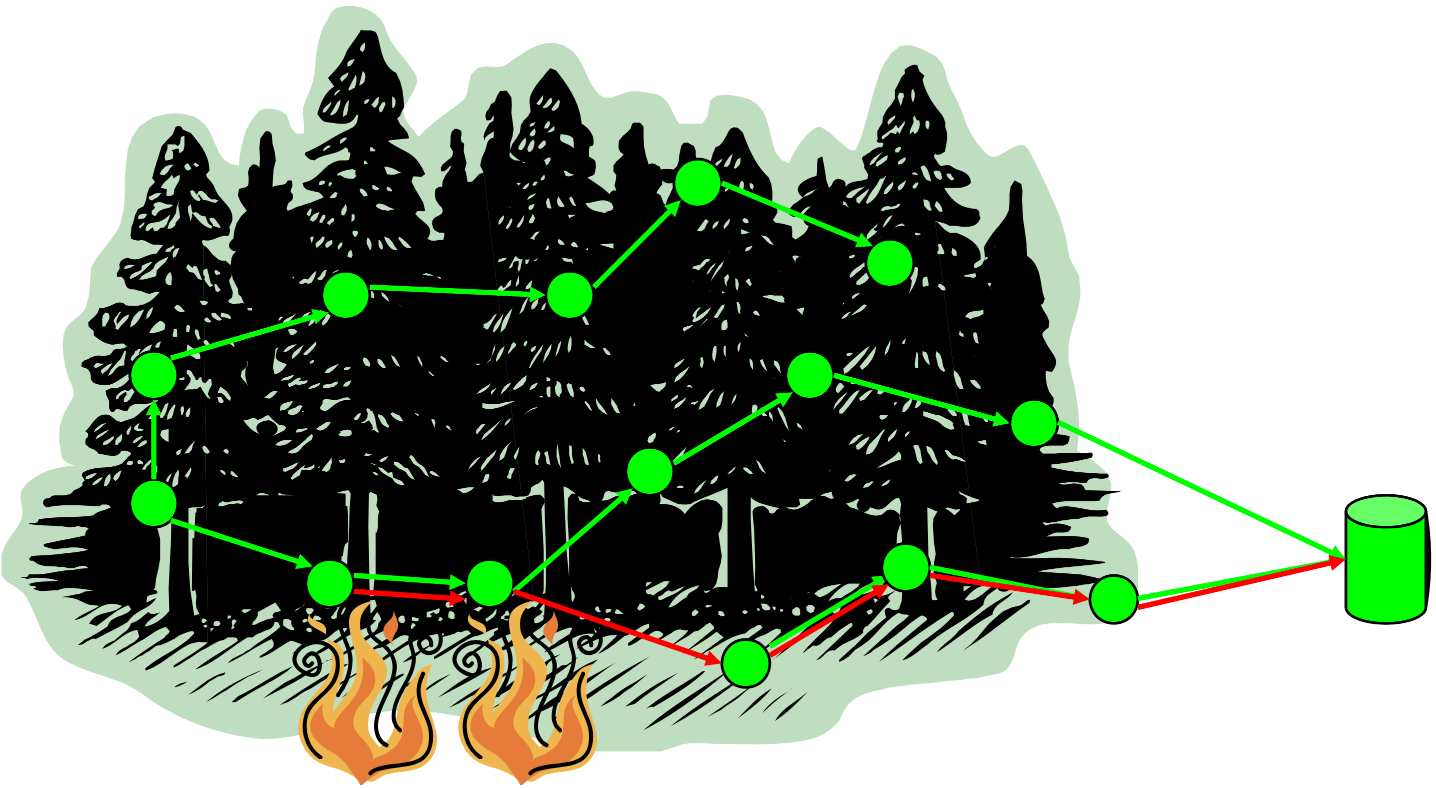
Probabilistic QoS Guarantee in Reliability and Timeliness Domains In Wireless Sensor Networks

Emad Felemban
Electrical and Computer Engineering Department
The Ohio State University
IEEE Infocom 2005 , Miami, FL
C.-G. Lee, E. Ekici, R. Boder, and S. Vural

Outline

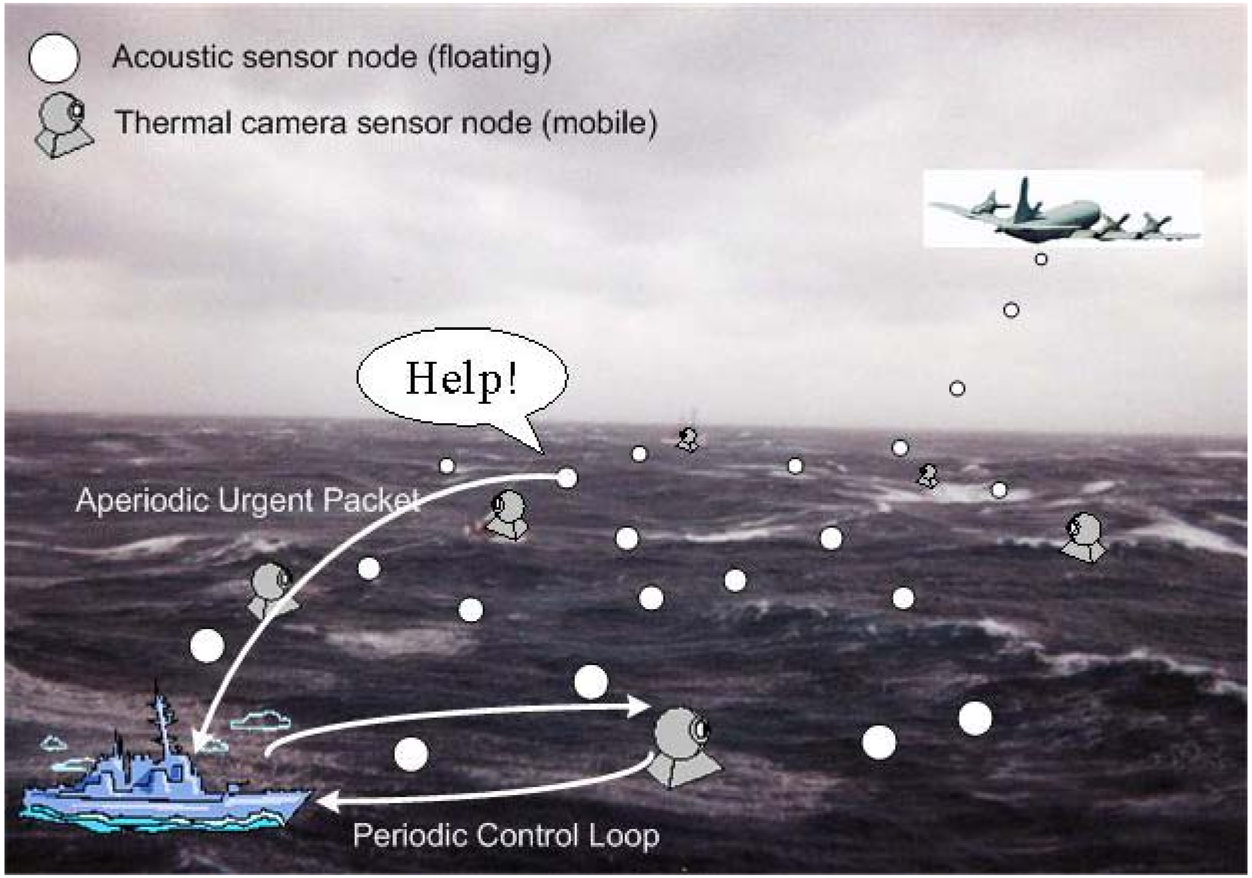
- Motivation
- Design Goals and Approach
- Localized Packet Forwarding
- Timeliness Domain Differentiation
- Reliability Differentiation
- Results
- Questions

Forest Monitoring Sensor Networks



Different Importance → Different Reliability Requirement

Rescue Supporting Sensor Networks



Different Dynamics → Different Real-Time Requirements
Mixture of Periodic and Aperiodic Packets

Summary of Observations

- Workload Characteristics
  - Diverse Real-Time requirements
  - Diverse Reliability requirements
  - Periodic and Aperiodic Packet patterns
- Network Characteristics
  - Large-Scale Dense Networks
  - Dynamic Topology Changes
  - Unreliable Nature of Wireless Links

Design Goals

- Deliver packets meeting various Application requirements
  - Diverse real-time and reliability requirements
  - Diverse packet patterns
- Scalable and Adaptive Protocol
  - Applicable to large-scale networks
  - Adaptive to frequent changes of network topology

QoS Mechanisms for Ad-Hoc Networks will not work
• global routing ← not scalable
• reservation based ← not adaptive, not aperiodic-friendly

Solution Approach

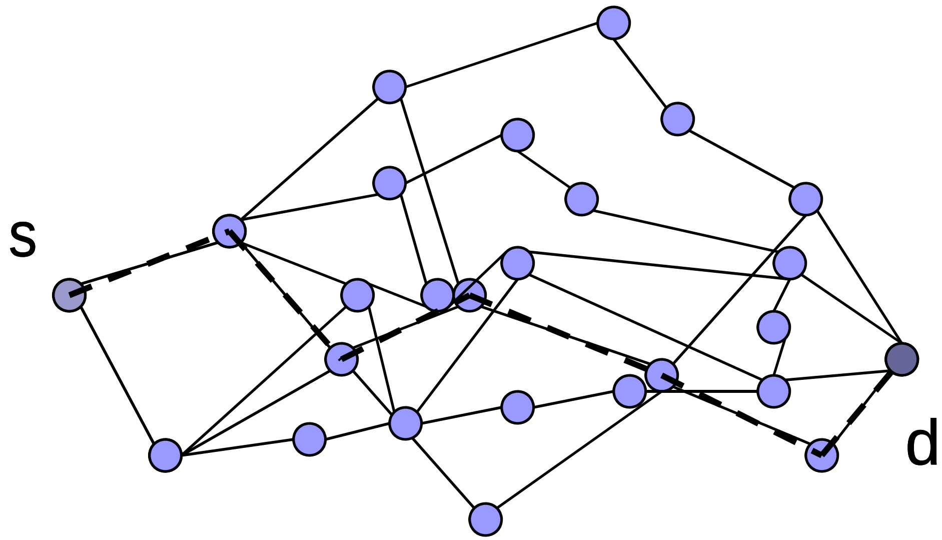
Multi-Path Multi-Speed Routing Protocol
(MMSPEED)

QoS provisioning for sensor networks

- Using localized packet forwarding
- In two isolated quality domains
  - Timeliness
  - Reliability

Globalized Packet Forwarding

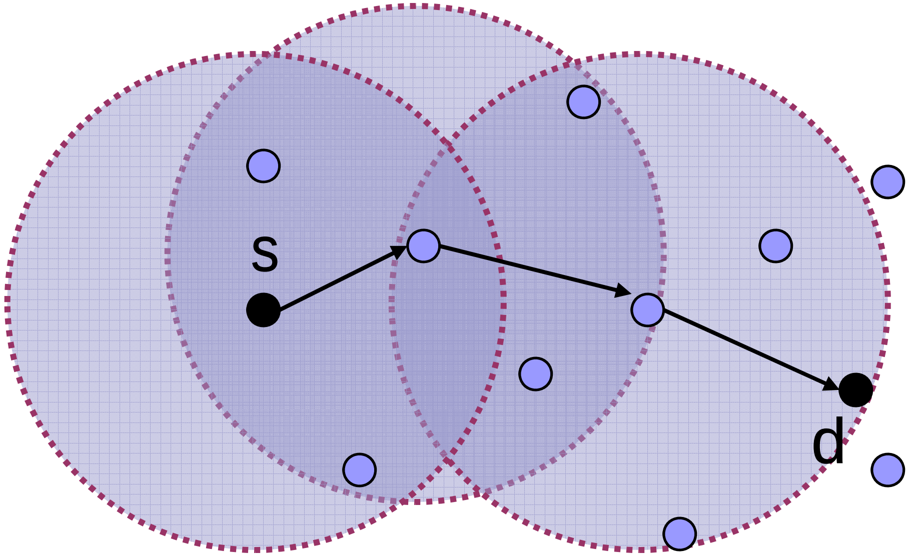
- Build a complete route to the final destination



- **Not Scalable**
- **Large overhead for path maintenance with topology changes**
- **Not aperiodic friendly**

Localized Packet Forwarding

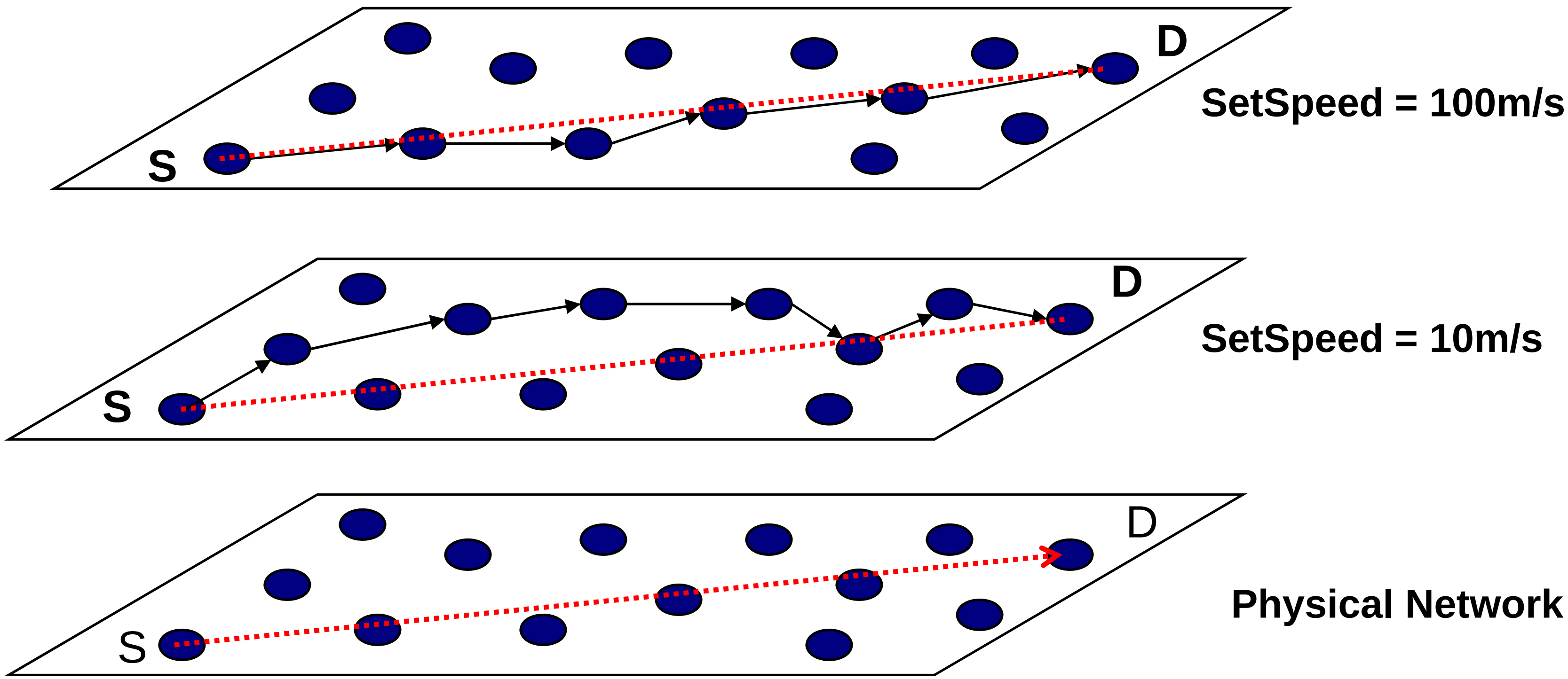
- Select nodes geographically closer to the final destination



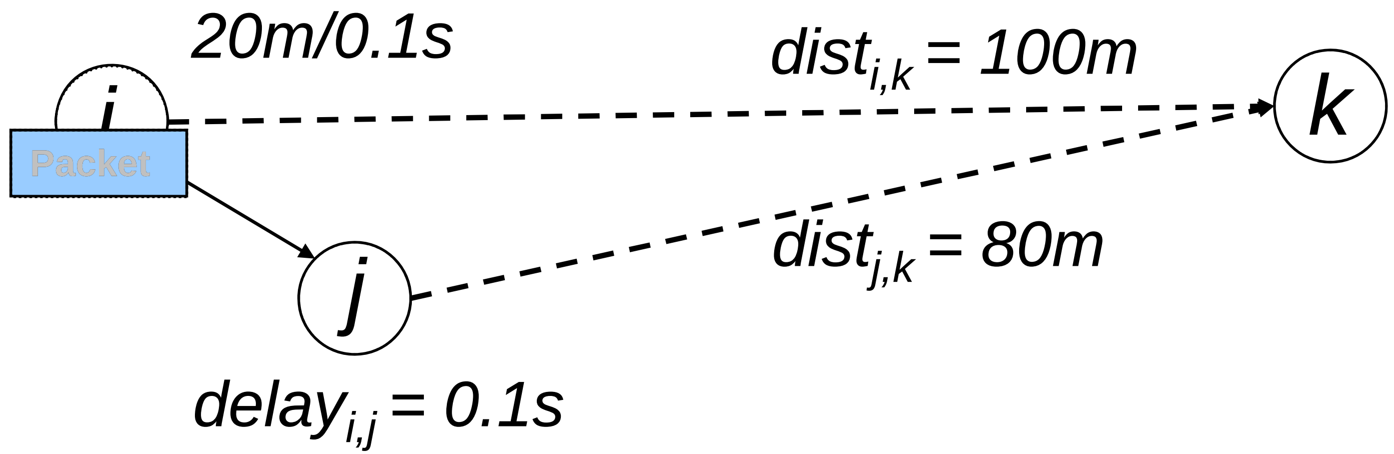
- **+ Scalable**
- **+ Handle aperiodic and periodic packets**
- **+ Packet-by-packet adaptation to network dynamics**

Service Differentiation in Timeliness Domain

- MMSPEED provides Multiple Delivery Speed Options



SPEED Protocol (Univ. of Virginia)

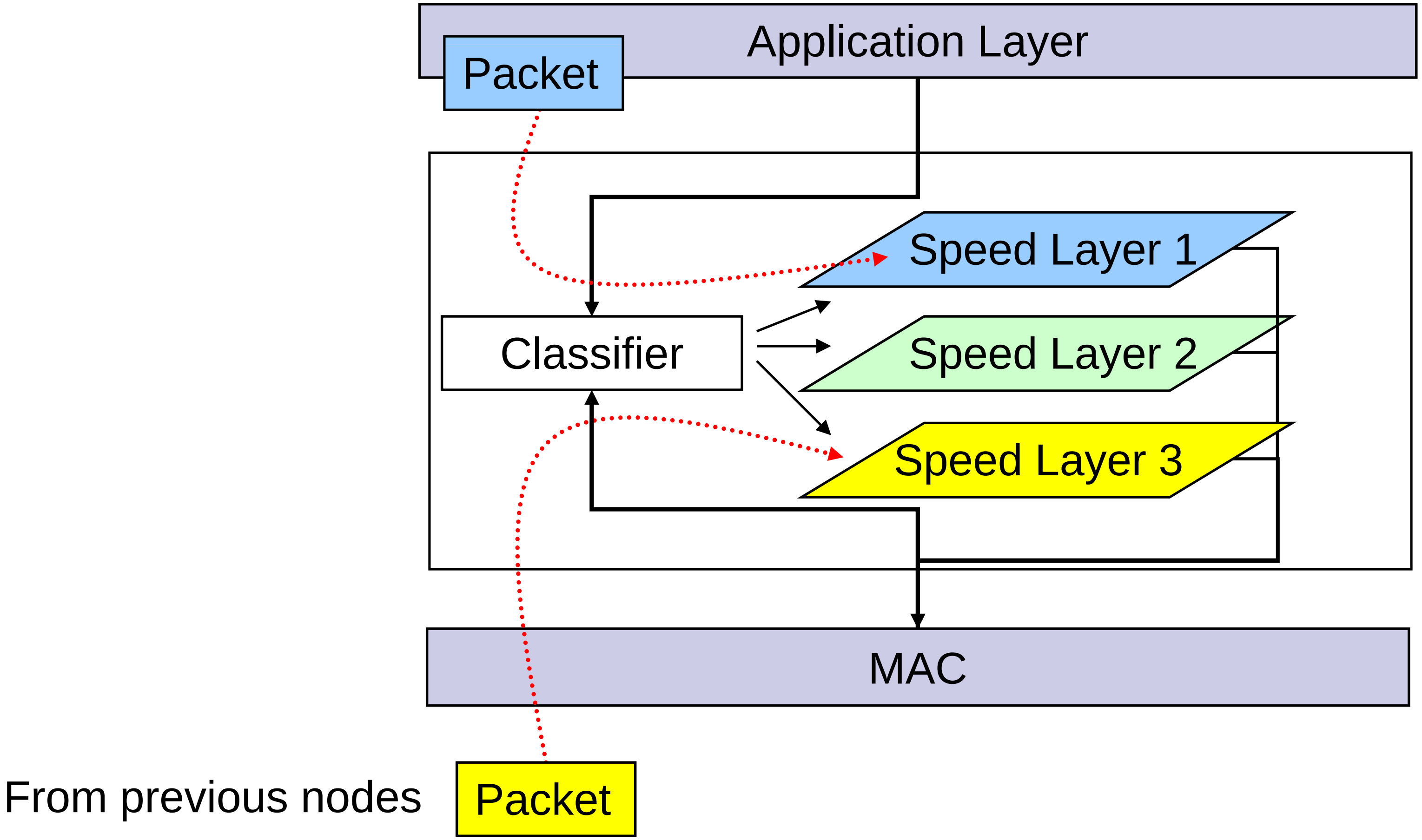


$$Speed_{i,j}^{k} = \frac{dist_{i,k} - dist_{j,k}}{delay_{i,j}} = \frac{100 - 80}{0.1} = 200m/\sec$$

- If every node can find a forwarding node with speed higher than SetSpeed, SetSpeed can be provided network-widely.
- This is not always possible when workload is high → probabilistic drop

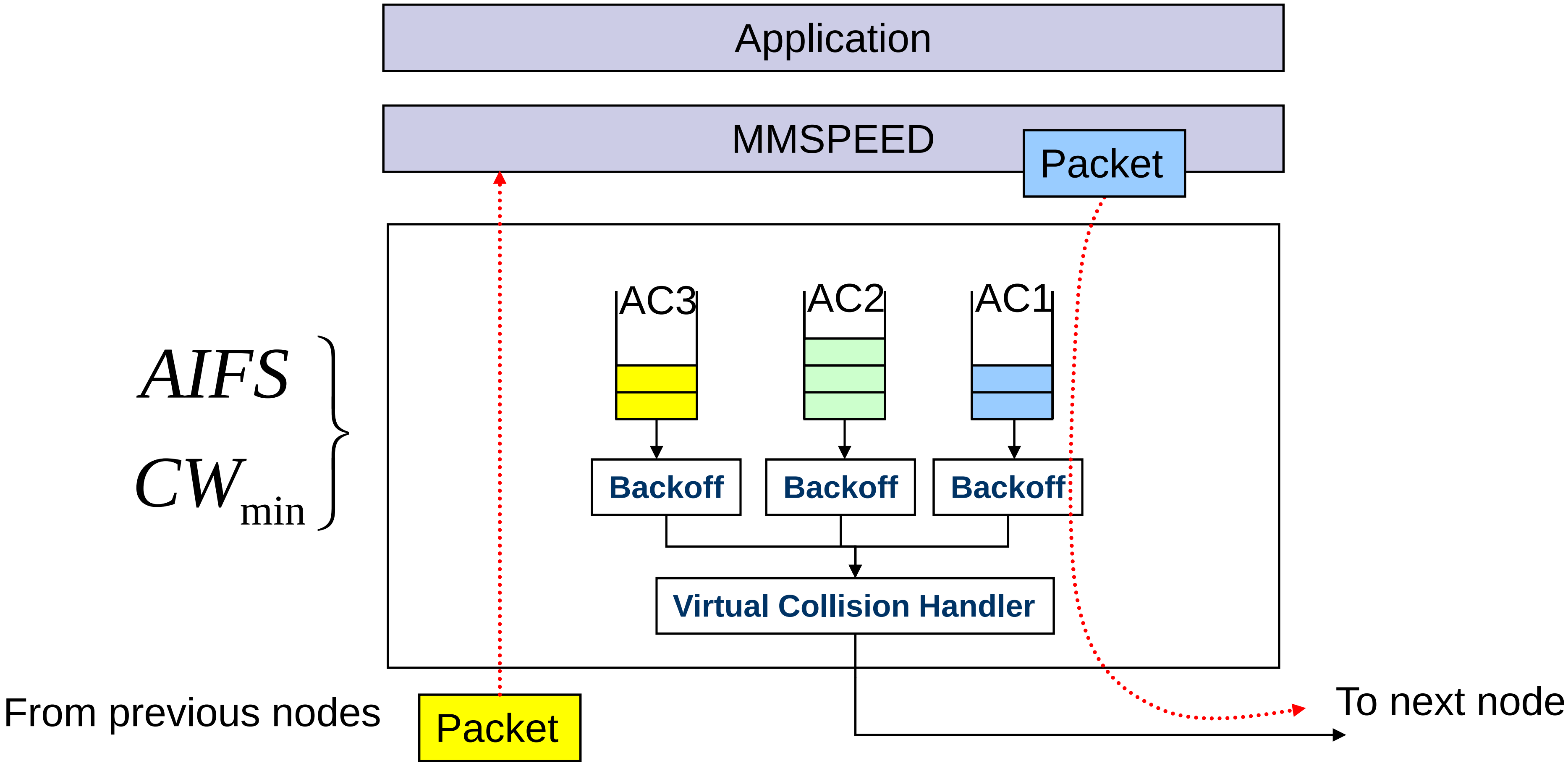
Service Differentiation in Timeliness Domain

- Virtual Isolation of packets within a single node (Routing Layer)



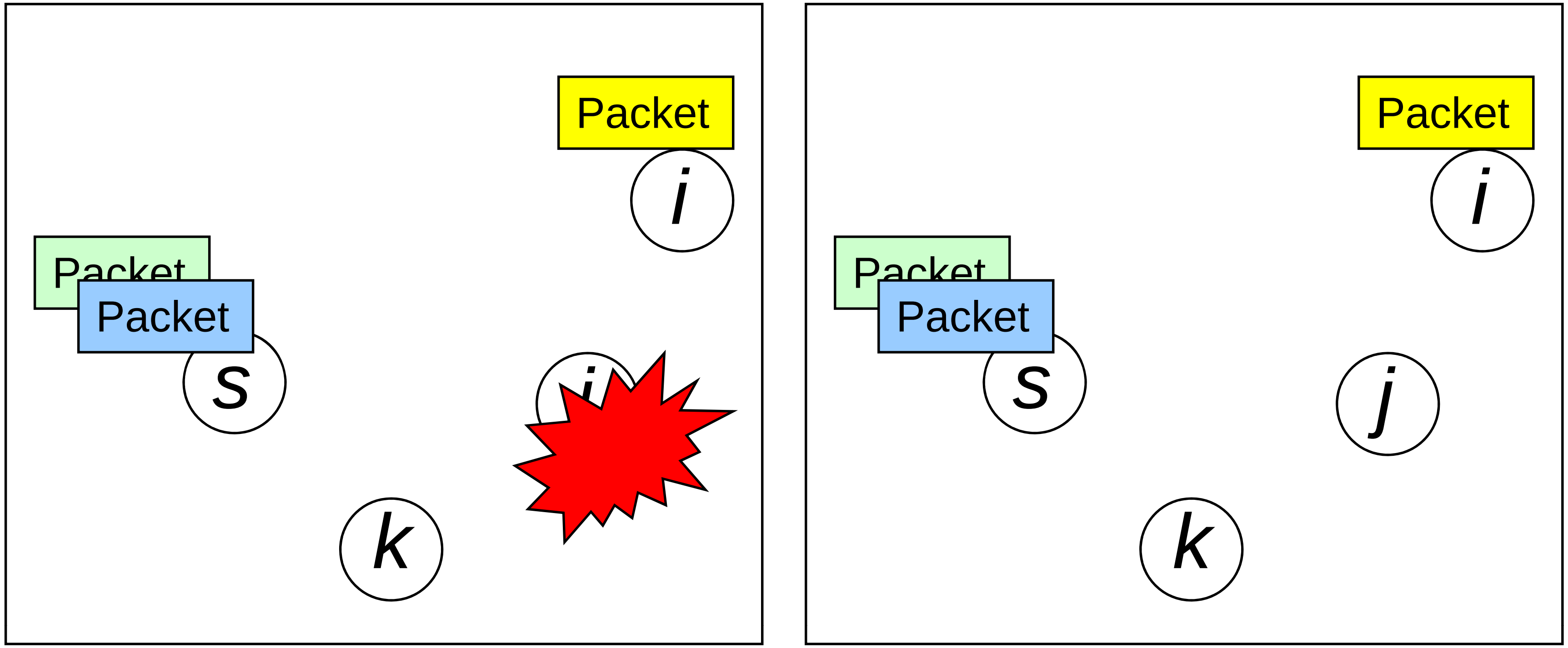
Service Differentiation in Timeliness Domain

- Virtual Isolation of packets within a single node (MAC layer)



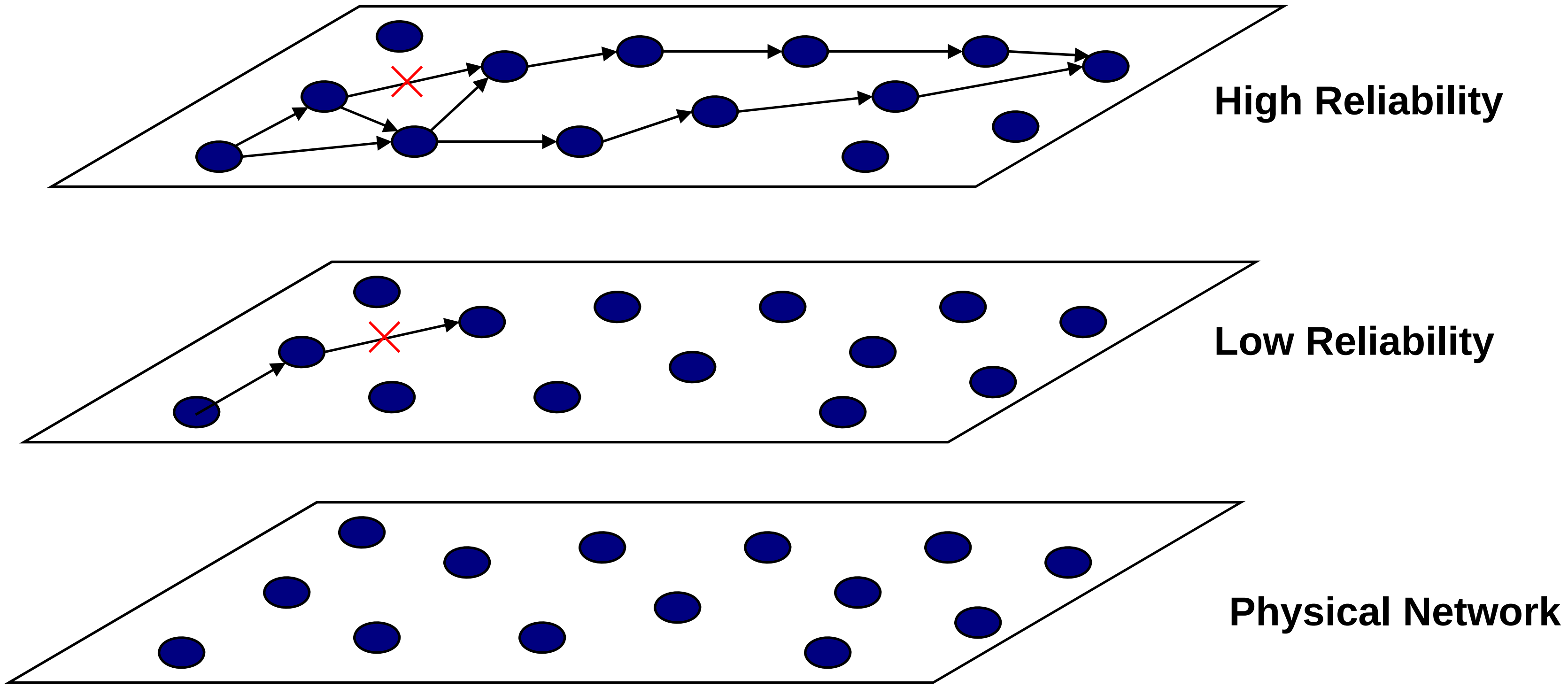
Service Differentiation in Timeliness Domain

- Low Priority Packets may delay High priority packets
- Inter-node prioritization is important



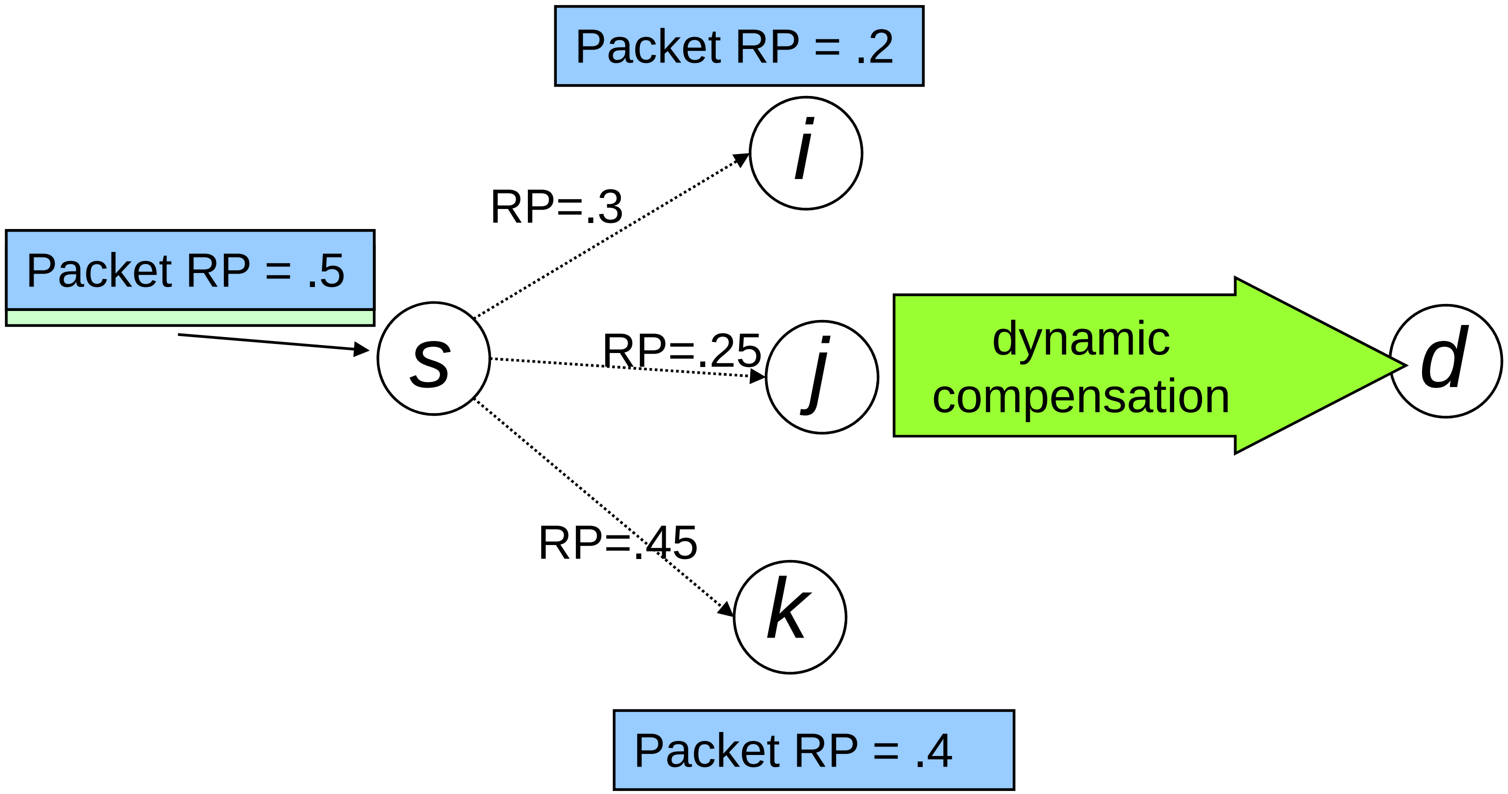
Service Differentiation in Reliability Domain

- MMSPEED utilizes natural multiple paths to increase reliability



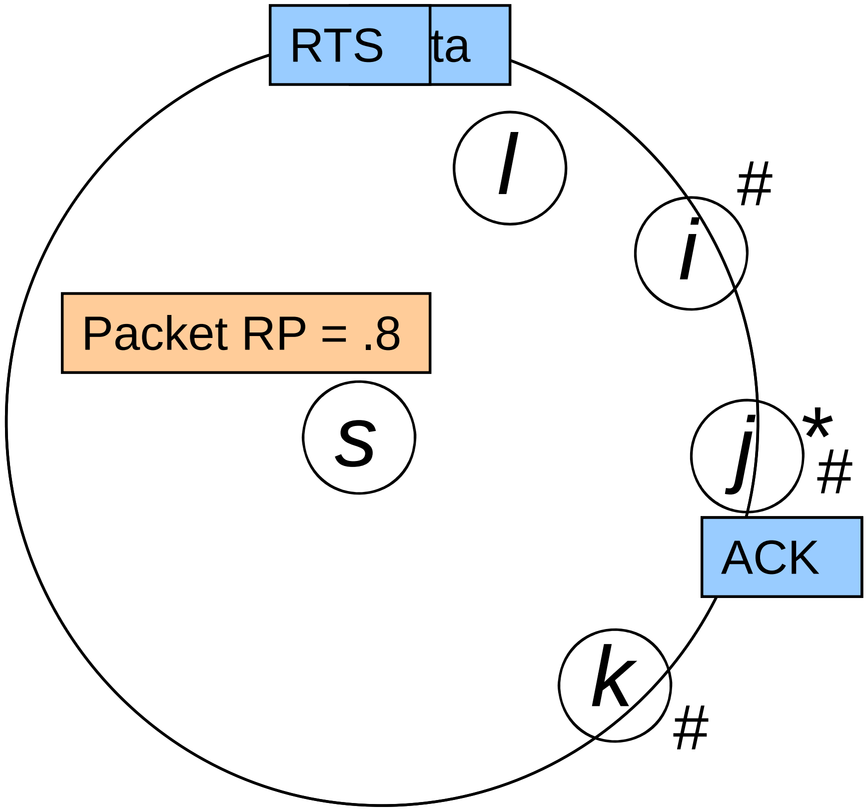
Service Differentiation in Reliability Domain

- Probabilistically forward packets through just adequate number of paths towards final destination
  - Local estimation of end-to-end reachability
  - Dynamic compensation



Service Differentiation in Reliability Domain

- Multicast service in MAC layer to insure parallel progress of copies
- Partially Reliable Multicast



•MMSPEED decides the Next Hops Group (NHG)

•Select a Primary Recipient (PR) from NHG

•RTS is sent to PR, other nodes in NHG listen

•PR sends CTS

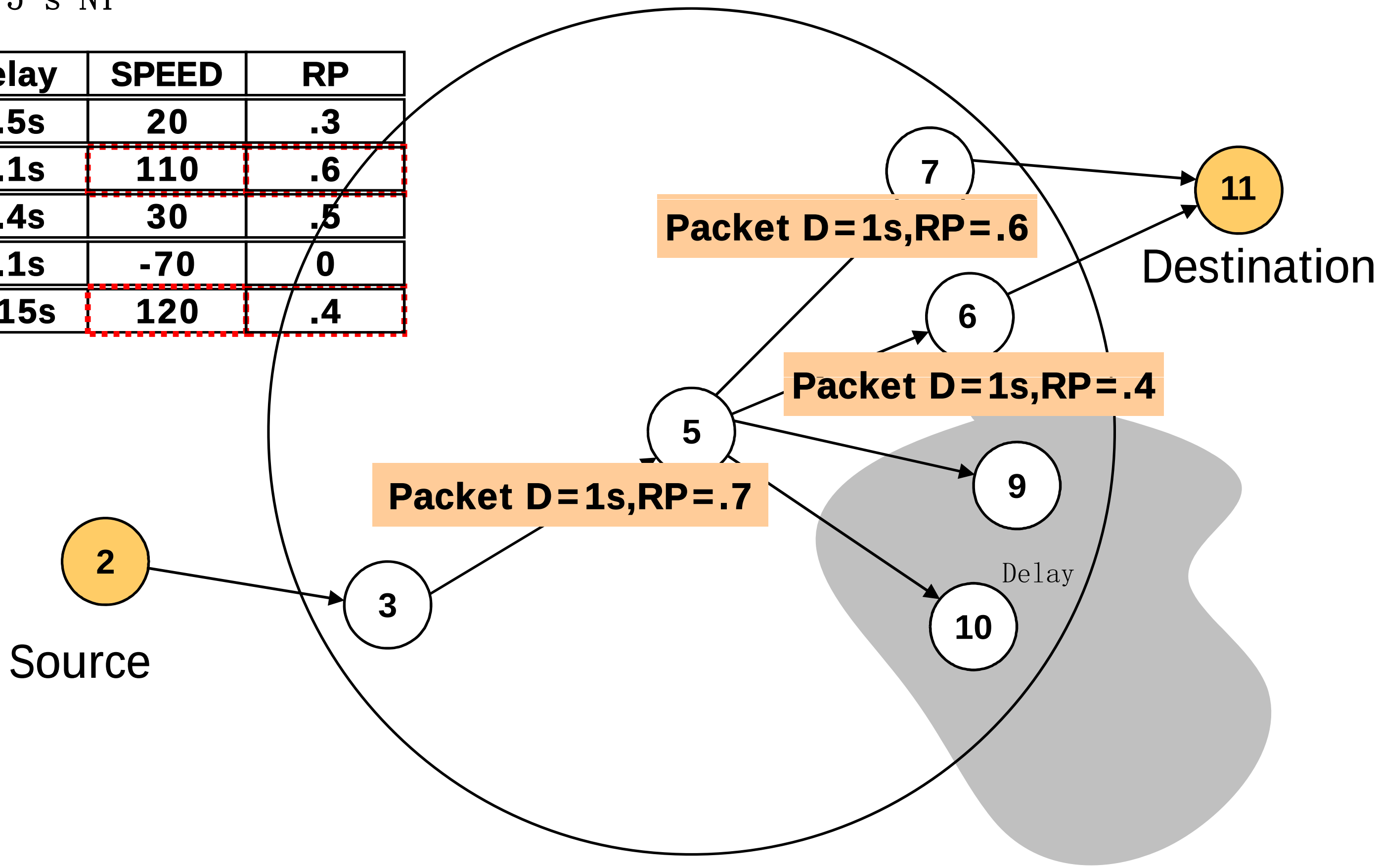
•DATA is sent to PR, other nodes in NHG capture the packet

•PR ACK the packet

How to combine the two domains?

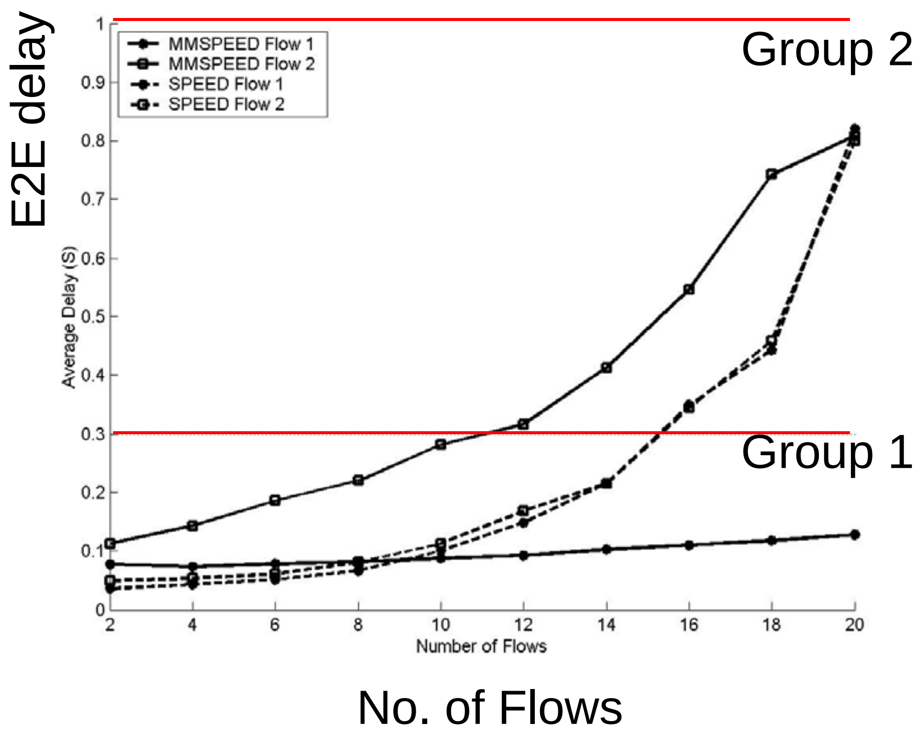
Node 5's NT

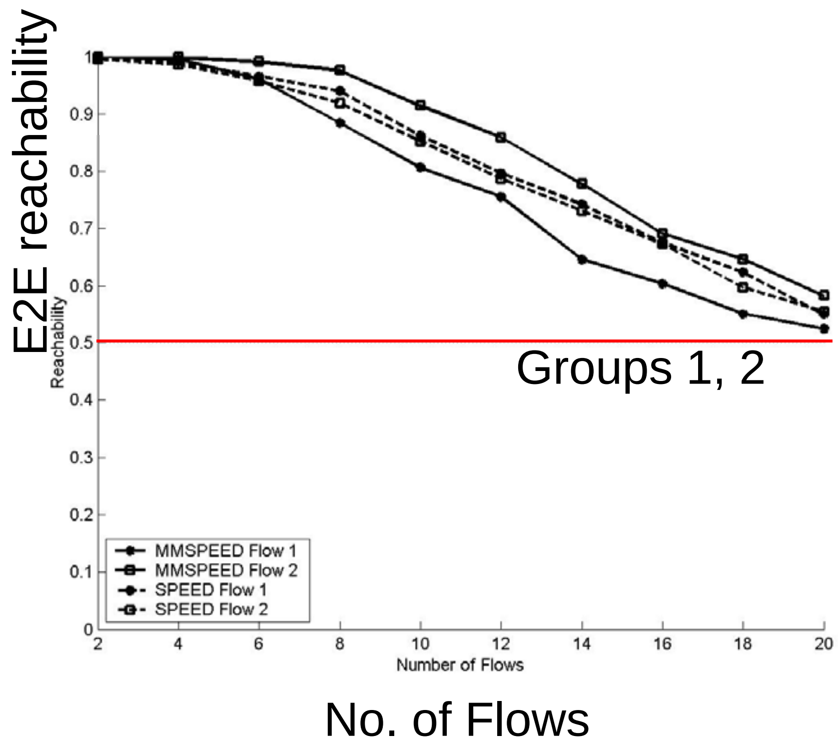
ID	Delay	SPEED	RP
9	0.5s	20	.3
7	0.1s	110	.6
10	0.4s	30	.5
3	0.1s	-70	0
6	0.15s	120	.4



Performance - Timeliness Differentiation

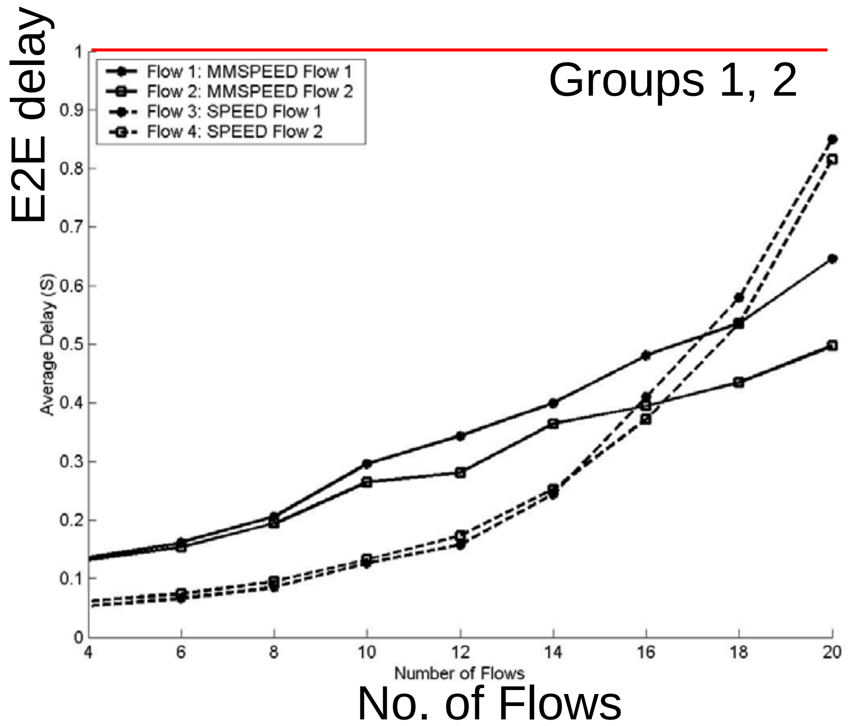
Flow Group 1 : Deadline = 0.3s , Reliability = 0.5
Flow Group 2 : Deadline = 1.0s , Reliability = 0.5

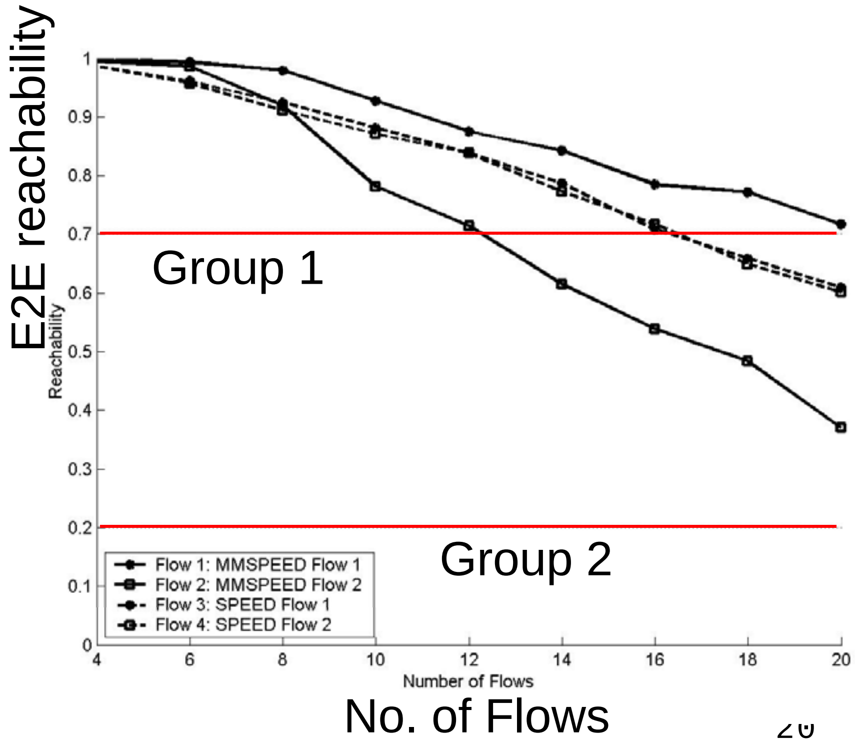




Performance - Reliability Differentiation

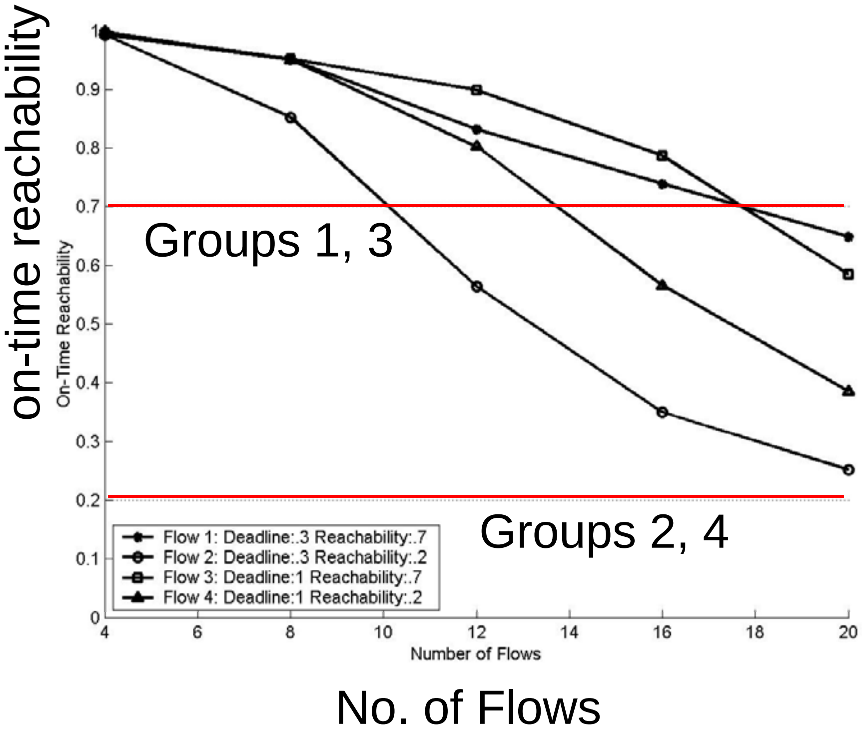
Flow Group 1 : Deadline = 1.0s , Reliability = 0.7
Flow Group 2 : Deadline = 1.0s , Reliability = 0.2

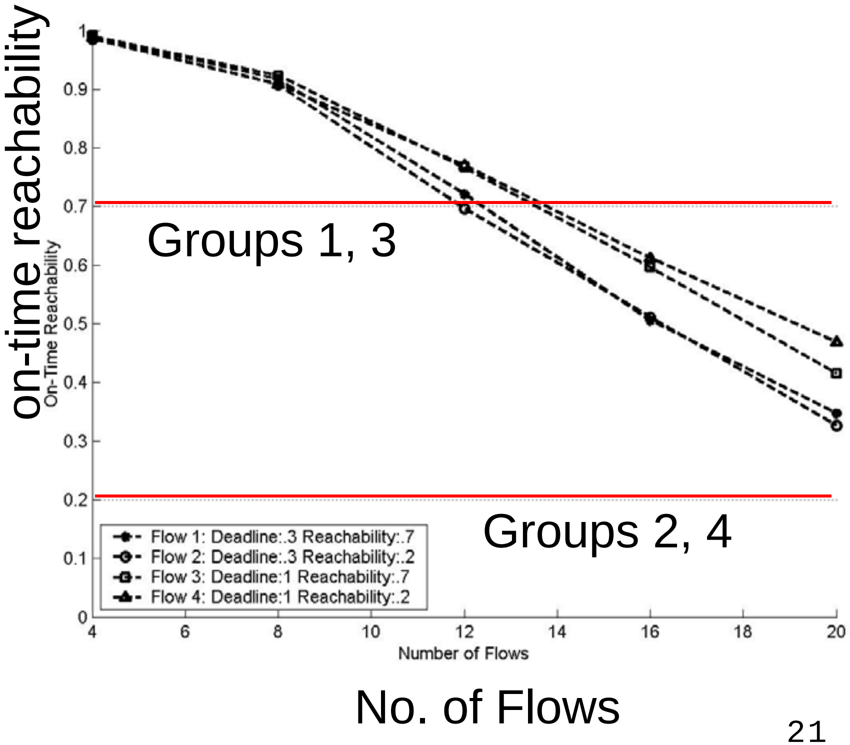




Performance– Mixed Flows (on-time reachability)

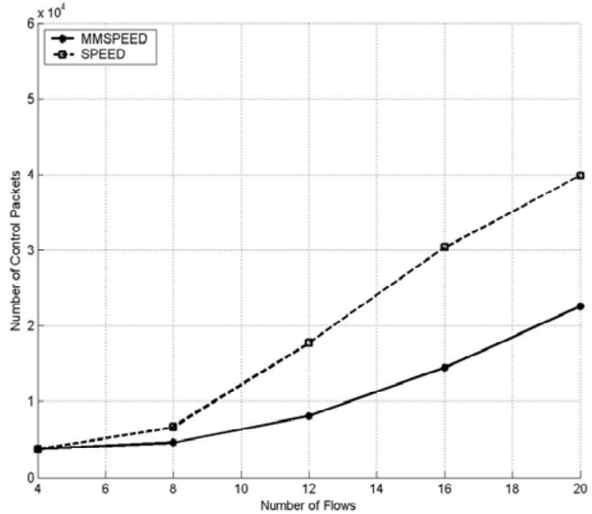
Flow Group 1 : Deadline = 0.3s , Reliability = 0.7
Flow Group 2 : Deadline = 0.3s , Reliability = 0.2
Flow Group 3 : Deadline = 1.0s , Reliability = 0.7
Flow Group 4 : Deadline = 1.0s , Reliability =0.2



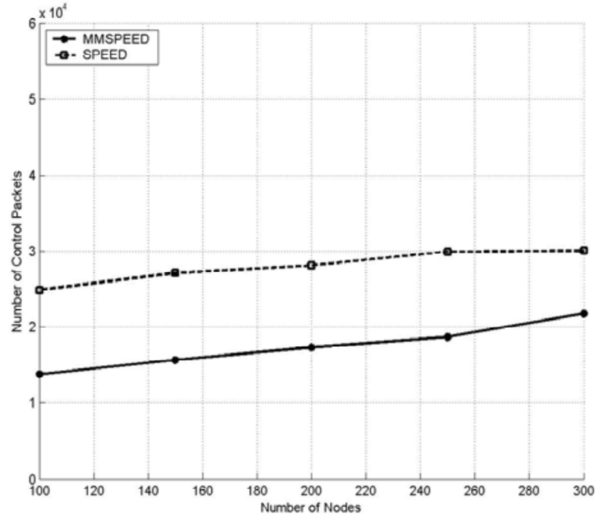


Performance – Control Packet Overhead

control packet overhead



As increasing no. of flows



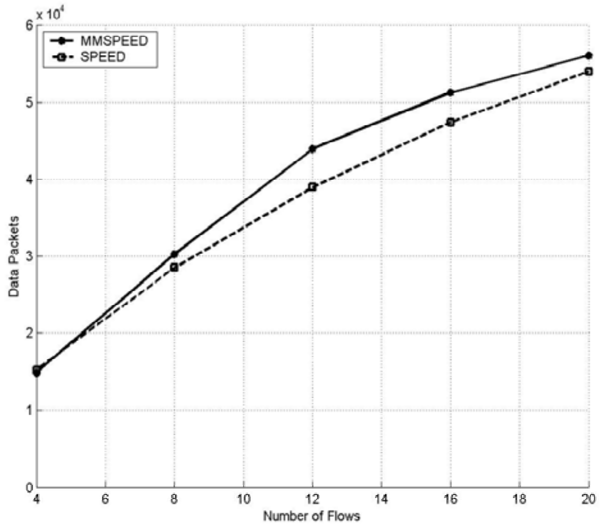
As increasing node density

- Smaller number of control packets than SPEED as increasing workload
- Scalable as Node density increases

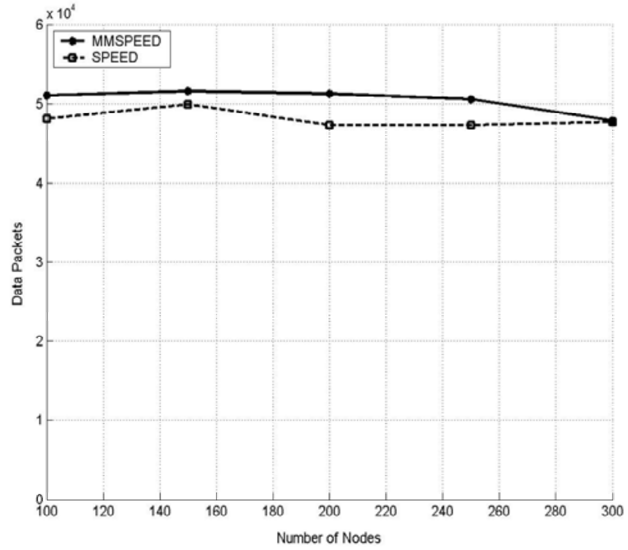
Performance – Data Packet Overhead

data packet

overhead



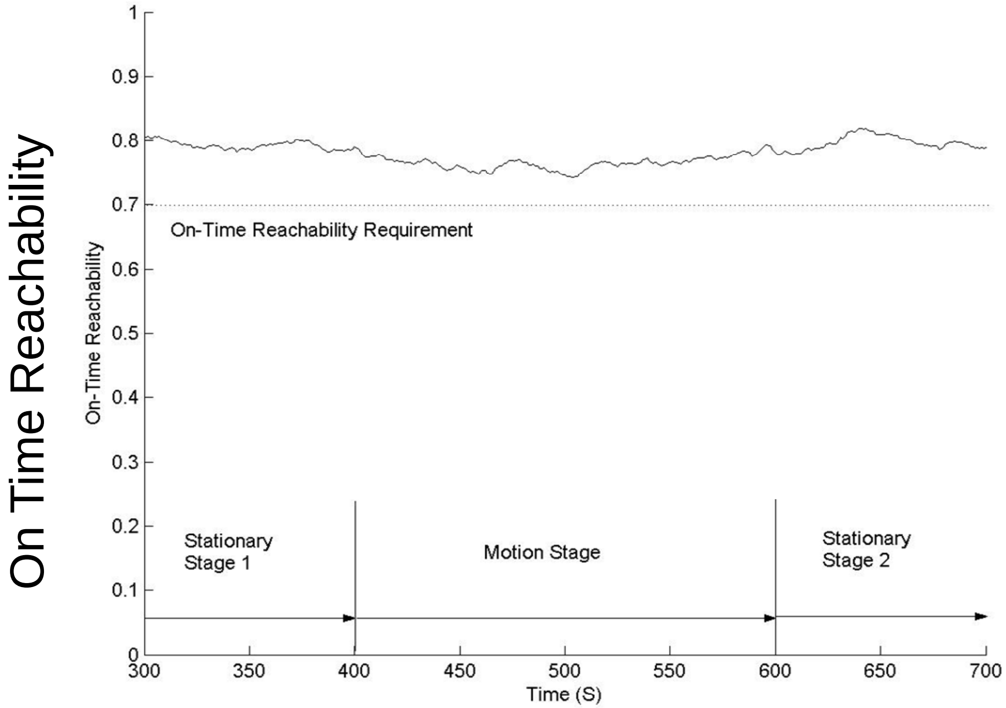
As increasing no. of flows



As increasing node density

- Scalable as Node density increases

Adaptability of MMSPEED



Time (s)

- Adaptability to node mobility
- Advantage of localized packet forwarding

Summary

- MMSPEED Provides
  - Service Differentiation in Timeliness domain
  - Service Differentiation in Reliability domain
- MMSPEED can probabilistically guarantee
  - reliability requirements
  - real-time requirements
  - both (on-time reachability)
- MMSPEED is a localized algorithm
  - scalable
  - adaptive

Open Issues

- Parameter Optimization
- Energy Overhead Analysis
- QoS Provisioning in Multi-tier Sensor Networks

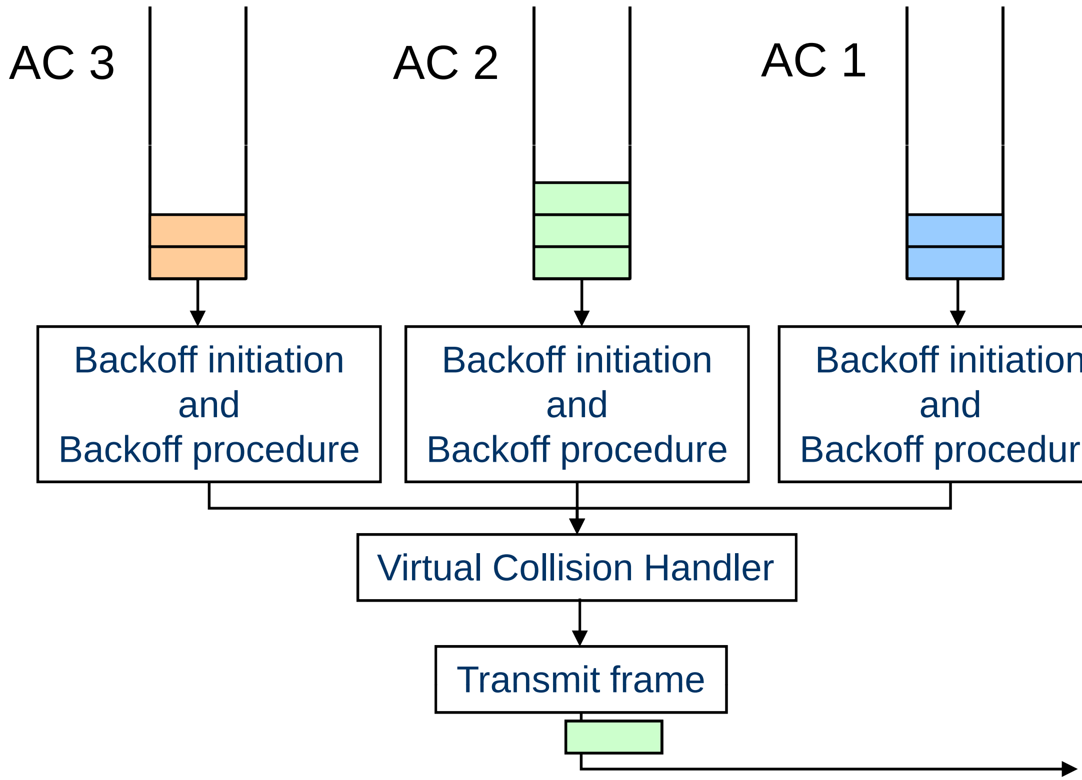
References

- Tian He, John A Stankovic, Chenyang Lu, and Tarek Abdelzaher, “SPEED: A Stateless Protocol for Real-Time Communication in Sensor Networks”, Proceedings of the 23rd international conference on Distributed Computing Systems, 2003
- Emad Felemban, Chang-Gun Lee, and Eylem Ekici, “MMSPEED: Multipath Multi-SPEED Protocol for QoS Guarantee of Reliability and Timeless in Wireless Sensor Networks”, IEEE Transactions on Mobile Computing, June 2006

Questions

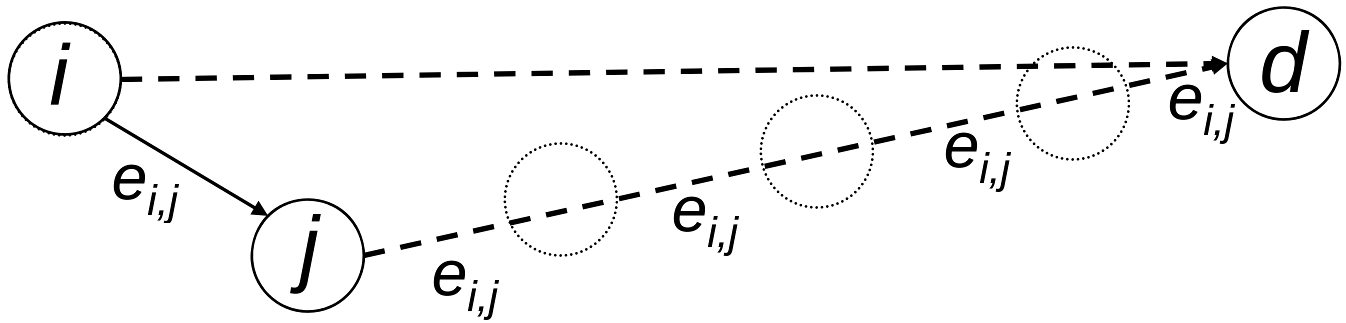
Service Differentiation in Timeliness Domain

- Shorter Backoff times and IFS for high priority Access Class → higher priority packets are likely to capture the channel earlier



$$\begin{cases} AIFS \\ CW\_\min \\ CW\_\max \end{cases}$$

RP (Reaching Probability) Calculation

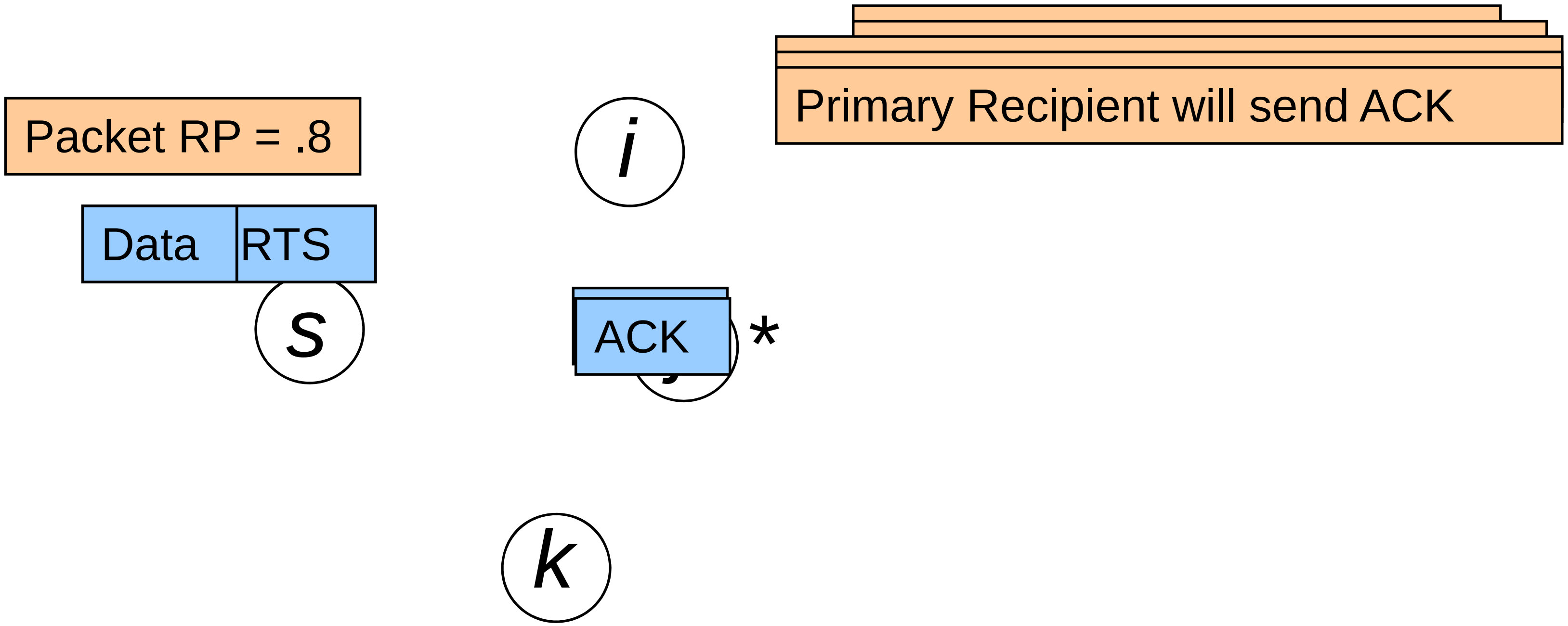


$$RP_{i,j}^{d} = (1 - e_{i,j})(1 - e_{i,j})^{\lceil dist_{j,d} / dist_{i,j} \rceil}$$

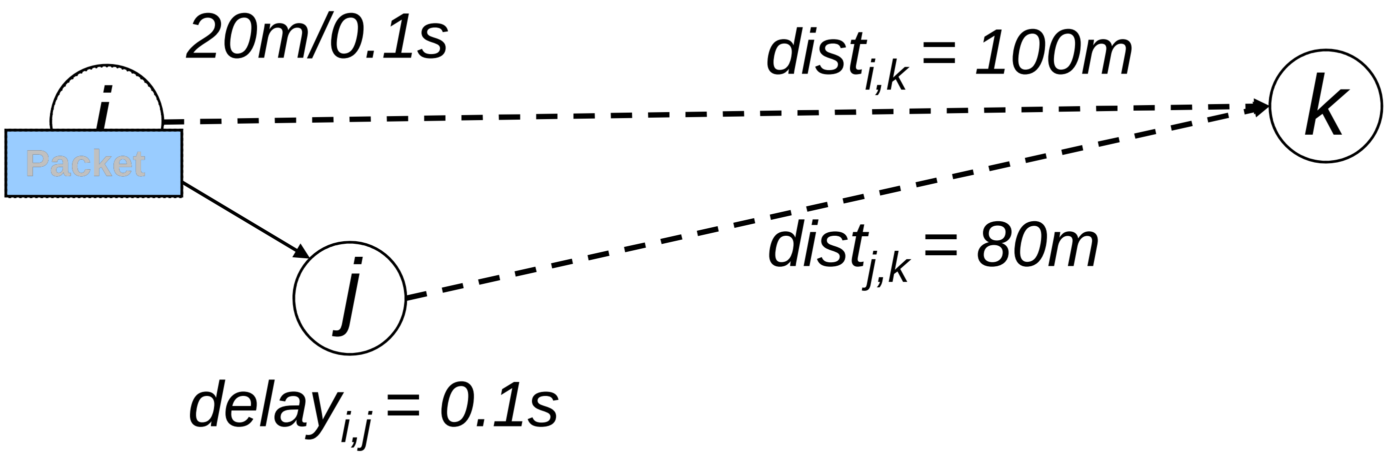
$$TRP = 1 - (1 - TRP)(1 - RP_{i,j}^{d})$$

Service Differentiation in Reliability Domain

- Multicast service in MAC layer → to insure parallel progress of copies
- Partially-reliable multicast



SPEED Protocol (Univ. of Virginia)



$$Speed_{i,j}^{k} = \frac{dist_{i,k} - dist_{j,k}}{delay_{i,j}} = \frac{100 - 80}{0.1} = 200m/\sec$$

- If every node can find a forwarding node with speed higher than SetSpeed, SetSpeed can be provided network-widely.
- This is not always possible when workload is high → probabilistic drop