

# A New Model for Packet Scheduling in Multihop Wireless Networks

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# Design Goals

- Support **Communication Intensive** Applications in Multihop Wireless Networks
  - Fair Allocation of Channel Bandwidth
  - Maximization of Channel Utilization
- Tradeoff between **Fairness** and **Maximizing** Aggregate System Throughput
- **Distributed** Packet Scheduling Design

# Outline

- Issues in Multihop Wireless Packet Scheduling
- Service Models for Multihop Wireless Packet Scheduling
- An Idealized Centralized Algorithm
- A Distributed Implementation
- Performance Evaluation
- Conclusion and Future Work

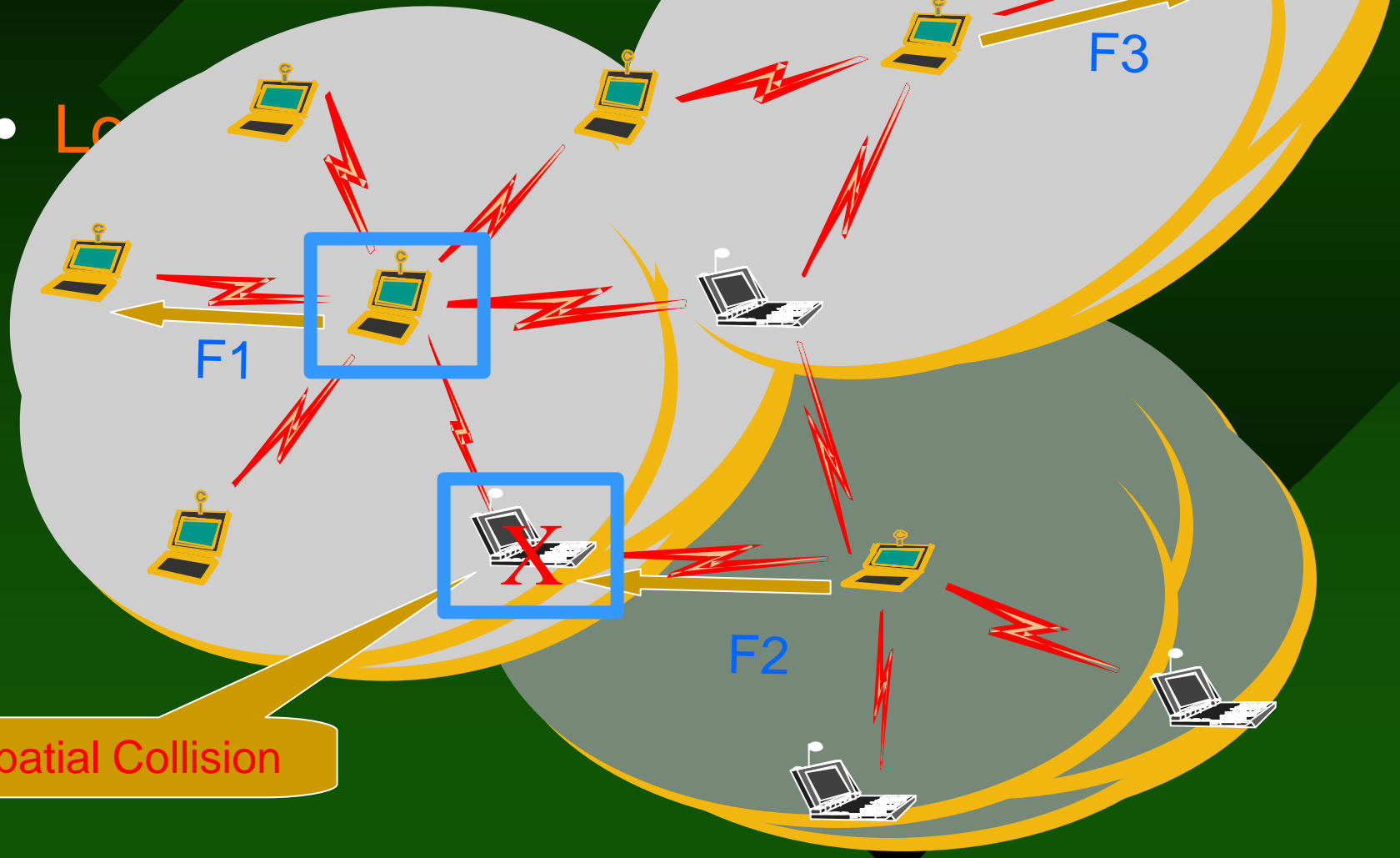
# Network Model

- A **Single** Shared Physical Channel
- **Collision** – Receiver in Transmission Range of More than One Transmitting Node
- **Flow** – Stream of Packets from Source to Destination <Sender, Receiver, Flow\_ID>
- **CSMA/CA** MAC Framework

# Design Issues

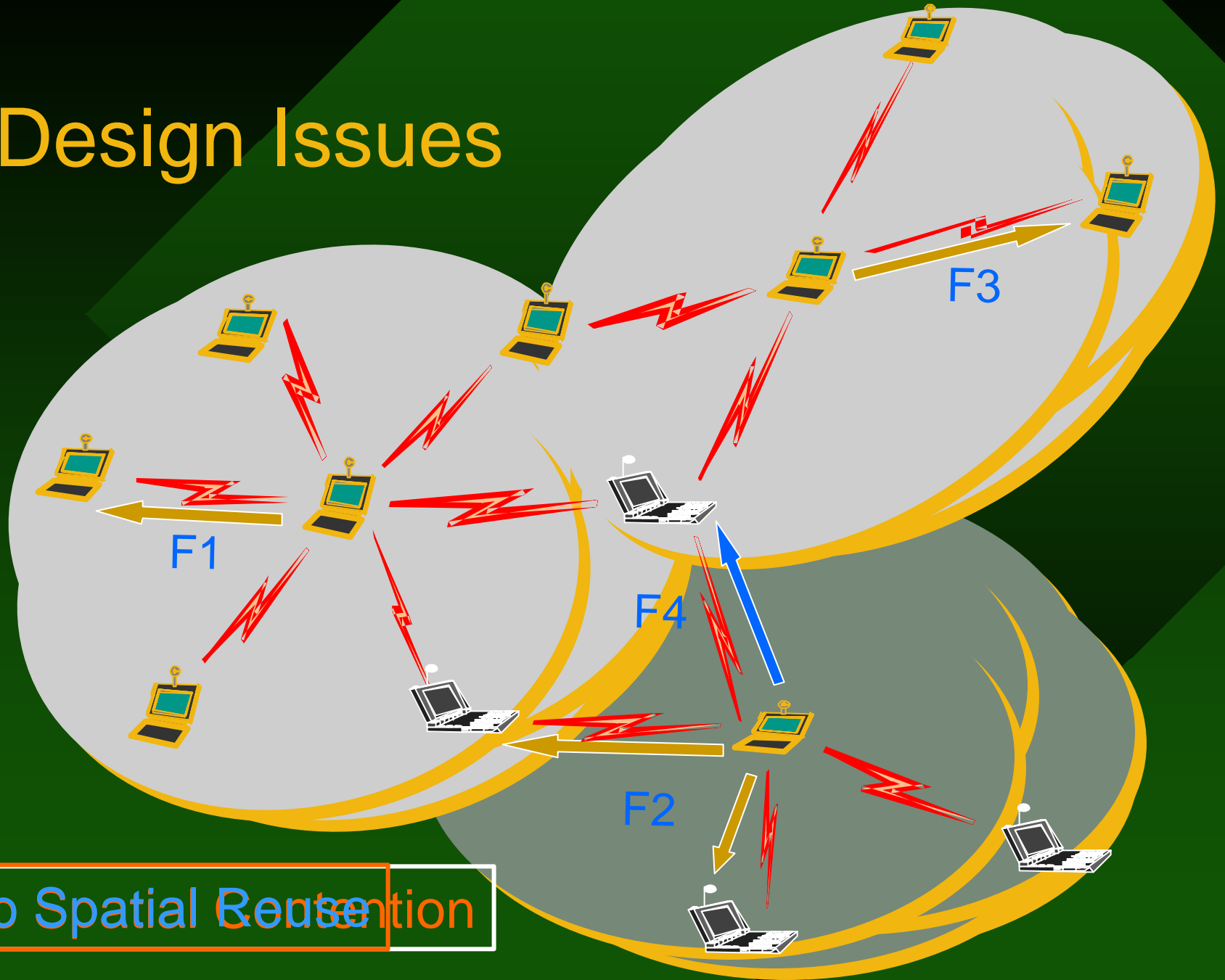
- Local

Spatial Reuse



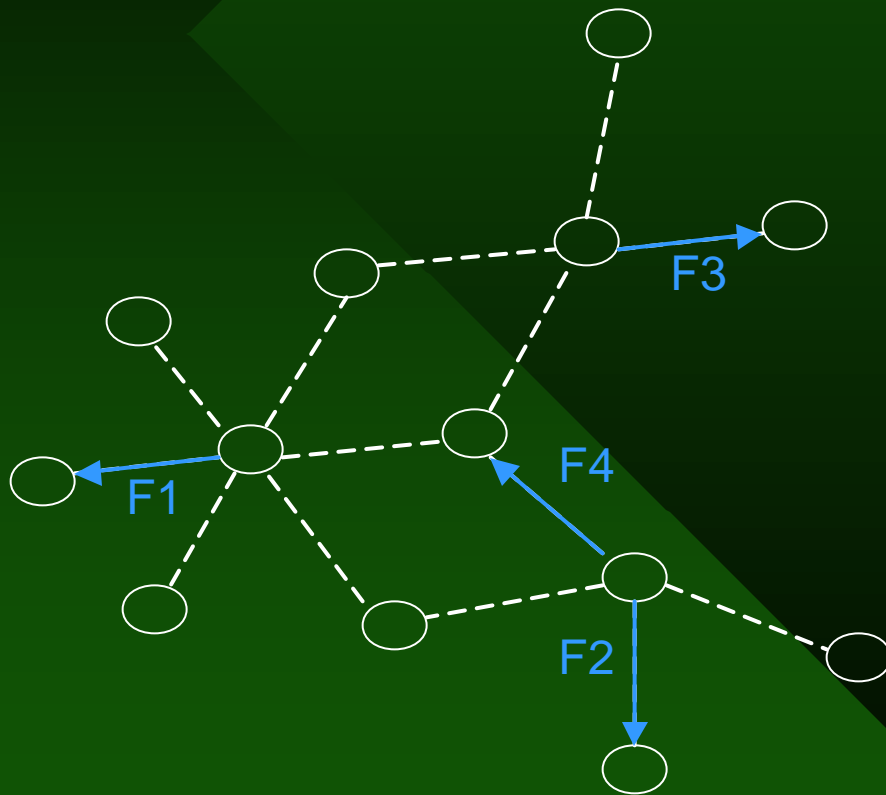
Spatial Collision

# Design Issues

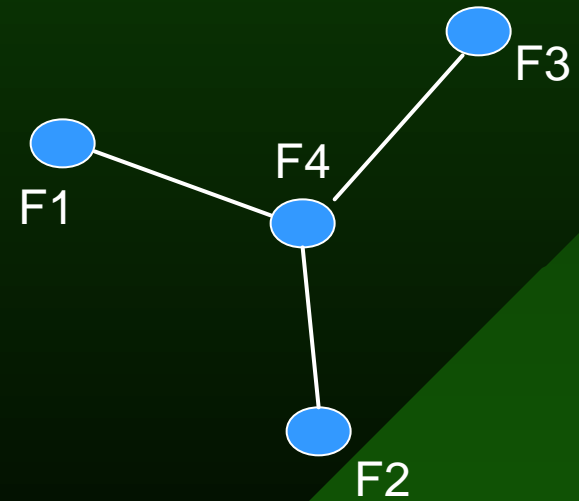


No Spatial Reuse

# Flow Contending Graph



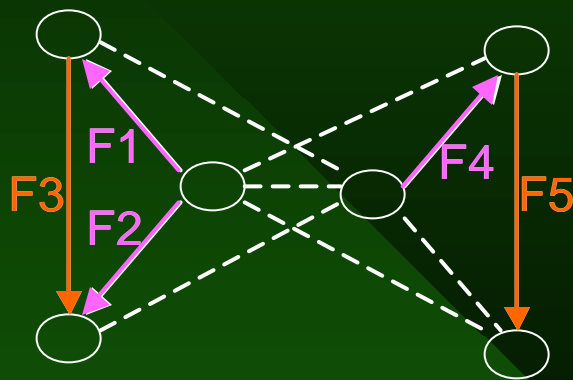
Node Graph



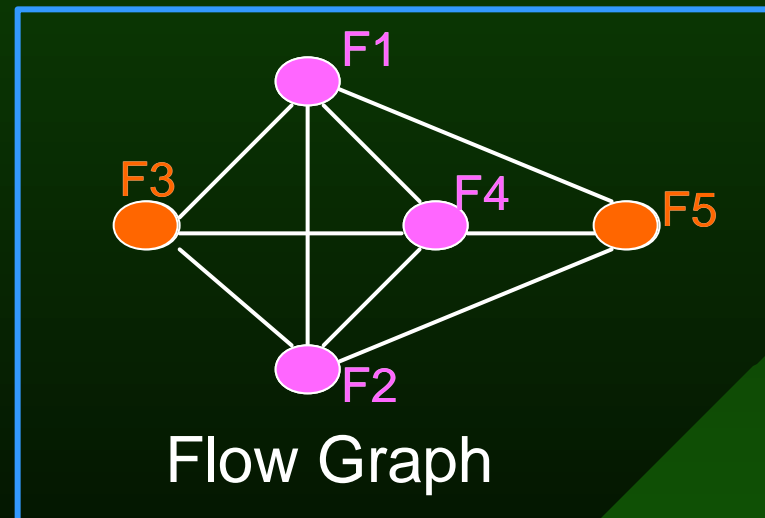
Flow Graph

# Design Issues (*cont'd*)

- Inherent **Conflict** between Achieving Fairness & Maximizing Channel Utilization



Node Graph

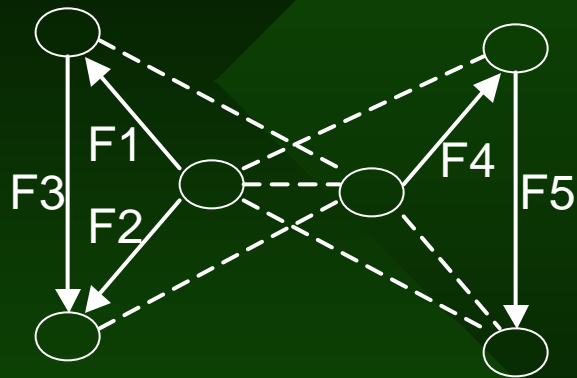


Flow Graph

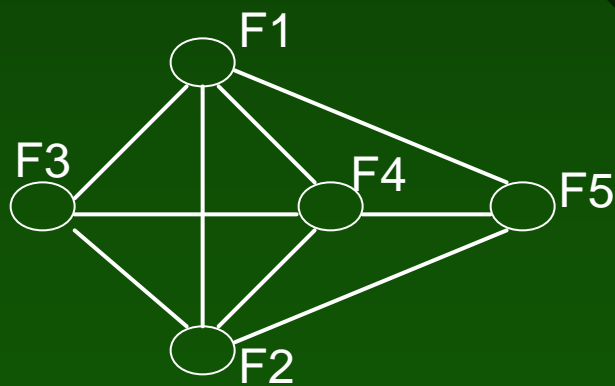
- To Maximize Channel Utilization

- Schedule **F3 & F5** always (**MIS**)
- Schedule the **Maximal Number of Flows** in Flow Graph
- Starve **F1, F2 & F4**

# Design Issues (*cont'd*)

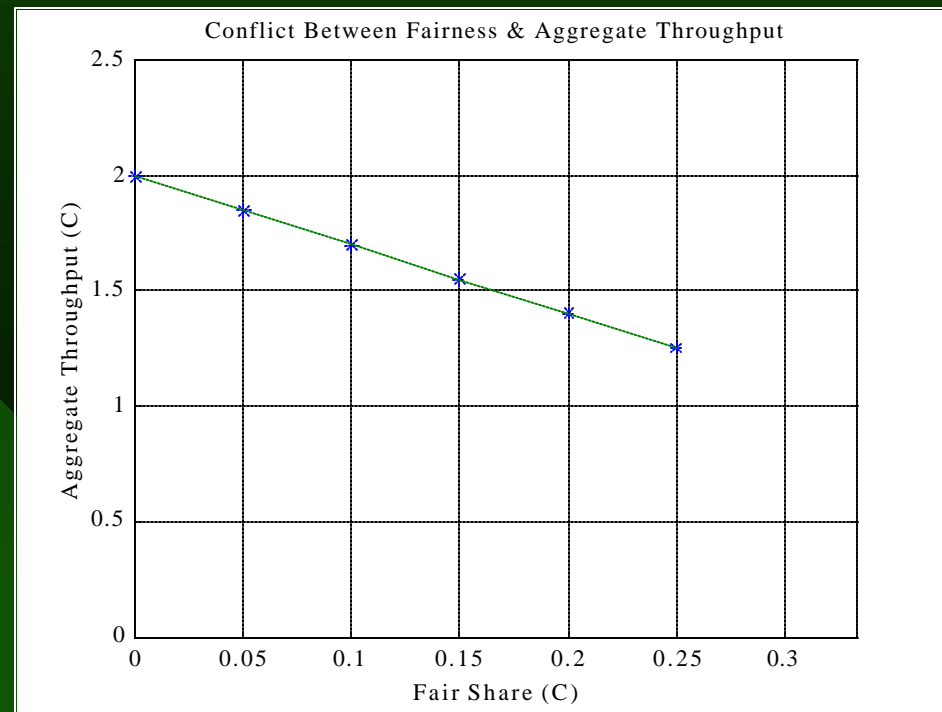


Node Graph



Flow Graph

*Inherent Conflict: Fairness, Throughput*



Fairness v.s. Aggregate Throughput

## Design Issues (*cont'd*)

- *Distributed Nature* of Packet Scheduling in Generic Multihop Wireless Networks
  - Unlike *Wireline* or *Packet Cellular* Networks. NO *Single Logical Entity* for Scheduling
  - NO *Direct Access* to All Contending Flow Info
- Provide QoS at Finest Time Scale (Packet Level)

# Solution Space

- One End – Ensure **Fairness** Always
  - “*Fair Scheduling in Broadcast Environments*,” by N. Vaidya & P. Bahl, Technical Report 1999
  - “*A Topology-Independent Fair Queuing Model in Ad Hoc Wireless Networks*,” by H. Luo & S. Lu, to Appear at *ICNP 2000*
  - At the Cost of Channel **Utilization**
- The Other End – **Maximize** Channel Utilization Always
  - Schedule **Largest Number** of Non-conflicting Flows
  - **Starvation** of Certain Flows

# Tradeoff Between Fairness & Maximizing Channel Utilization

- Each Flow is Provided a **Basic Fair Share**
  - Global Topology-Independent Fairness
  - Local Topology-Dependent Fairness
- Further **Maximize Channel Utilization**

# Global Topology-Independent Fairness Model

- Every Flow with Weight  $r_i$  Receive a Proportional Basic Fair Share:

$$\frac{r_i}{\sum_{j \in B(t_1)} r_j} C(t_1, t_2)$$

- Flow Set  $B(t_1)$ : All Backlogged Flows in Connected Flow Graph – Global Flow Information Propagation
- A Priori Fair Share Bounds
- Topology Independent

# Local Topology-Dependent Fairness Model

- Every Flow with Weight  $r_i$  Receive a Proportional Basic Fair Share:

$$\frac{r_i}{\sum_{j \in B_i(t_1)} r_j} C(t_1, t_2)$$

- Flow Set  $B_i(t_1)$ : Backlogged Flows in Flow's Local Contending Flow Set – Only Local Flow Information Necessary
- Larger Basic Fair Share
- Topology Dependent
- Lower Spatial Channel Reuse

# Maximize Spatial Channel Reuse

- Maximizing Spatial Reuse is Equivalent to *Maximum Independent Set* (MIS) Problem in Flow Contending Graph
- Solution to **MIS** Problem
  - NP Complete
  - Greedy Approximation: Minimum Degree First

# An Example

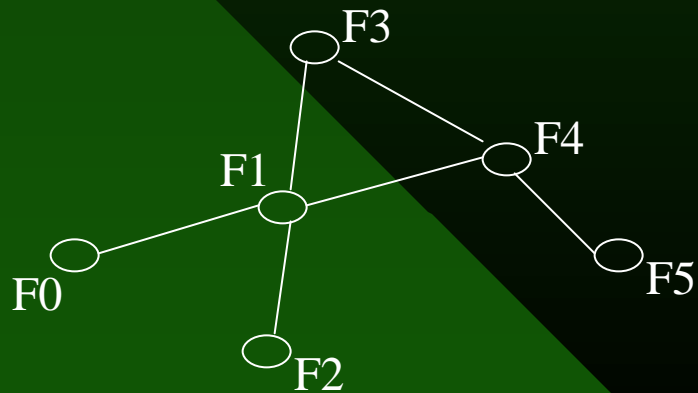
Flow ID : F0 F1 F2 F3 F4 F5

Spatial Reuse :

Basic Fair Share :

Time : 

Flow Graph :



# An Example

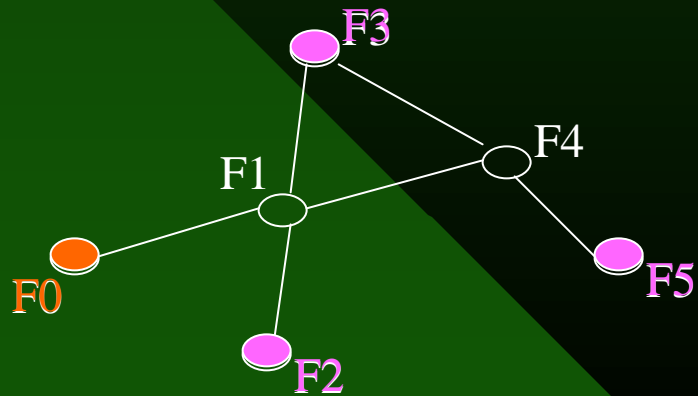
Flow ID : F0 F1 F2 F3 F4 F5

Spatial Reuse :  
F2  
F3  
F5

Basic Fair Share : F0



Flow Graph :



# An Example

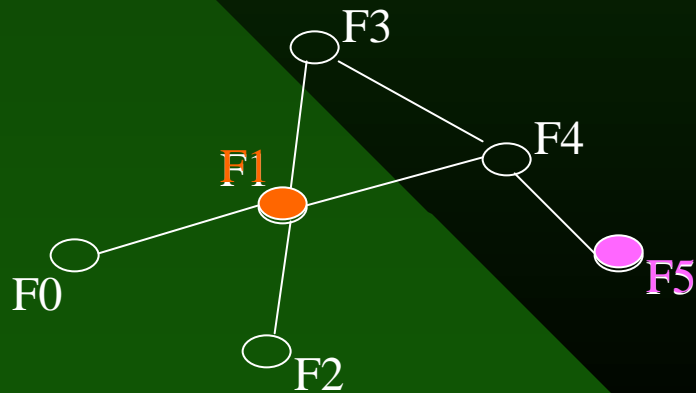
Flow ID : F0 **F1** F2 F3 F4 **F5**

Spatial Reuse : F2  
F3 F5  
F5

Basic Fair Share : F0 F1

Time : 

Flow Graph :



# An Example

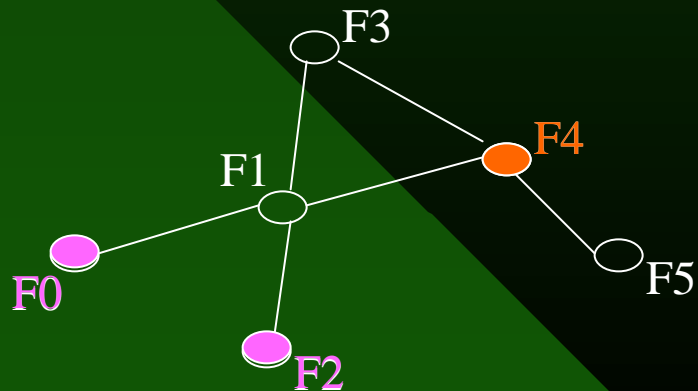
Flow ID : F0 F1 F2 F3 F4 F5

Spatial Reuse : F2 F0 F2  
F3 F5 F2  
F5

Basic Fair Share : F0 F1 F4



Flow Graph :



# An Example

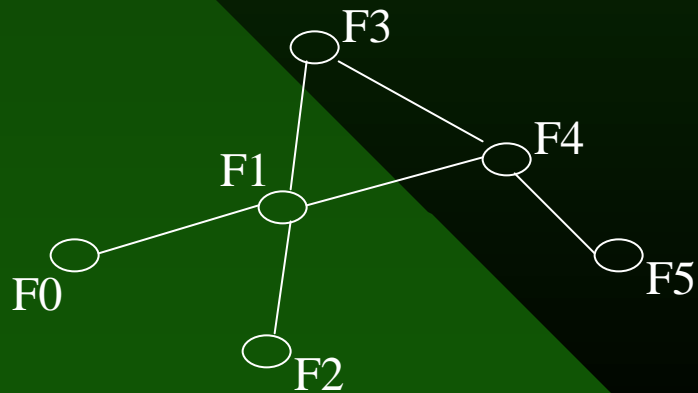
Flow ID : F0 F1 F2 F3 F4 F5

Spatial Reuse : F2  
F3 F5 F0  
F5 F2 .....

Basic Fair Share : F0 F1 F4 .....

Time : 

Flow Graph :



# Centralized Algorithms

- Ensure Per-flow Basic Fair Share
  - Fair Queuing
- Maximize Spatial Reuse
  - Simultaneously Schedule *MIS* of other Non-conflicting Flows
- Analytical Performance Bounds
  - Basic Fair Share Service Bound
  - Optimal Aggregate Channel Utilization

# Distributed Implementation

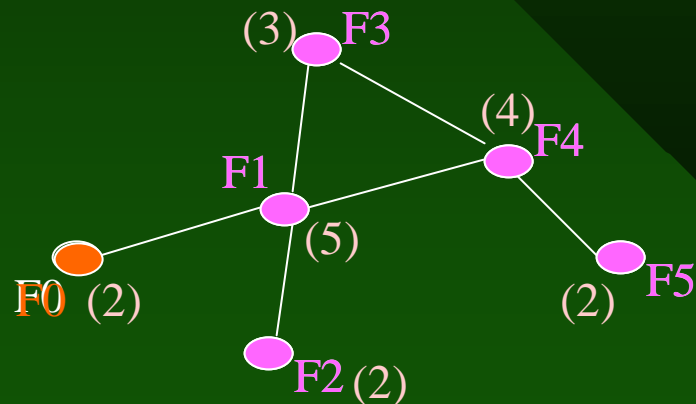
- Two Key Issues
  - How to **Ensure** Fair Share to Every Flow
  - How to **Maximize** Spatial Reuse Distributedly
- Solution
  - Within CSMA/CA MAC Framework
  - Basic Fair Share: Approximate **WFQ** with Modified **WRR**
  - Maximizing Spatial Reuse: Backoff Based Implementation of **MIS** Greedy Algorithm

# Distributed Implementation

- Backoff Based Implementation of *MIS Greedy* Approximation
  - Smaller-Degree Flow Transmits First
  - For Potential Spatial Reuse, Set *Backoff = Flow\_Degree*
- Integration
  - Basic Fair Share has Priority Over Spatial Reuse
  - For Basic Fair Share, Set *Backoff = Zero*

# An Example

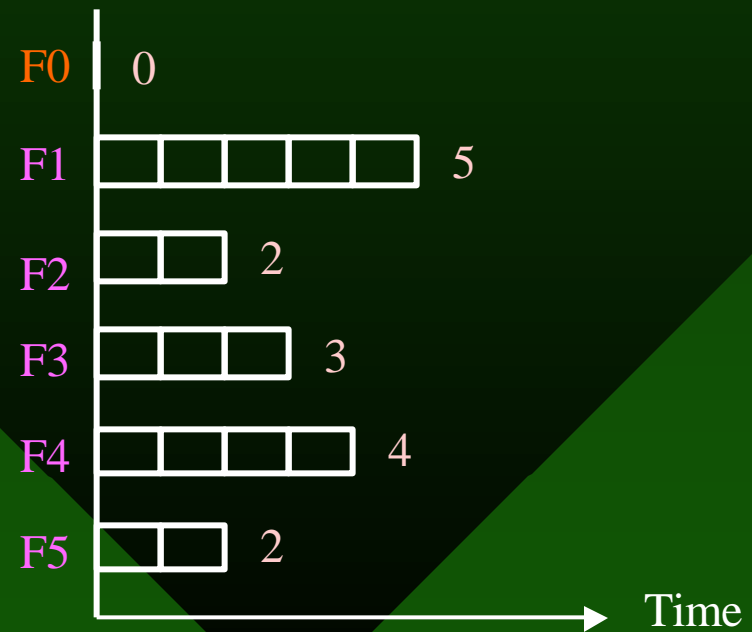
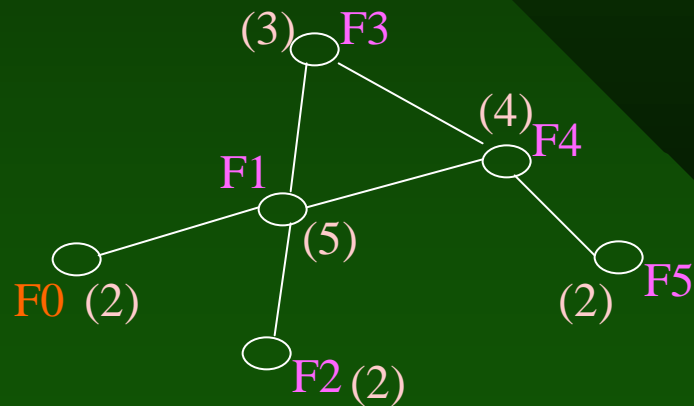
- Set *Backoff* = *Zero* or *Flow\_Degree*



- *F0* Contends for Fair Share According to WRR
- *F1, F2, F3, F4 & F5* Contend for Spatial Reuse

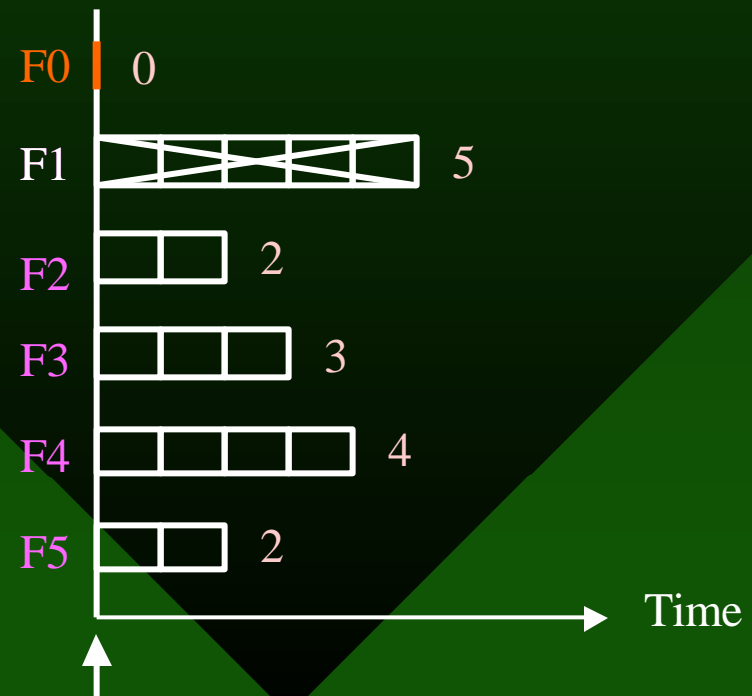
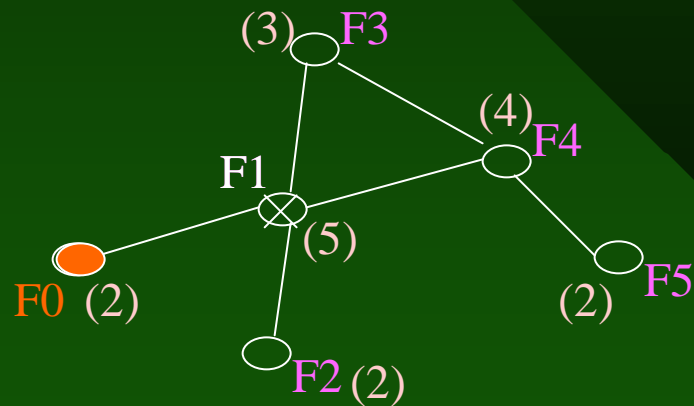
# An Example

- Set *Backoff* = *Zero* or *Flow\_Degree*



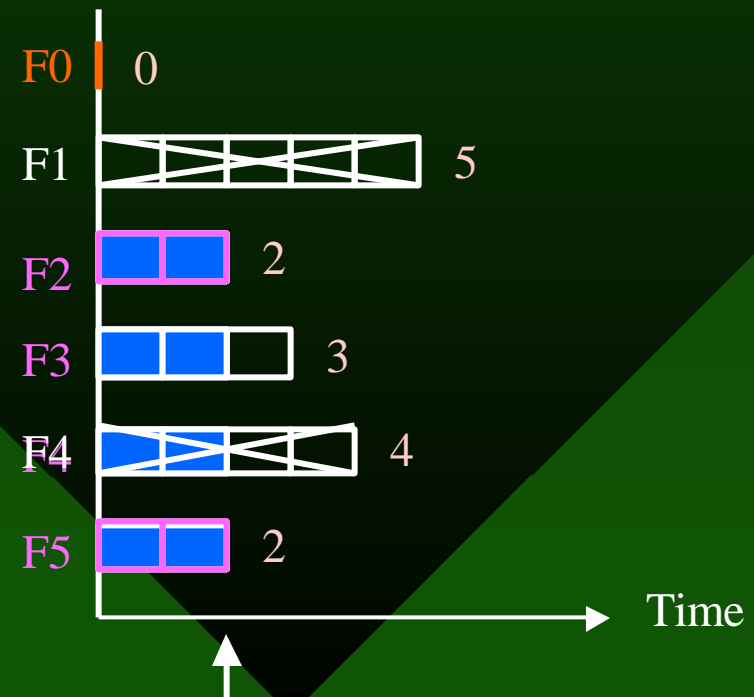
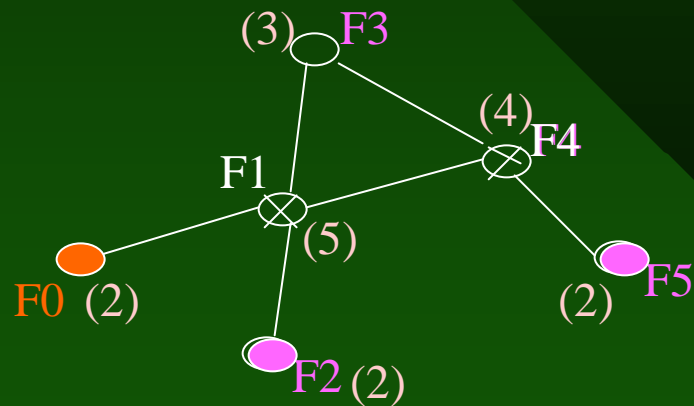
# An Example

- Set *Backoff* = *Zero* or *Flow\_Degree*



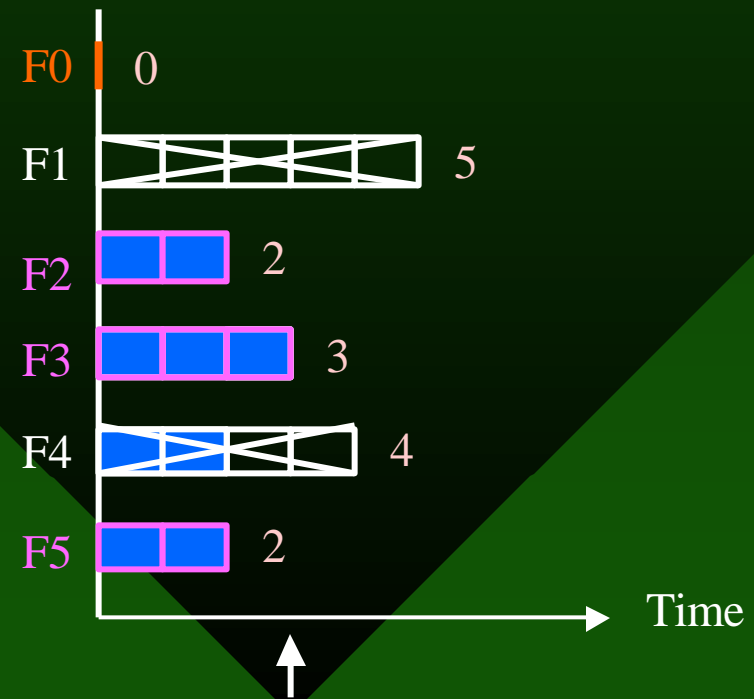
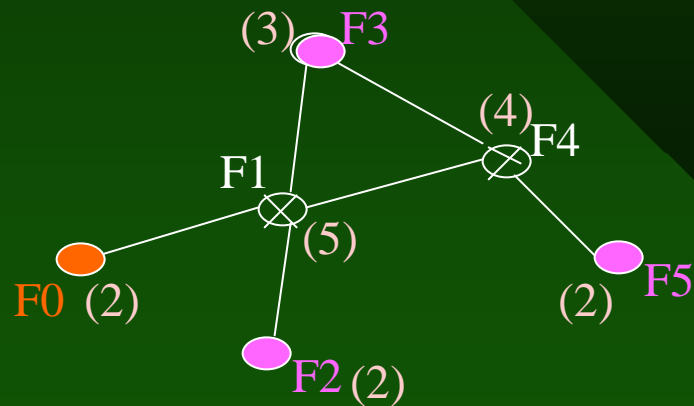
# An Example

- Set *Backoff* = *Zero* or *Flow\_Degree*



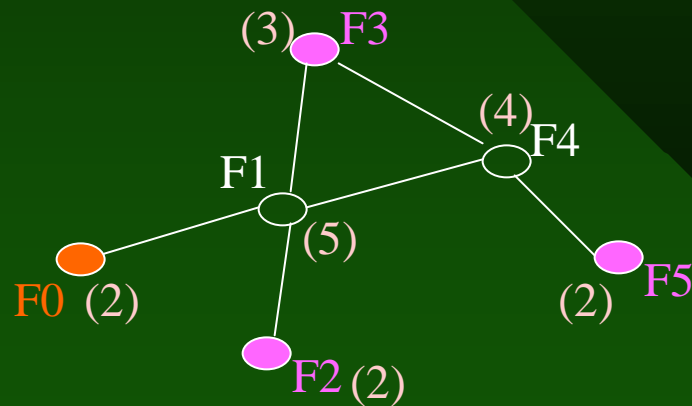
# An Example

- Set *Backoff* = *Zero* or *Flow\_Degree*



# An Example

- Set *Backoff* = *Zero* or *Flow\_Degree*



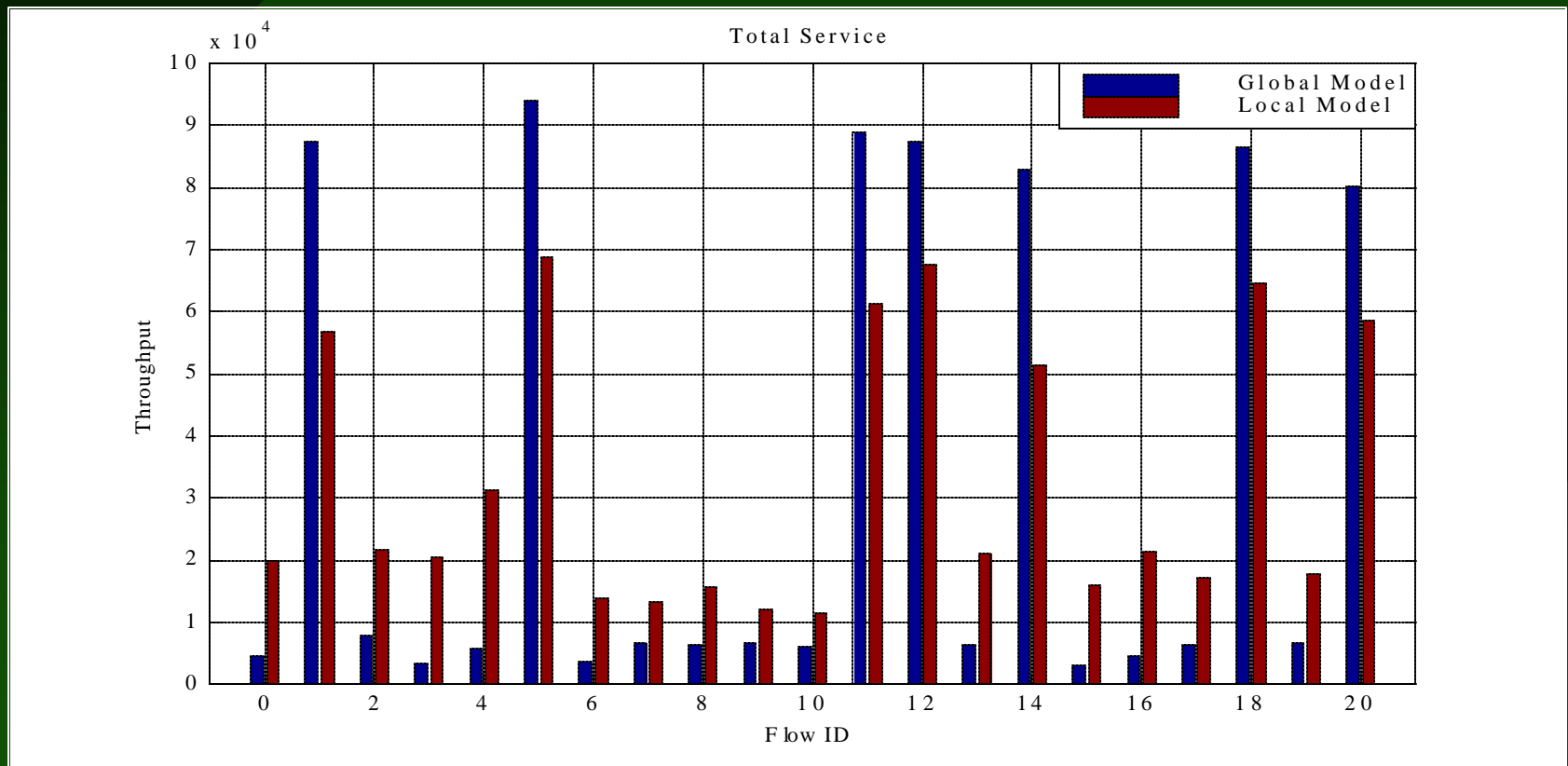
- *F0* is Provided its Fair Share Service Bound
- *F2*, *F3* & *F5* Maximize Spatial Reuse – *Maximum Independent Set*

# Other Issues

- Detailed MAC Layer Design
  - CSMA/CA Paradigm
- Global Flow Information (*i.e.* Flow Weights) Propagation for Global Fairness Model
  - Conflict-free Multicast Tree

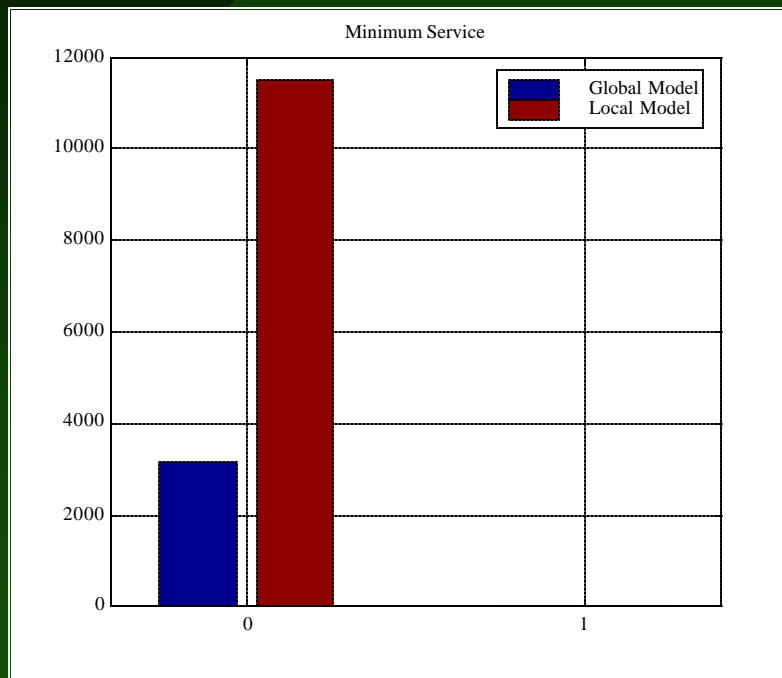


# Simulation Example (*cont'd*)

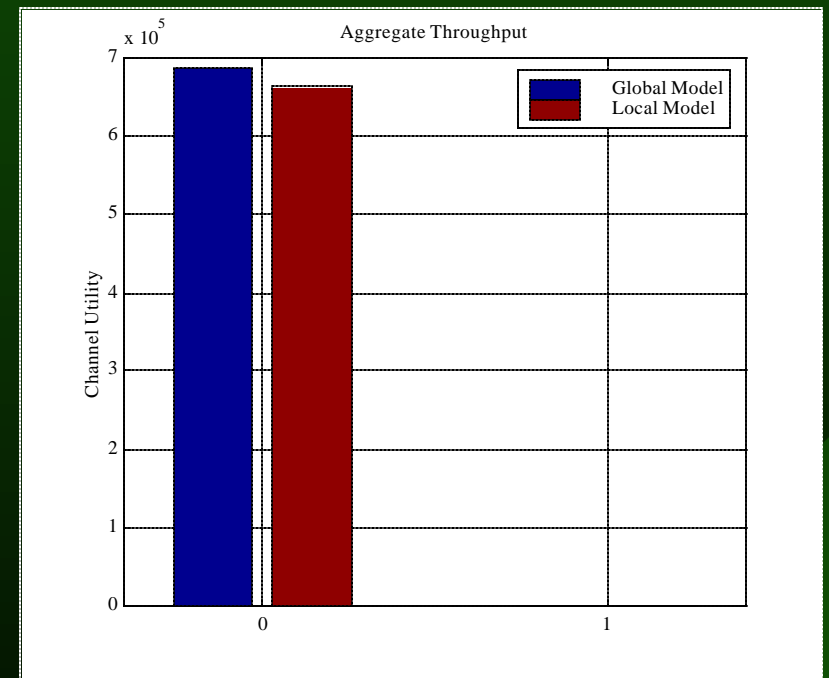


Per-Flow Throughput Comparison

# Simulation Example (*cont'd*)



Minimal Per-flow Throughput  
Comparison

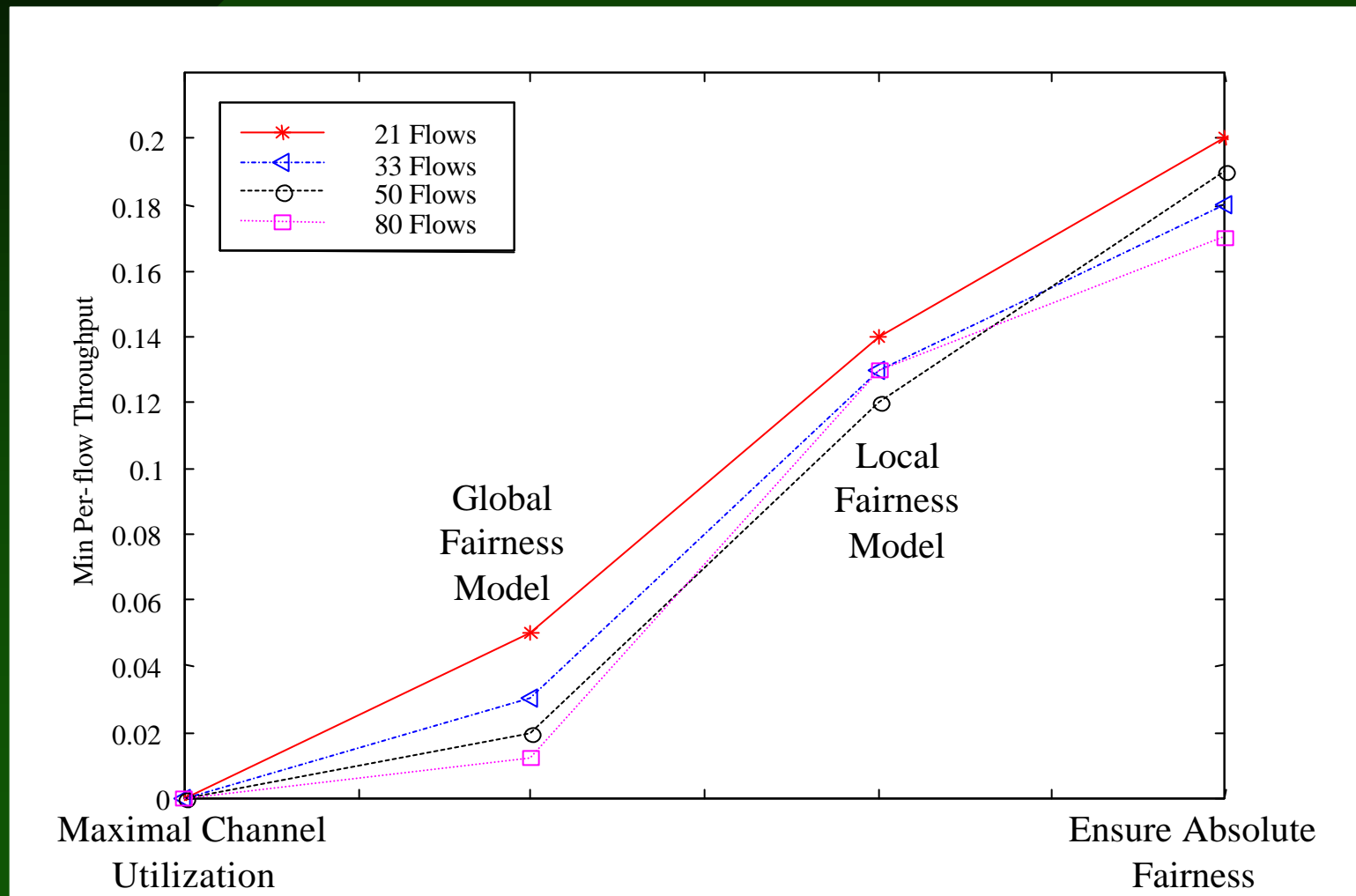


Aggregate Throughput  
Comparison

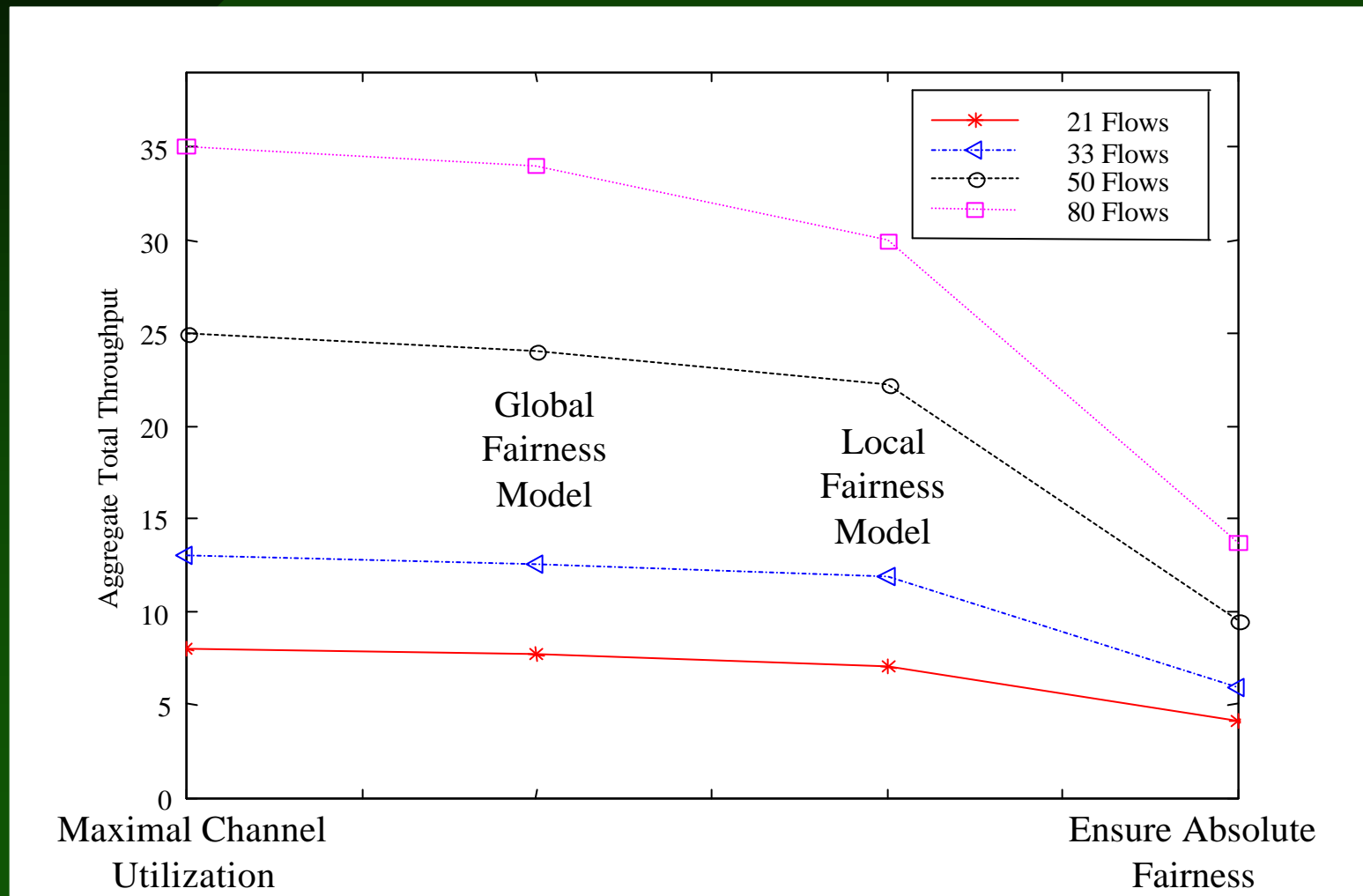
# Summary of Simulation Findings

- Comparison of
  - Minimum Per-Flow Throughput
  - Aggregate System Throughput
- Four Approaches
  - Always Maximize Channel Utilization
  - Global Topology-Independent Fairness Model
  - Local Topology-Dependent Fairness Model
  - Always Ensure Fair Allocation of Communication Bandwidth

# Minimal Per-Flow Throughput



# Aggregate System Throughput



# Related Work

- Distributed Fair Queuing
  - Adapt Fair Queuing Algorithm to **Wireless LAN**
  - Distributed Fair Scheduling
  - Backoff Based on Virtual Time
  - No Explicit Effort to Maximize Spatial Channel Reuse
  - “*Distributed Fair Scheduling in a Wireless LAN*,” by N. Vaidya, P. Bahl & S. Gupta, at MOBICOM 2000

## Related Work (*cont'd*)

- MAC Layer Approach
  - Arbitrate Medium Access Control
  - Seek to Maximize Spatial Reuse of Bandwidth
  - Fairness on Wireless Links (not Packet Flows)
  - Work with TDMA Cycle
  - No Tradeoff between Fairness & Maximal Channel Utilization
  - *I. Chlamtac & A. Lerner*, IEEE/ACM Trans. Communications, Jul. 1987
  - *J. Ju & V.O.K. Li*, IEEE Trans. Networking, Jun. 1998
  - *Z. Tang & J.J. Garcia-Luna-Aceves*, WCNC, Sep. 1999
  - T. Nandagopal, T. Kim, X. Gao & V. Bharghavan, MobiCom Aug. 2000

# Summary & Future Works

- Two-tier Service Models for Multihop Wireless Packet Scheduling
  - Ensure **Basic Fair Share** to Individual Flows
  - Maximize Further **Spatial Reuse**
- A Backoff-based Distributed Algorithm Closely Realize Ideal Models
- Improve the Design of the Distributed implementation
  - Interaction with underlying MAC Layer Protocols
  - Frequent Node Mobility
- More Extensive Simulation Evaluation