

# COOPERATION IN WIRELESS COMMUNICATION NETWORKS

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IEEE Wireless Communications, April 2012



# Outline

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Introduction

Potential Benefits

Challenging Issues at Different Protocol Layers




Future Directions

Conclusion

# Introduction

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## Cooperation:

- The process of working together
- Social science & Economics  Wireless communications
  -  User mobility support
  -  Limited resources

## Cooperation Scenarios

Improve channel  
reliability through  
spatial diversity

Improve throughput  
through resource  
aggregation

Achieve seamless  
service provision

# Introduction Cont.

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- Modifications to the networking protocol

- Questions:

- What are potential benefits of cooperation in wireless communication networks?
- What are challenging issues that arise at different layers of the protocol stack to support cooperation and how can we handle them?
- What are open research issues?

# Outline

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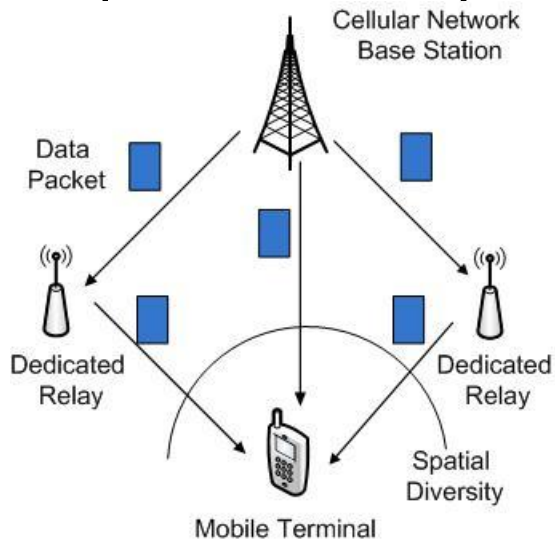
# Potential Benefits

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## 1 Improved Channel Reliability

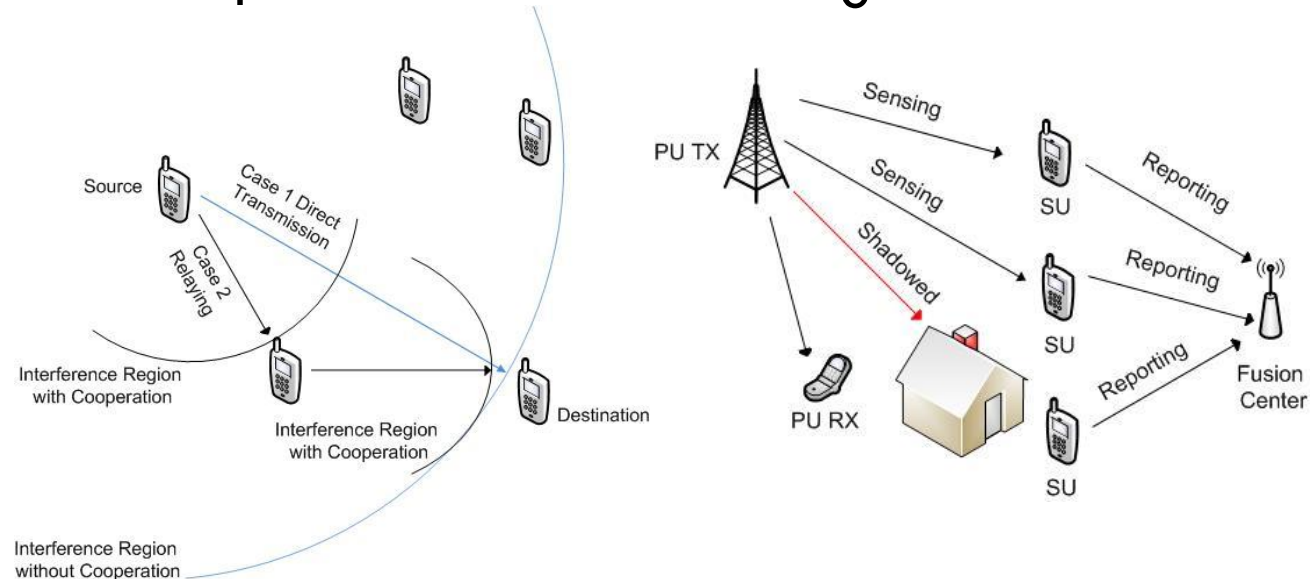
Mitigating Channel Impairments

Spatial Diversity



Interference Reduction

Txion power reduction Solving hidden terminal



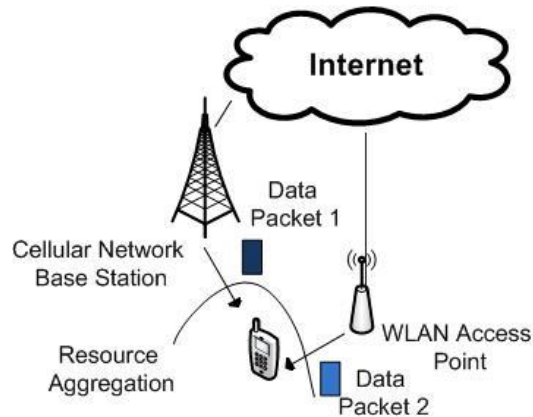
# Potential Benefits Cont.

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## 2 Improved System Throughput



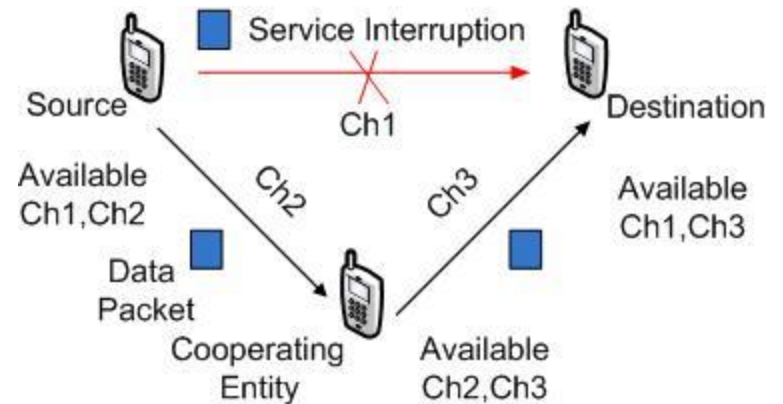
### Resource Aggregation



## 3 Seamless Service Provision



### Substitute Path



## 4 Operation Cost Reduction



Improved Energy  
Efficiency



Network Coverage  
Extension

# Outline

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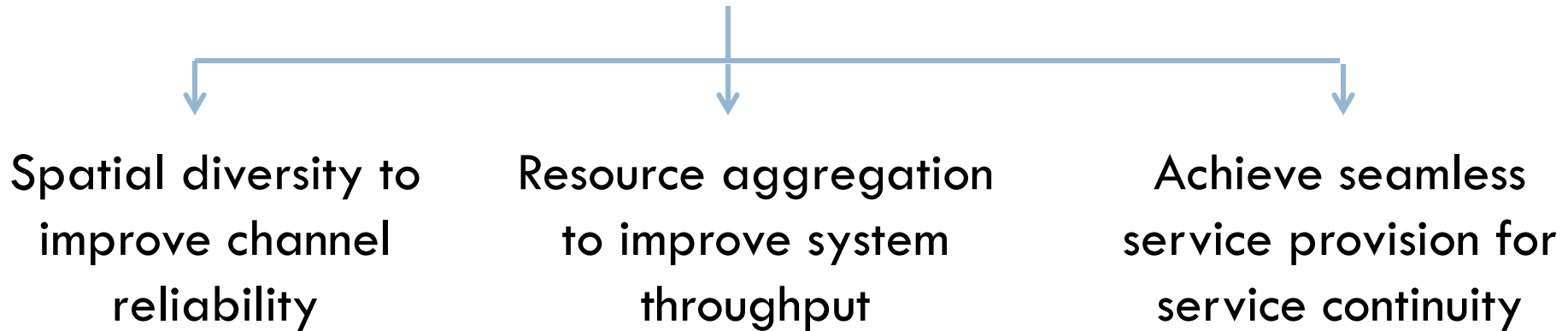
Conclusion



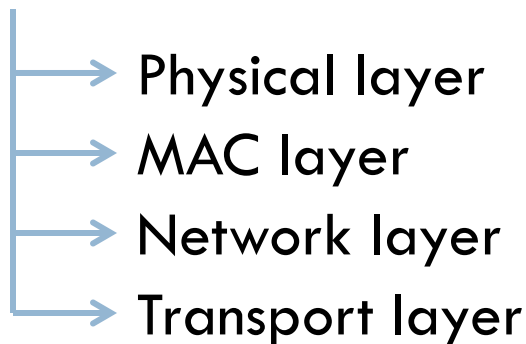
# Challenging Issues

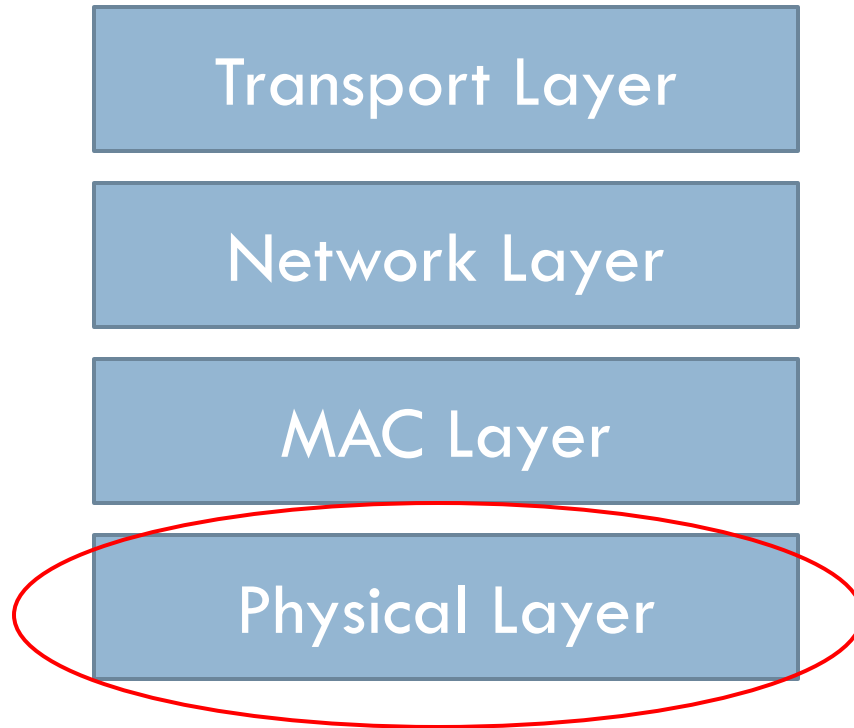
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- Objective → Improve QoS



- Challenging issues at different layers of protocol stack





# Challenging Issues → Physical Layer

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## 1 Challenges at Physical Layer

### Spatial Diversity

- Cooperative strategies:

AF, DF, and CC

Channel  
information

Hardware  
complexity

- Exchange
- Update

- Sample buffer
- Combiner

### Resource Aggregation & Seamless Service Provision

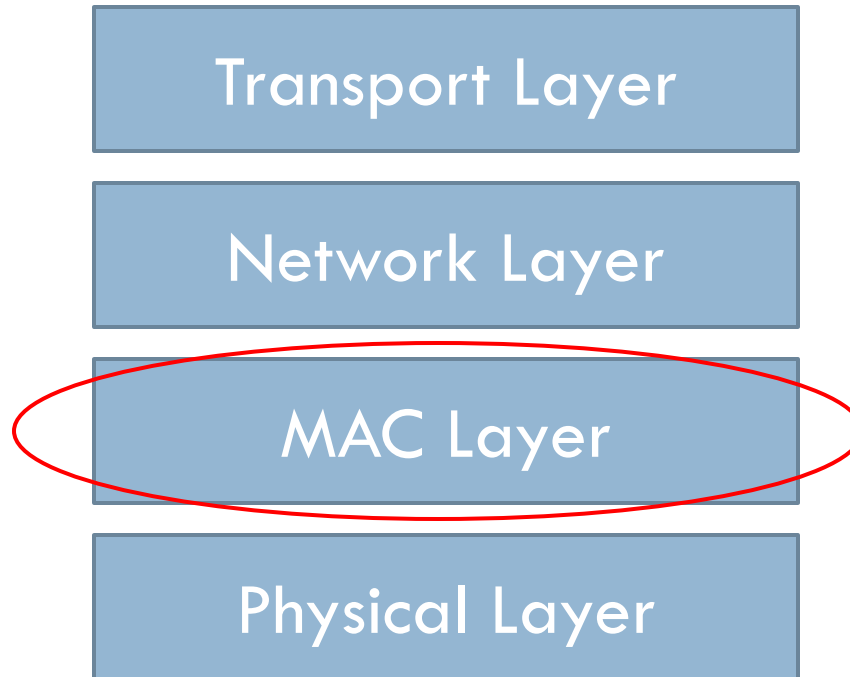
- TX and RX on multiple channels simultaneously

Multiple radio  
interfaces

Single radio  
interface

- Parallel physical layers

- D-OFDM



# Challenging Issues → MAC Layer

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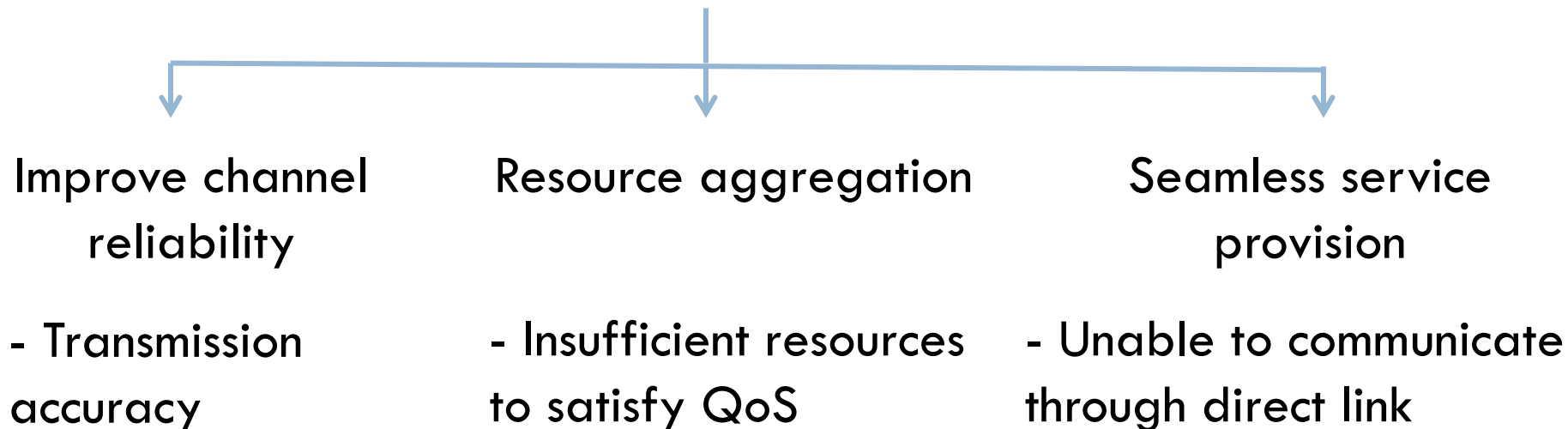
## ② Challenges at MAC Layer

### A. When to use cooperation?

- Cooperation not always beneficial

➔ Cooperation gain too small to compensate for its cost

### Adaptive MAC Protocol



# Challenging Issues → MAC Layer Cont.

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- Consider cooperation overhead in making cooperation decision

→ Signaling overhead required to select cooperating entities

EX: Cooperation to improve channel reliability is beneficial only when:

Payload length is sufficiently large compared to signaling overhead

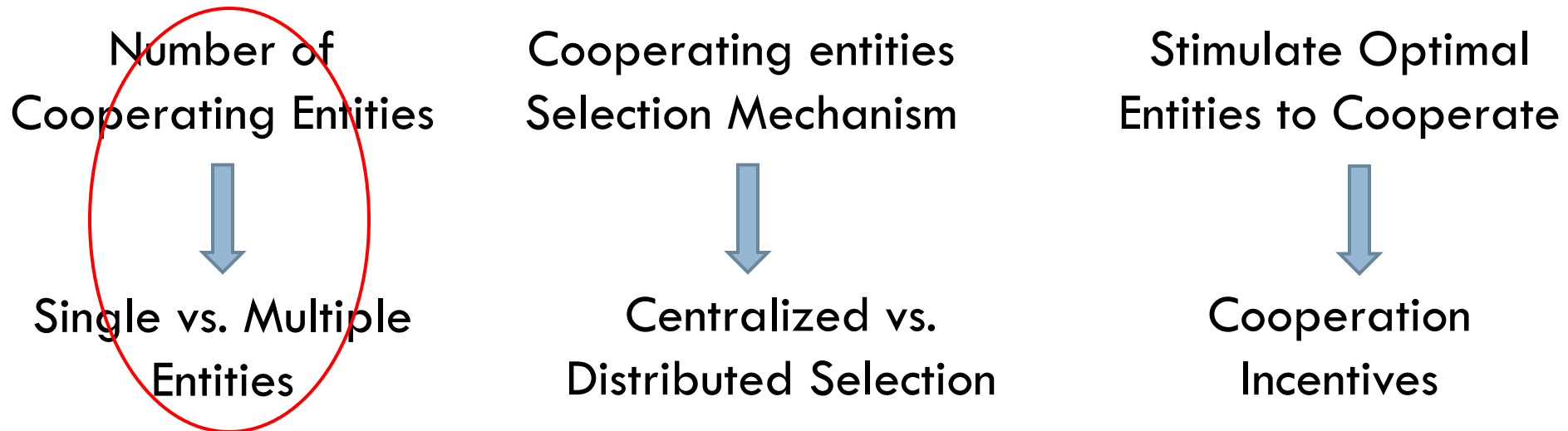
- Decision is based on instantaneous measurements of channel gain and achieved throughput

→ Cross-layer design between MAC & physical layers

# Challenging Issues → MAC Layer Cont.

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## B. Optimal selection of cooperating entities



# Challenging Issues → MAC Layer Cont.

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## I. Number of Cooperating Entities

### Single Entity Selection

- Only best cooperating entity is selected
- Adv.: simplicity of selection operation
- Disadv.: may fail to meet the required QoS

### Multiple Entity Selection

#### Enlarged interference

- Proportional to number
- Reduce spatial freq. reuse
- Obj.: Min. number of entities and reducing interference range while satisfying QoS

#### More ctrl signaling overhead

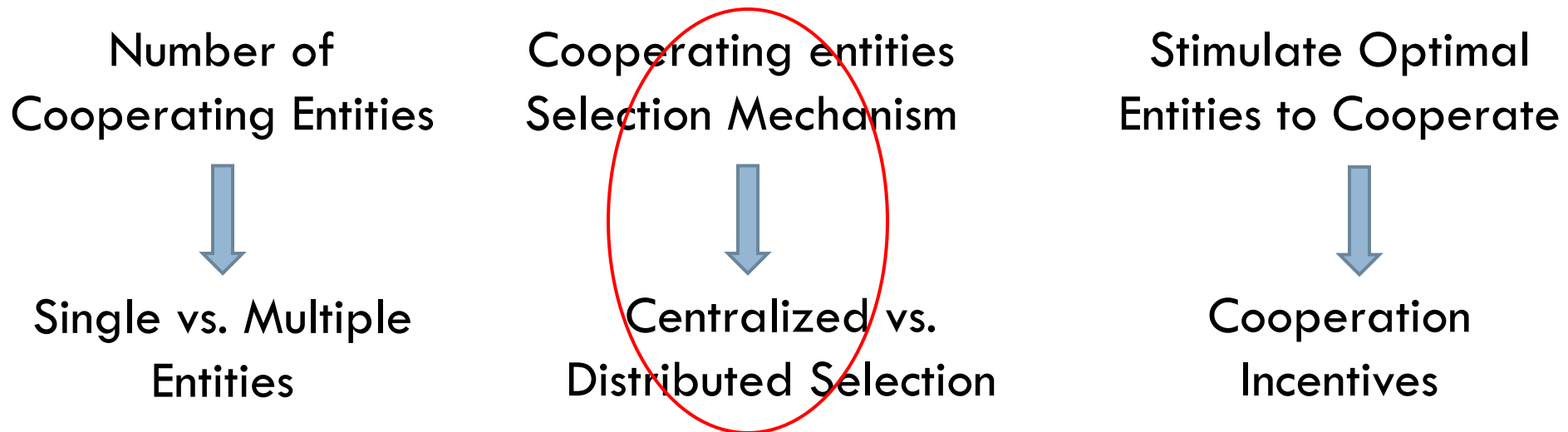
- Maybe addressed through clustering



# Challenging Issues → MAC Layer Cont.

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## B. Optimal selection of cooperating entities



# Challenging Issues → MAC Layer Cont.

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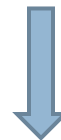
## II. Selection Mechanism

### Centralized

- Employs central controller
- Adv.: global view → optimal selection
- Disadv.:
  - i. Significant feedback msgs
  - ii. Maybe infeasible

### Distributed

Identify Cooperation Capabilities



Utility Function

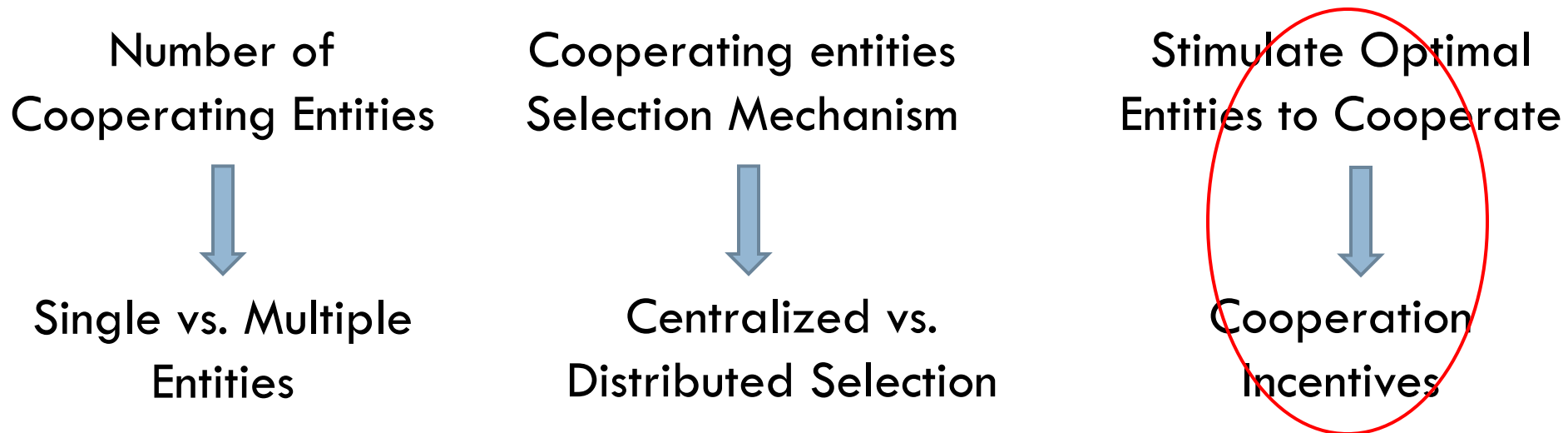
Perform Selection

- i. Busy Tone
- ii. Timer Based

# Challenging Issues → MAC Layer Cont.

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## B. Optimal selection of cooperating entities

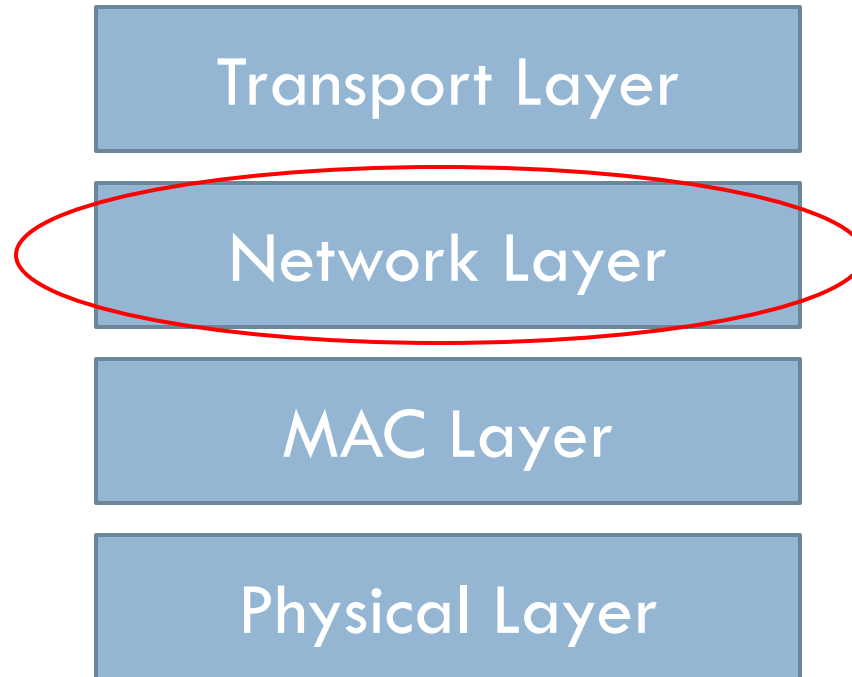


# Challenging Issues → MAC Layer Cont.

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## III. Cooperation Incentives

- Cooperation is a two-way decision
- Different entities can choose not to cooperate
- Optimal selection design must guarantee win-win situation
- Incentive schemes
  - a. Reputation based
  - b. Remuneration based
  - c. Game theory

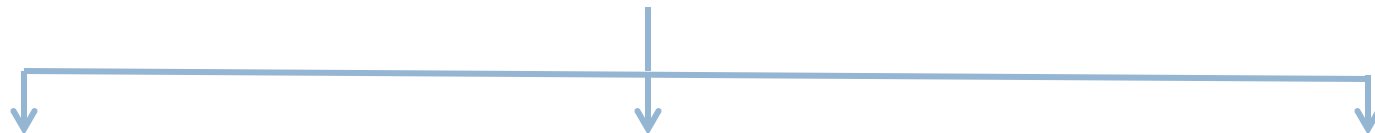


# Challenging Issues → Network Layer

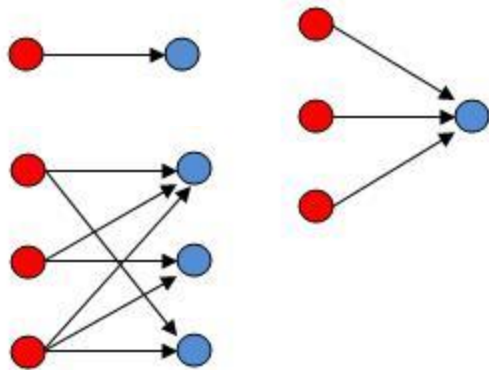
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## ③ Challenges at Network Layer

### A. Cooperation through Spatial Diversity



New Link Definition



Reinvestigate  
routing protocols

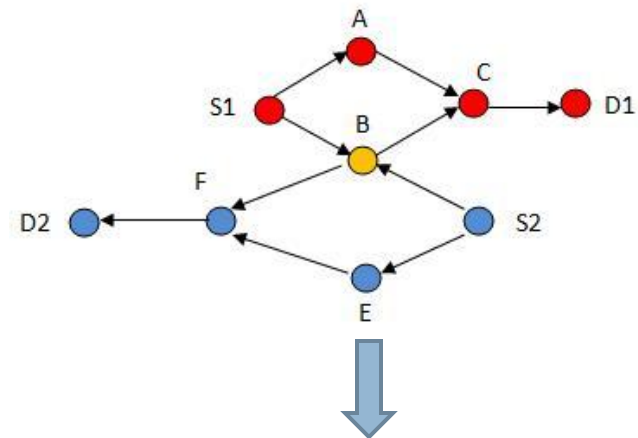
Optimality vs. Complexity

- Can be computational  
intractable



Heuristic Techniques

Multi-flow Throughput



Contention graph

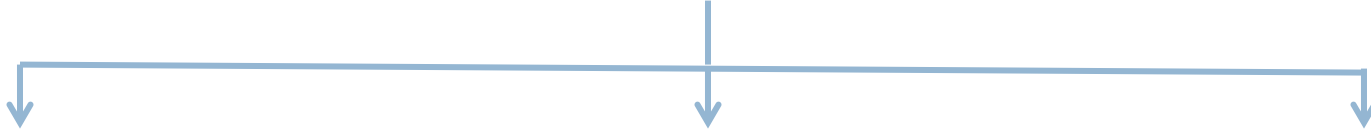
# Challenging Issues → NW Layer Cont.

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## B. Cooperation through Resource Aggregation & Seamless Service Provision



### Multi-path Routing



Cost of Route Establishment and Maintenance

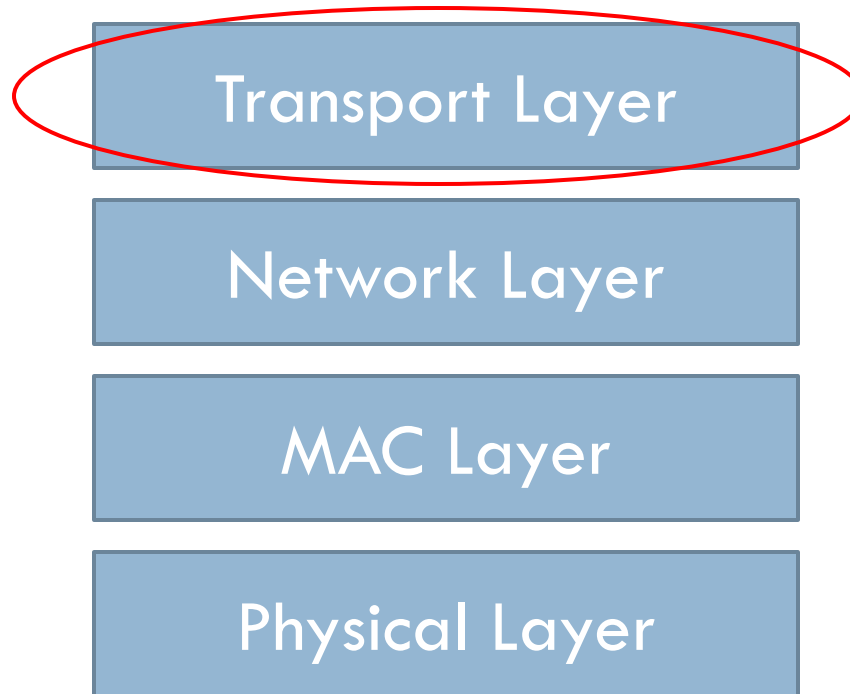
- Heuristic algorithms for route establishment
- $N$  path route discovery

Delay Differences

- Differential delay problem
- Reordering buffer limited size

Multi-path Interference

- Mutually independent paths
- Path coupling metric Heuristic Algorithms





# Challenging Issues → Transport Layer

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## ④ Challenges at Transport Layer

### A. Cooperation through Resource Aggregation



#### Multi-homing Capabilities

- Multiple paths
  - ➔ Several IPs
- Multiple TCP sockets
  - ➔ Fails
- Multi-homing feature
  - ➔ SCTP

#### Simultaneous Transmissions

##### Path Assignment

- Which path for which packet?
- Reassignment of packets

##### Packet Reordering

- Unnecessary SACKs
- NW load
- Retransmission
- Reduce Congestion window

# Challenging Issues → Transport Layer

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## B. Seamless Service Provision



Handoff from original path to alternative cooperative path → TCP



Low to High  
Delay Path



Spurious  
RTO

High to Low  
Delay Path



Packet  
Reordering

High to Low  
BDP Path



Congestion  
→ Packet loss

Low to High  
BDP Path



Inefficient  
Utilization

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**Future Directions**

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# Future Directions

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## Open Research Issues

```
graph TD; A[Open Research Issues] --> B[Cooperation Overhead]; A --> C[Mobility]; A --> D[Cross-layer Design]; B --- B1[- Appropriate modeling]; B --- B2[- Reduction techniques]; C --- C1[- Impact of node mobility on framework]; D --- D1[- Network & MAC]; D --- D2[- Network & Transport];
```

### Cooperation Overhead

- Appropriate modeling
- Reduction techniques

### Mobility

- Impact of node mobility on framework

### Cross-layer Design

- Network & MAC
- Network & Transport

# Conclusion

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# THANK YOU !

For more information please refer to: W.Zhuang and M.Ismail, "Cooperation in wireless communication networks," IEEE Wireless Communications, vol. 19, no. 2, April 2012.