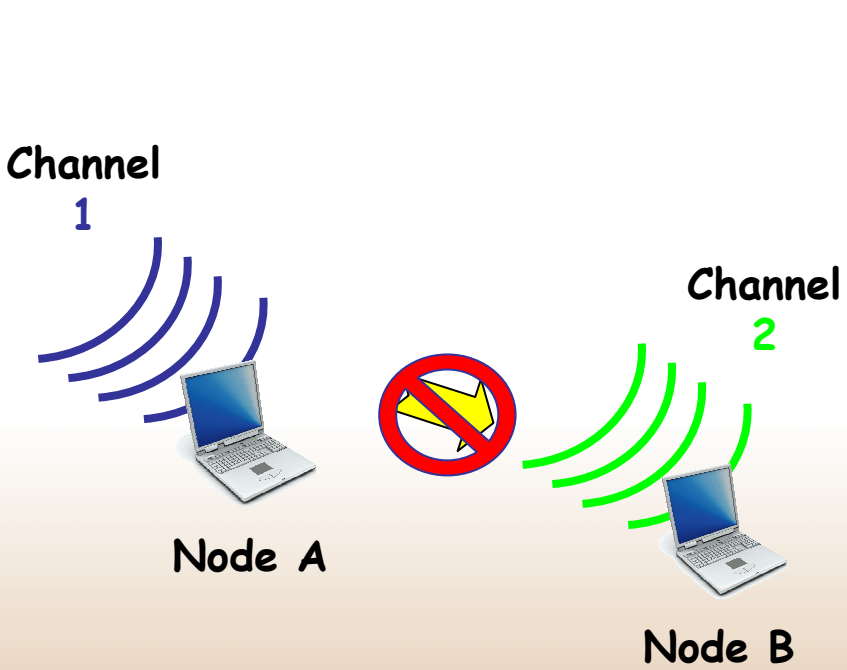
Wireless Mesh Networks (WMNs)



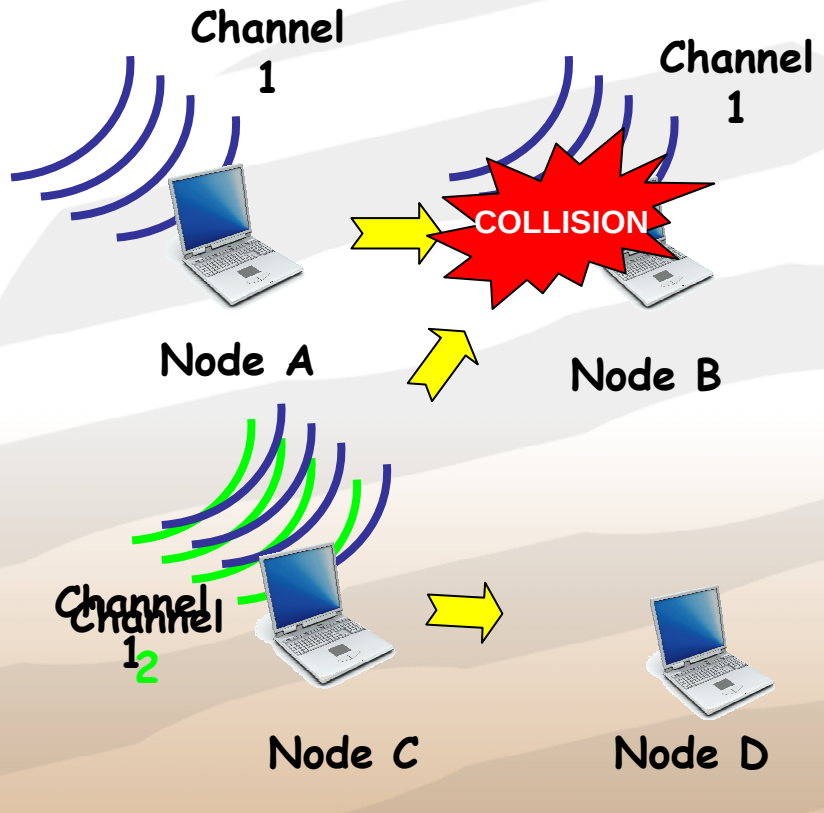
- Nodes Hetereogeneity: mesh clients (**MC**) vs mesh routers (**MR**)
- **Multiple radio interfaces** available for each node
- Design Issues: Scalability, Security, Load Balancing, Coverage, …
  - » Protocol Issues: **MAC** , Routing, Transport, Application …

MAC Problems and Design Issues

MAC Protocols for WMNs face new challenges caused by the multi-channel environment.

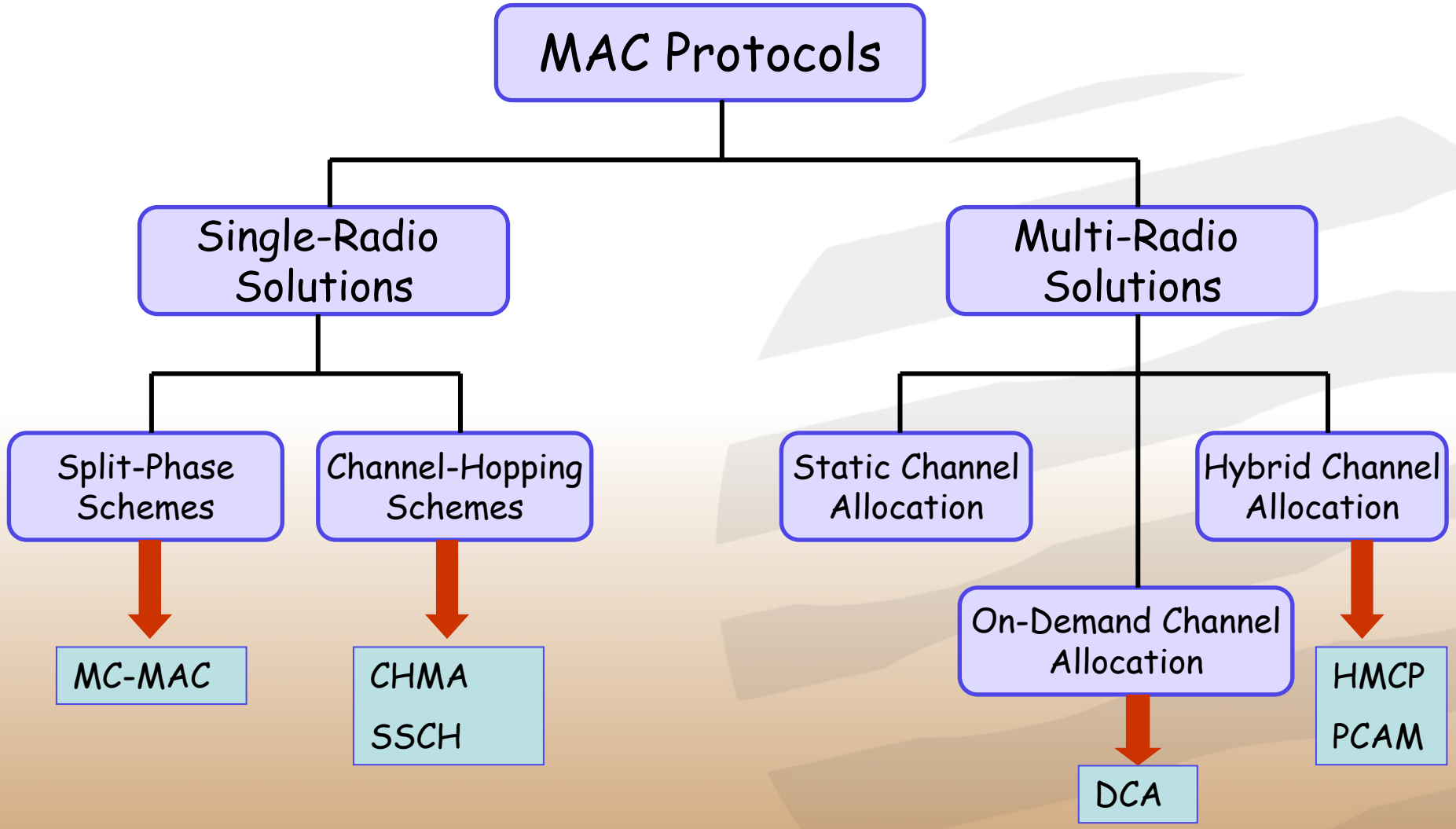


Deafness Problem



Multi-Channel Hidden Terminal Problem

MAC Solutions for WMNs



Assumptions

*The overall bandwidth is divided into **N** channels:*

- **1 Control Channel (CC)**: for control messages (RTS/CTS/RES)
- **N-1 DATA Channels**: for DATA traffic and ACKs.

*Each node is equipped with **2** half-duplex radios:*

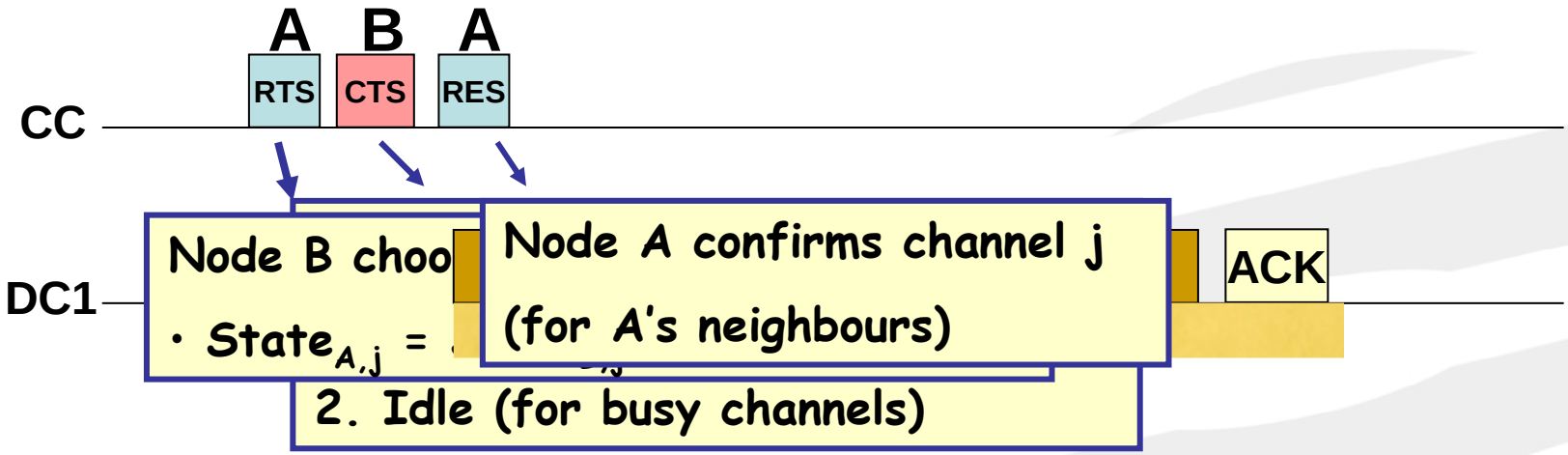
- 1 **Control Radio**: non-tunable and fixed on the common Control Channel (CC).
- 1 **Data Radio**: tunable and switchable among the N-1 DATA Channels.

The utilization of the Control Channel mitigates the impact of multi-hop hidden terminal and deafness problems and provides on-demand channel allocation.

FCR-MAC Protocol

1. On-Demand Channel Allocation
2. Efficient DATA Channel Utilization
3. Channel Access Differentiation
4. Multi-Hop Communication Support

FCR-MAC Protocol (1)



Each node (e.g. X) maintains a **Channel List** (CL) for all the DATA channels. Each channel list entry (e.g. CL[i]) has two fields:

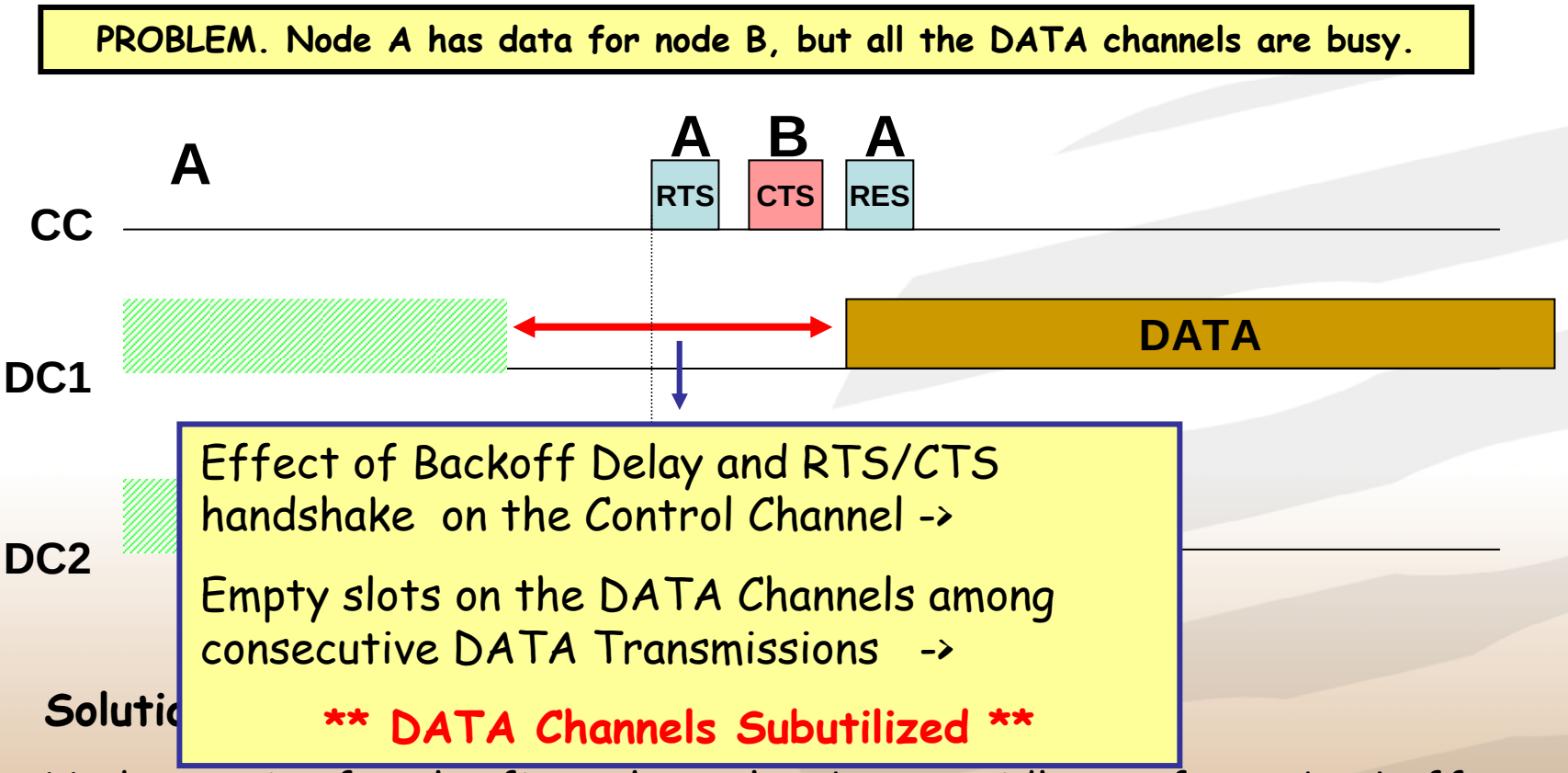
1. **State$_{i,x}$** -> channel i is available for X or not ({Free,Busy })
2. **Idle$_{i,x}$** -> Time when channel i will be released by node X or by X's neighbours.

ON-DEMAND CHANNEL ALLOCATION

FCR-MAC Protocol

1. On-Demand Channel Allocation
2. Efficient DATA Channel Utilization
3. Channel Access Differentiation
4. Multi-Hop Communication Support

DATA Channel Utilization

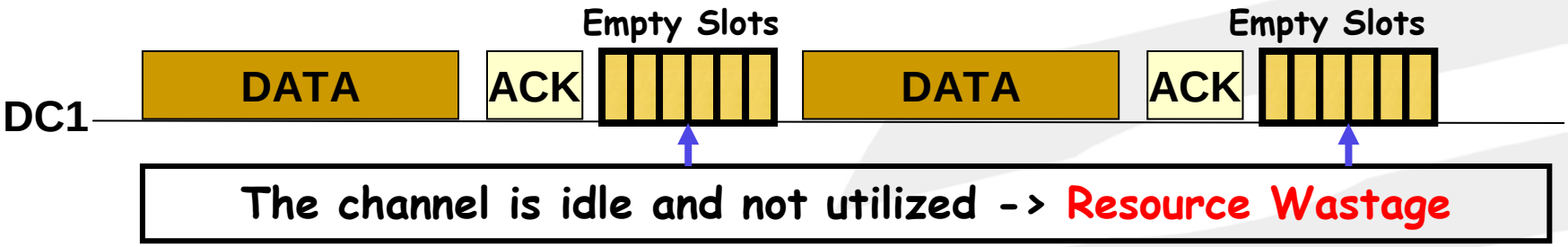


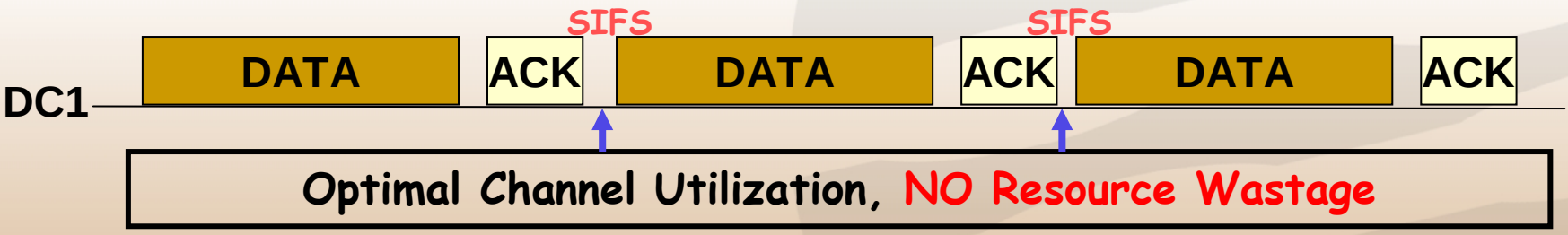
Solutic

Node A waits for the first channel to become idle, performs backoff and transmits the RTS to Node B on the Control Channel.

DATA Channel Utilization

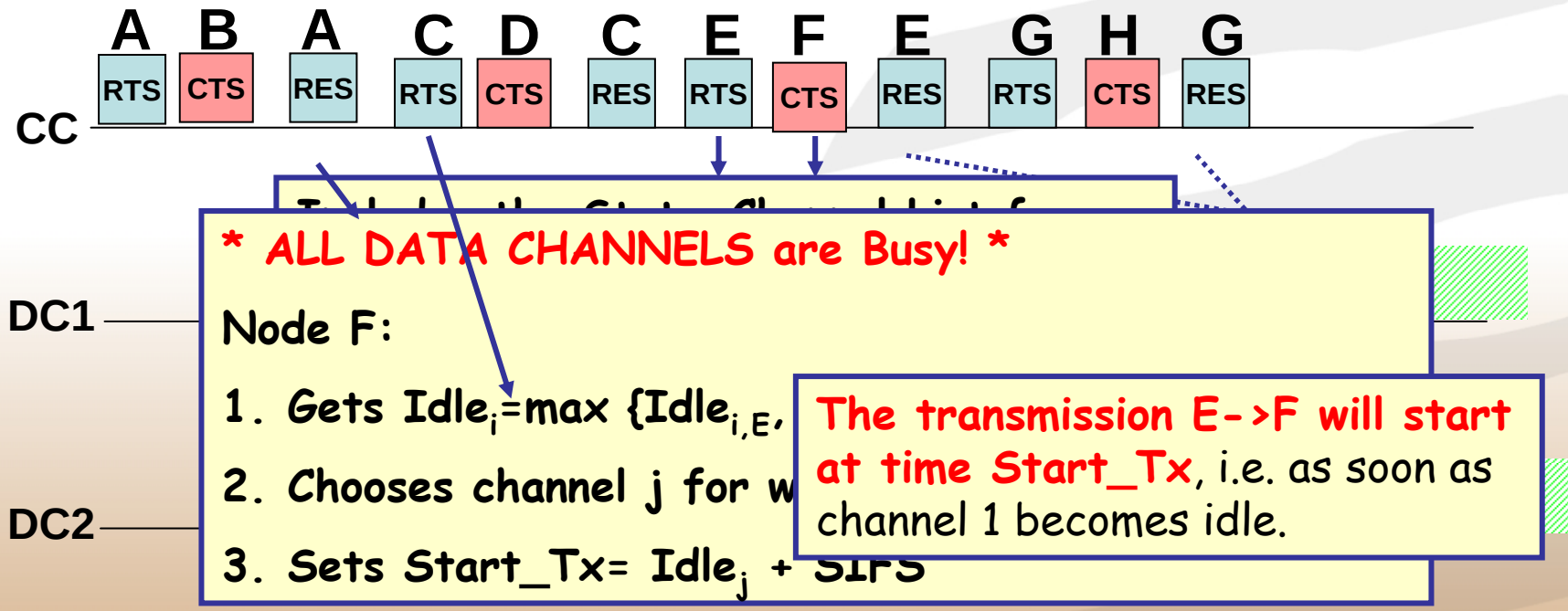
PROBLEM. Node A has data for node B, but all the DATA channels are busy.





FCR-MAC Protocol (2)

Example: 2 Data Channels, A-B are transmitting on channel 1, C->D are transmitting on channel 2, node E->F can access the channel as soon as channel 1 is available.



FUTURE CHANNEL RESERVATION

FCR-MAC Protocol

1. On-Demand Channel Allocation
2. Efficient DATA Channel Utilization
3. Channel Access Differentiation
4. Multi-Hop Communication Support

Channel Access Differentiation

FCR-MAC can support **effective channel access differentiation** among traffic classes with different Quality-of-Service (QoS) requirements.

Case **0**: Two Traffic Classes (Best Effort vs Real-Time)

- *Best Effort*: The basic FCR-MAC scheme is implemented:
  1. On-Demand Channel Allocation: **ENABLED**
  2. Channel Reservation in Advance: **DISABLED**
- *Real-Time*: The full FCR-MAC scheme is implemented:
  1. On-Demand Channel Allocation: **ENABLED**
  2. Channel Reservation in Advance: **ENABLED**

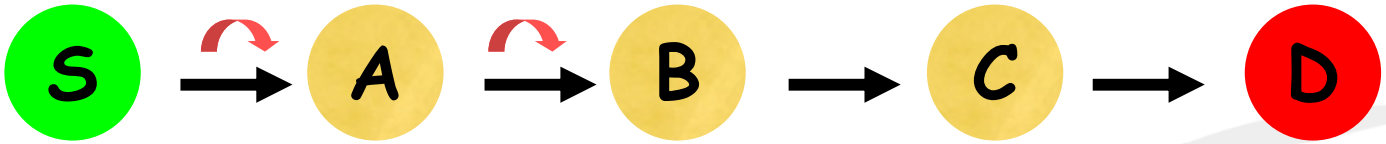
Case **1**: L (L>2) Traffic Classes

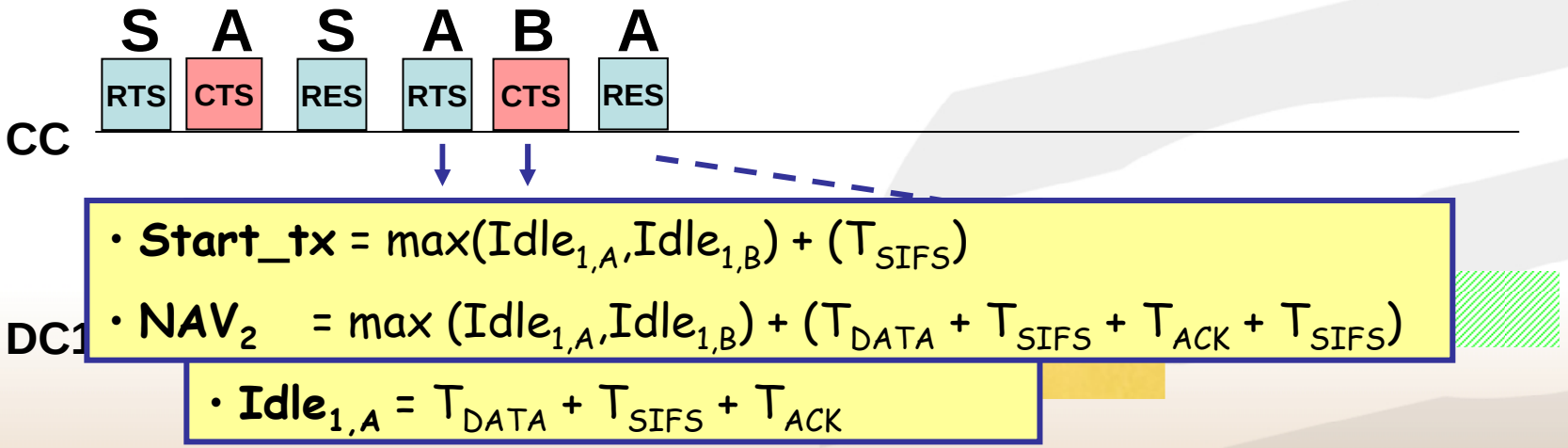
• Each Traffic Class (i.e. k) has a factor $\mathbf{p_k}$ giving the probability for a node to implement the full FCR-MAC scheme.

FCR-MAC Protocol

1. On-Demand Channel Allocation
2. Efficient DATA Channel Utilization
3. Channel Access Differentiation
4. Multi-Hop Communication Support

Multi-Hop Communication Support





1. S reserves **DATA Channel 1** with Node A.
2. Node A reserves DATA Channel 1 **in advance** with the next-hop Node B.
3. After receiving from S, Node A **forwards** the packet to Node B.

Performance Evaluation (1)

Test Performed:

- FCR-MAC Evaluation
  - Single Collision Domain (**SCD**)
  - Multiple Collision Domain (**MCD**)
- FCR-MAC for Channel Access Differentiation
- FCR-MAC for Multi-Hop Communication Support

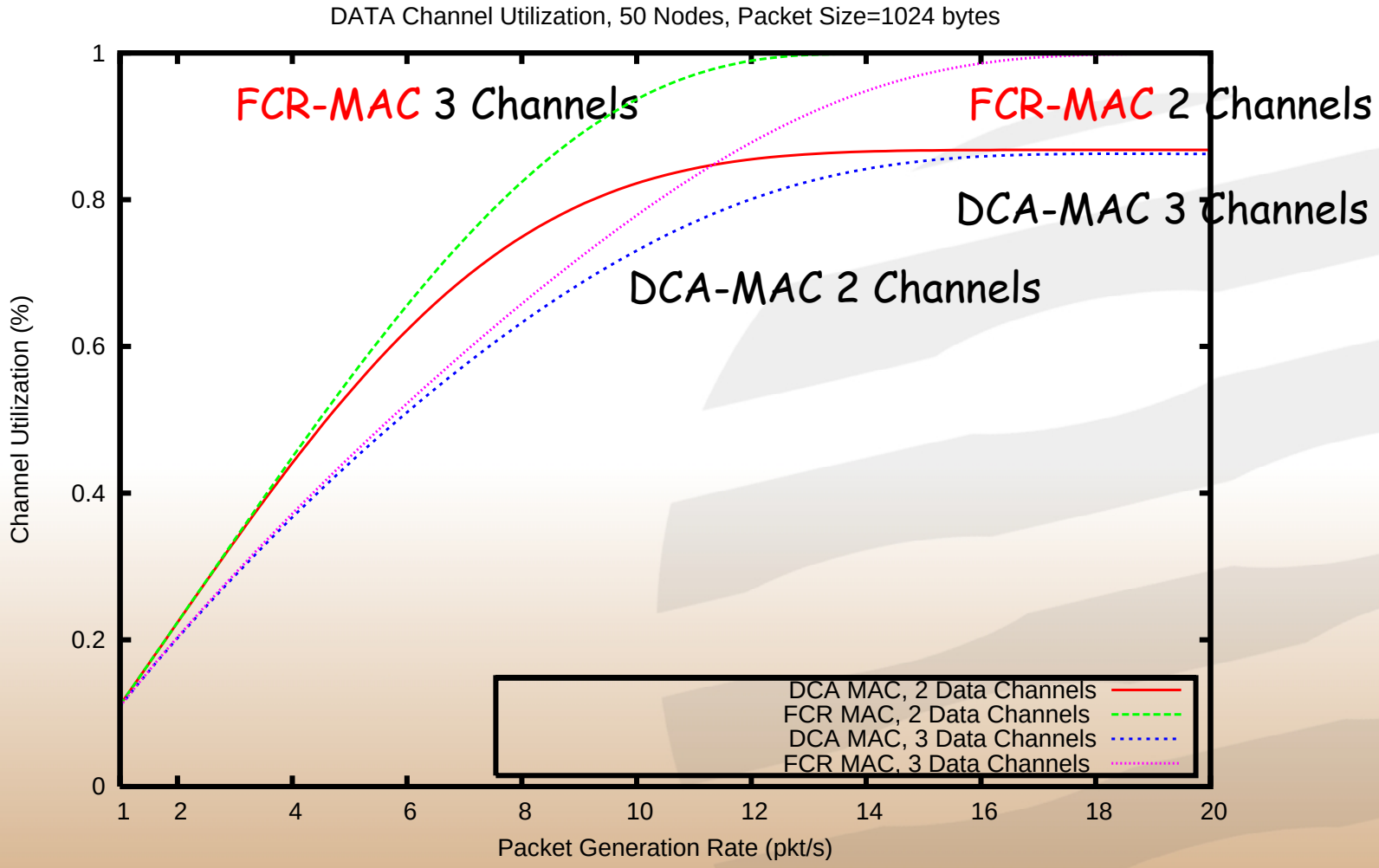
Metrics Considered:

1. System Goodput
2. End-to-End Delay
3. Average Utilization of the DATA Channels

Performance Evaluation (2)

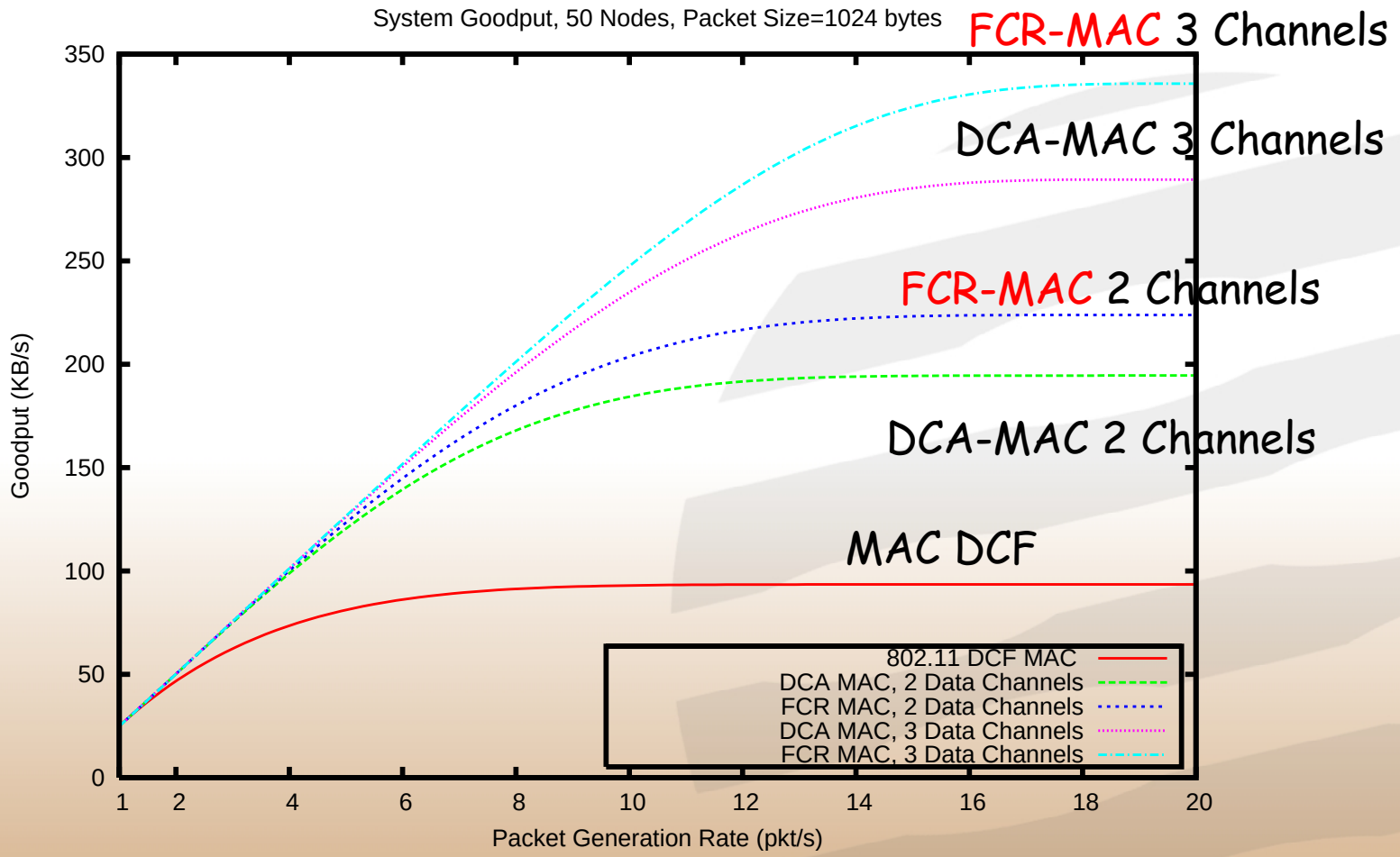
Simulation Tool	Network Simulation vs 2
Protocols	MAC 802.11 DCF, DCA-MAC, FCR-MAC
Number of Nodes	50
Radio Interfaces	2 for each node
Orthogonal DATA channels	{2,3}
Traffic Type	UDP - CBR
Data Packet Size	1024 Bytes

FCR-MAC Evaluation (1)



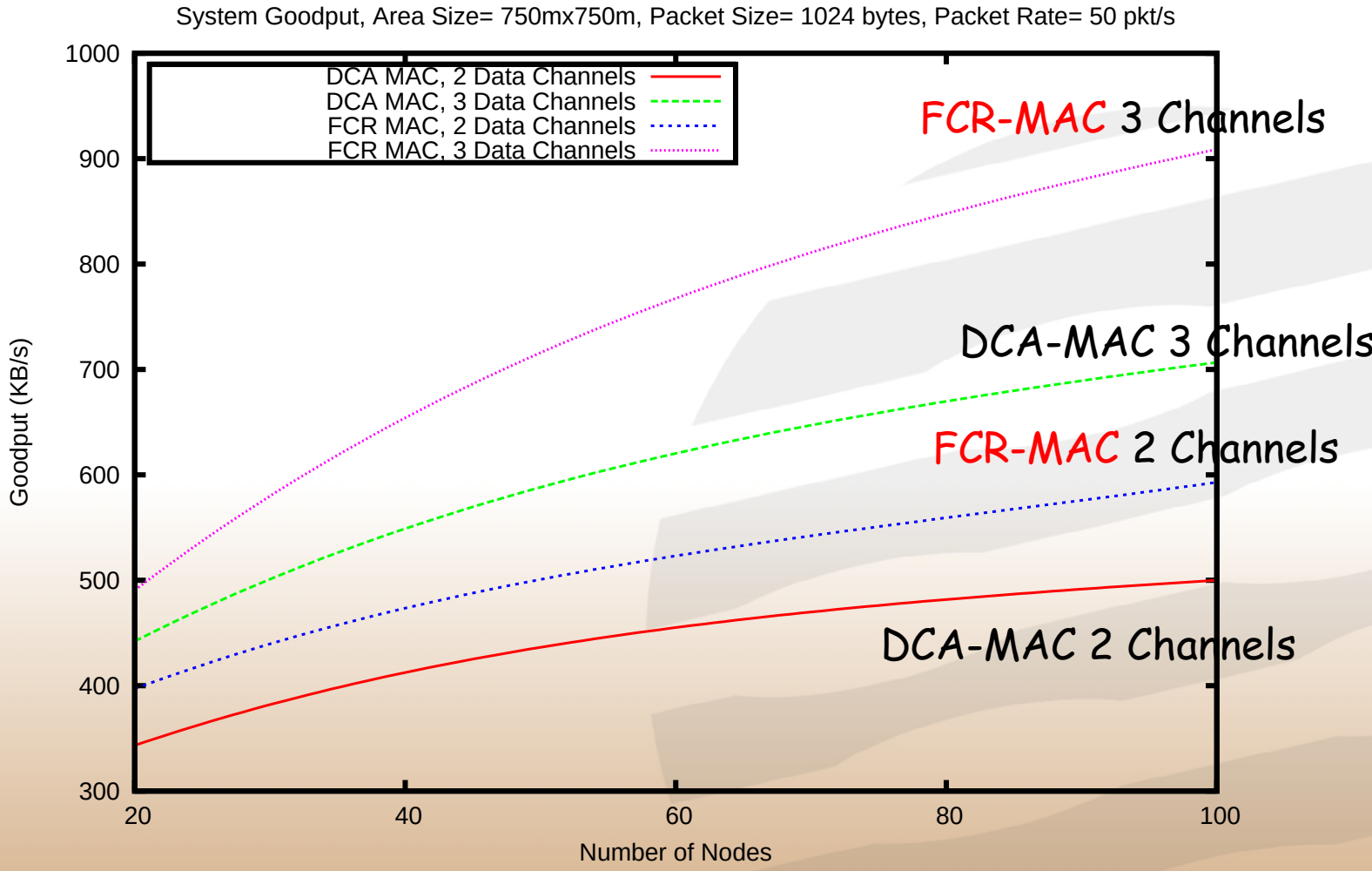
DATA Channel Utilization vs Packet Generation Rate

FCR-MAC Evaluation (2)



System Goodput vs Packet Generation Rate

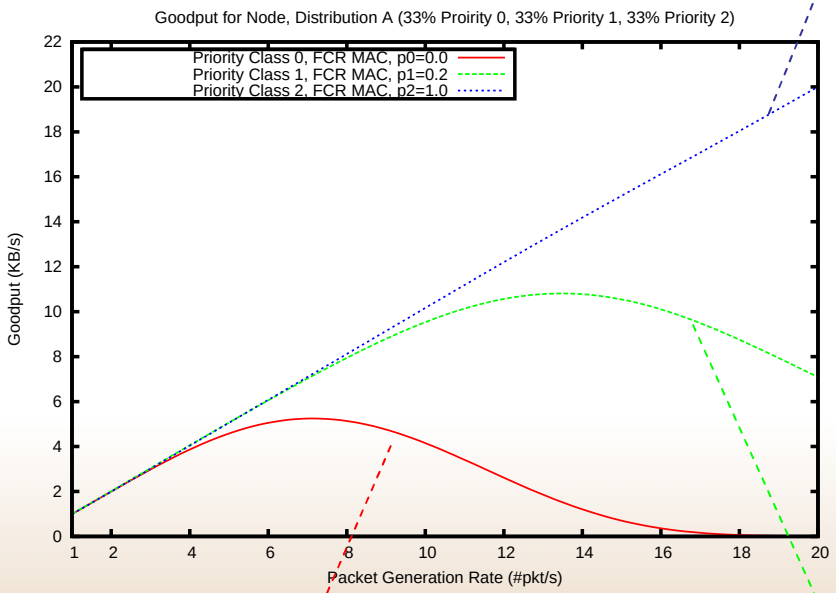
FCR-MAC Evaluation (3)

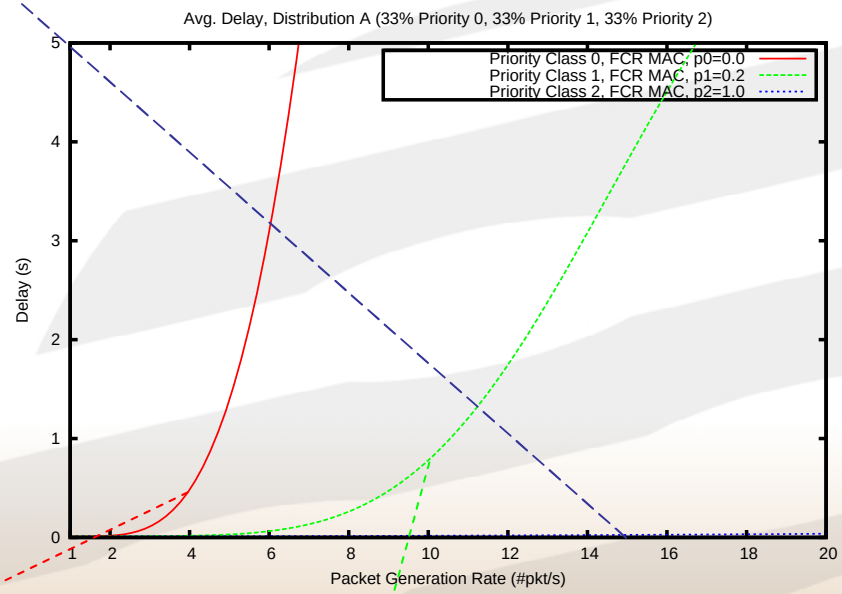


System Goodput vs Number of Nodes (MCD)

Channel Access Differentiation

Class **0**: High Priority, p_0=100%





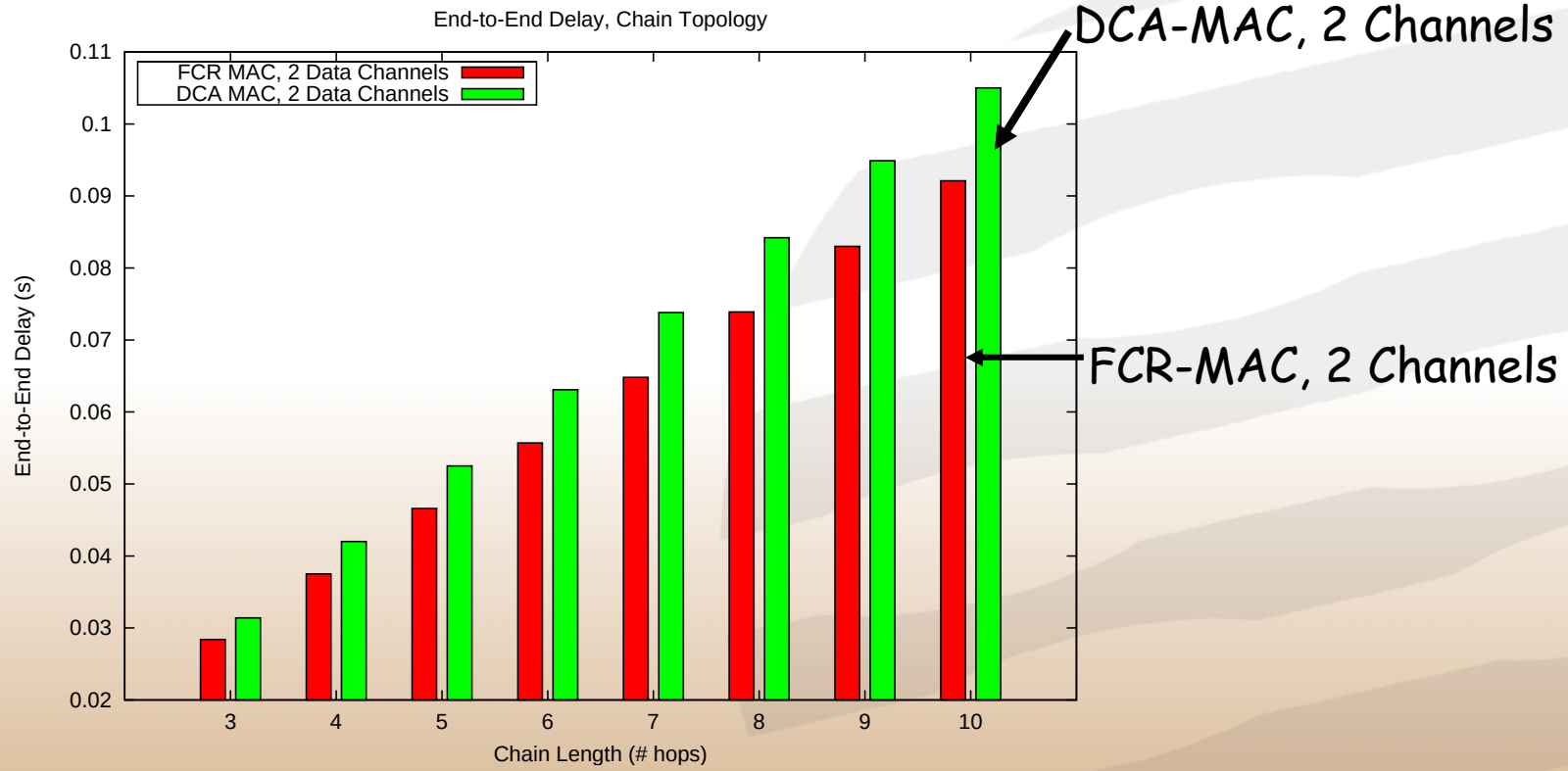
Goodput for Traffic Class

Delay for Traffic Class

Class **1**: Medium Priority, p_1=20%

Class **2**: Low Priority, p_2=0%

Multi-Hop Communication



End-to-End Delay vs Chain Length

Conclusions and Future Works

Future Channel Reservation MAC Protocol (FCR-MAC) for Multi-Radio Multi-Channel Wireless Mesh Networks (WMNs).

1. **On-Demand** Channel Reservation
2. Enhanced **DATA Channel Utilization**
3. Support to **Channel Differentiation** and **Multi-Hop Communication**

Results: high data Channel Utilization, improvements in terms of system goodput and end-to-end Delay

Future works: Extended support to multi-hop communication, Cross-Layer Integration with Routing Protocols for WMNs.

THANKS!

Questions?