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# Chapter 13. An On-Demand, Link-State, Multi-Path QoS Routing in a MANET

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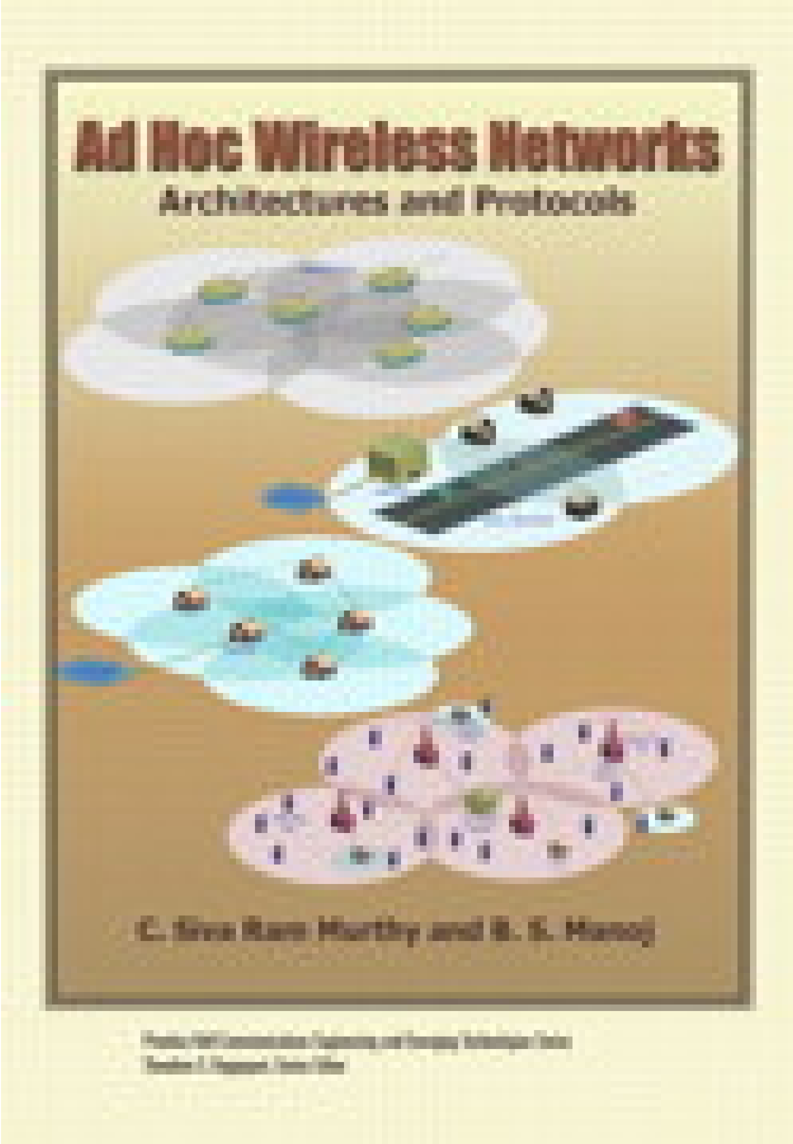
Jan. 2008

# This result is included in

**Ad Hoc Wireless Networks Architectures and Protocols**



# Outline

- Introduction
- Basic ideas and challenges
- The on-demand, link-state, multi-path QoS routing protocol
- Experimental results
- Conclusions

# Introduction

- The MANET consists of wireless hosts that communicate with each other in the absence of a fixed infrastructure.
- In a MANET, host mobility can cause frequent unpredictable topology changes.
- In this paper, the 'bandwidth' is considered as the main factor of the QoS issues by omitting the signal-to-interference ratio (SIR) and packet loss rate.
  - The bandwidth guarantee is one of the most critical requirements for real-time applications.

# Introduction

- TDMA (time division multiple access) scheme.
  - ‘Bandwidth’ in time-slotted network system is measured in terms of the amount of ‘free’ slots.
- The goal of the QoS routing protocol
  - searching for one (uni-path) or more paths (multi-paths) from a source to a destination such that the total bandwidth on these available paths is above the minimal requirement.
- To compute the bandwidth-constrained paths from source to destination
  - to know the available bandwidth on each link along all possible paths.
  - to do a suitable scheduling of free slots.

# Introduction

- A new on-demand QoS multi-path routing protocol in a MANET.
  - calculates the end-to-end path bandwidth of a QoS multi-path routing under CDMA-over-TDMA channel model.
  - offers a bandwidth routing protocol for QoS support in a multihop mobile network.
  - a source node may dynamically request a QoS route under a given bandwidth requirement.
  - (The path searching phase), the source node floods a path-searching packet into MANET to try to identify a QoS route and calculate the path bandwidth simultaneously.

# Introduction

- The main idea is to collect the information of the available link bandwidth of all paths during the path-searching phase.
  - constructs a partial network topology, or referred to as a flow sub-graph, at the destination.
- To satisfy a given bandwidth requirement
  - the bandwidth calculation of one or more paths are determined at the destination.
- The bandwidth reservation operation
  - performed after the destination determines the QoS uni-path or multi-path route depending on the status of the network bandwidth.

# Basic ideas and challenges

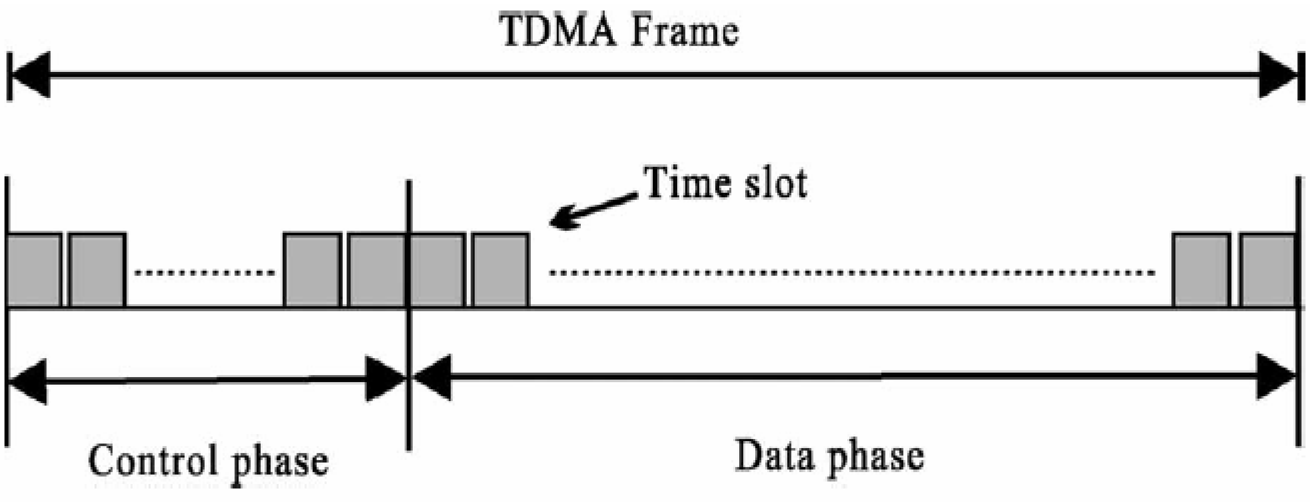



Fig. 1. TDMA frame structure.

- The CDMA (code division multiple access) is overlaid on top of the TDMA infrastructure.

# Basic ideas and challenges

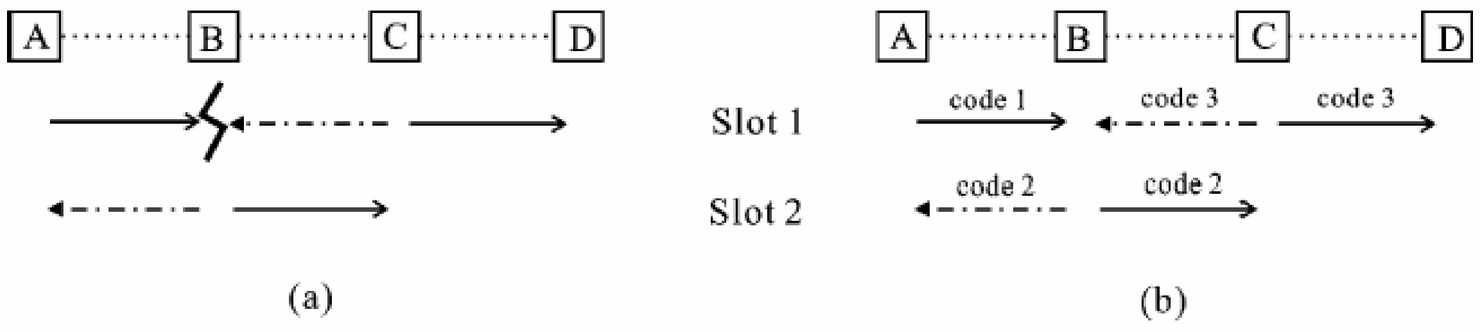



Fig. 2. (a) Hidden terminal problem, (b) CDMA-over-TDMA.

- To overcome the problem, an orthogonal code used by a host should differ from that used by any of its two-hop neighbors as shown in Fig. 2(b).
- The use of a time slot on a link is only dependent on the status of its one-hop neighboring links.

# Basic ideas and challenges

A successful QoS route

A failed QoS route

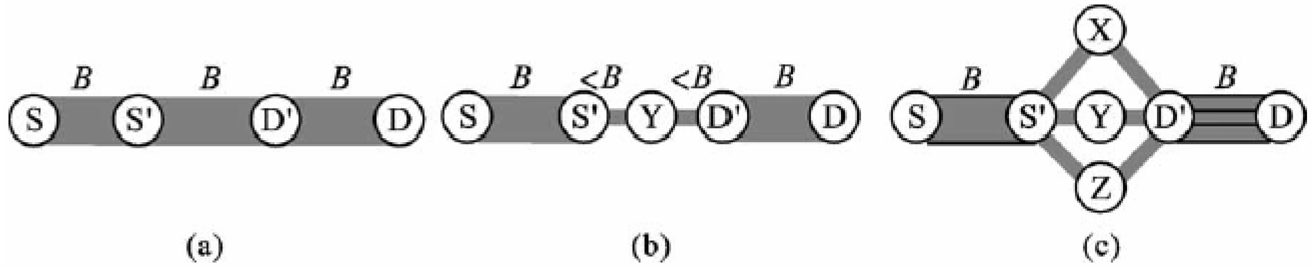



Fig. 3. Multi-path approach.

- A source node S initiates a QoS Route REQuest (QRREQ) with a bandwidth requirement B.

- Fig. 3(c) shows that the bandwidth requirement B is divided into three sub-bandwidth requirements, while each sub-ticket is responsible for searching a multi-path to cover its corresponding sub-bandwidth requirement.

# Basic ideas and challenges

- The link-state information is recorded in a long packet during the QoS multi-path searching, and than forms a flow-network.
- In a MANET, every mobile host (from source to destination) knows the available bandwidth to each of its neighbors.

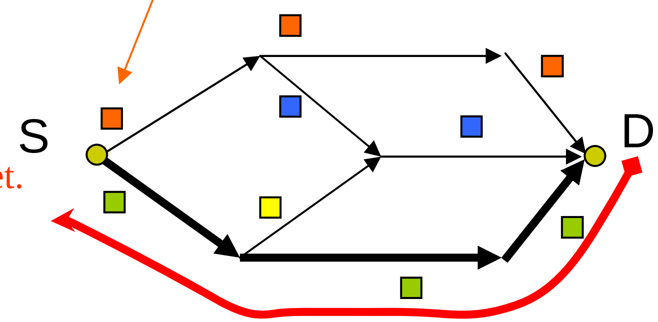
Route REQuest (RREQ) packet

Carries the path history and link-state information

1. Determine a better QoS multi-path routing.

2. Sent back the reply packet.

3. Confirmed and reserved bandwidths.




Collects all possible link-state information from different RREQ packets.

# Basic ideas and challenges

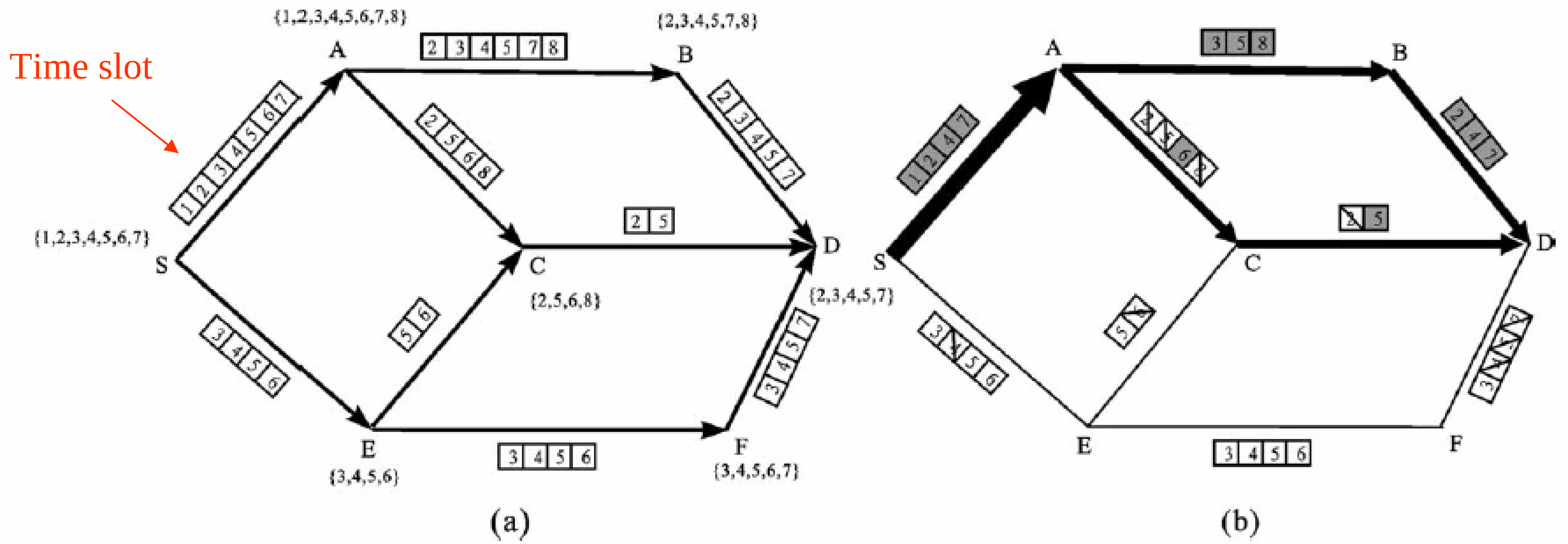



Fig. 4. Example of multi-paths in a CDMA-over-TDMA channel model.

- The multi-path routing is constructed using multiple uni-paths.
- Paths (S; A; B; D) and (S; A; C; D) are established if the path bandwidth requirement is four slots.

# Basic ideas and challenges

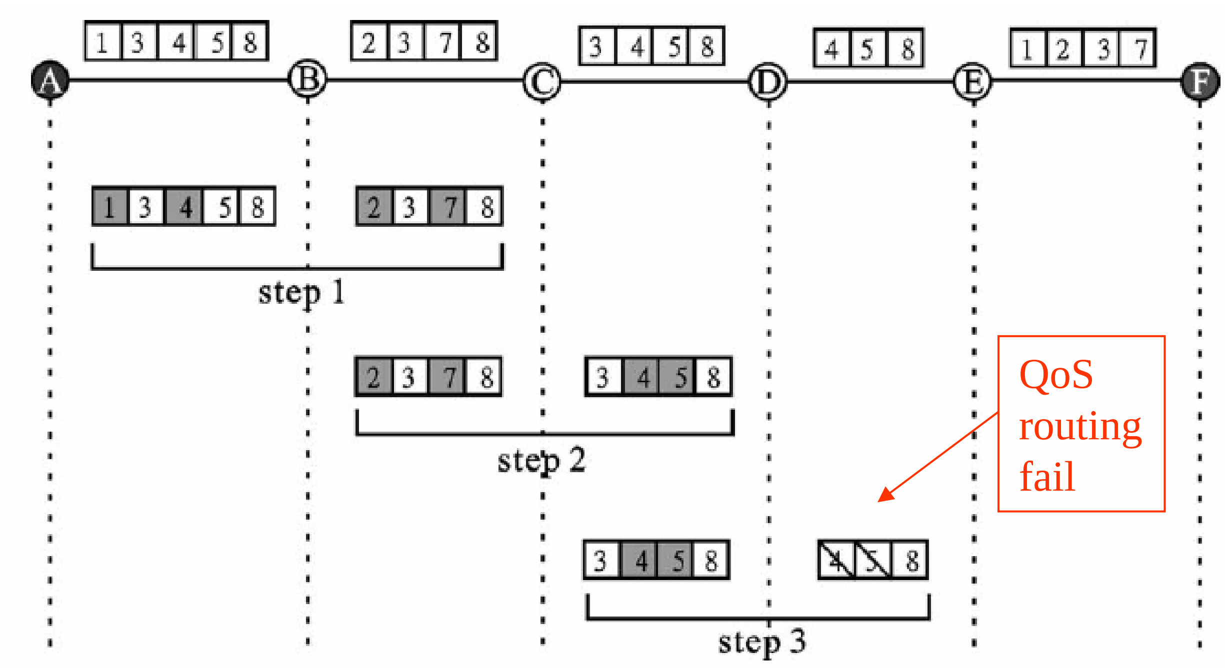



Fig. 5. Example of a hop-by-hop time slot reservation scheme.

Path requirement = two slots.

Each node only needs to maintain the link bandwidth of its neighbors.

QoS routing fail

- The uni-path routing scheme under the CDMA-over-TDMA channel model, Lin [10,11] calculated the end-to-end uni-path bandwidth by the hop by hop calculation for the time slot reservation.

# Basic ideas and challenges

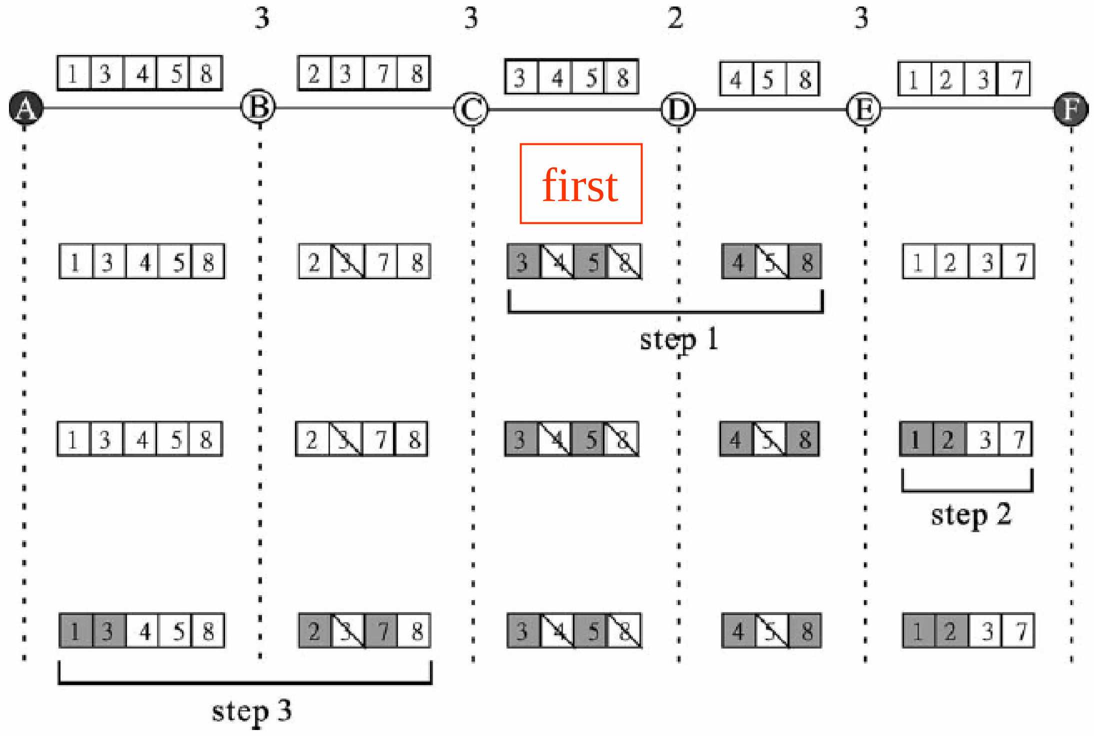



Fig. 6. Example of slot reservation by our QoS uni-path protocol.

- The scheme in this paper has to collect link-state information, and after that, an efficient algorithm of QoS uni-path time slot reservation is developed.

# The on-demand, link-state, multi-path QoS routing protocol

Phase 1: **on-demand, link-state delivery and collection**

Phase 2: **uni-path discovery**

Phase 3: **multi-path discovery and reply**

Phase 4: **multi-path maintenance**

- A QRREQ packet is denoted as
  - QRREQ (S; D; node_history, free_time_slot_list, B; TTL).

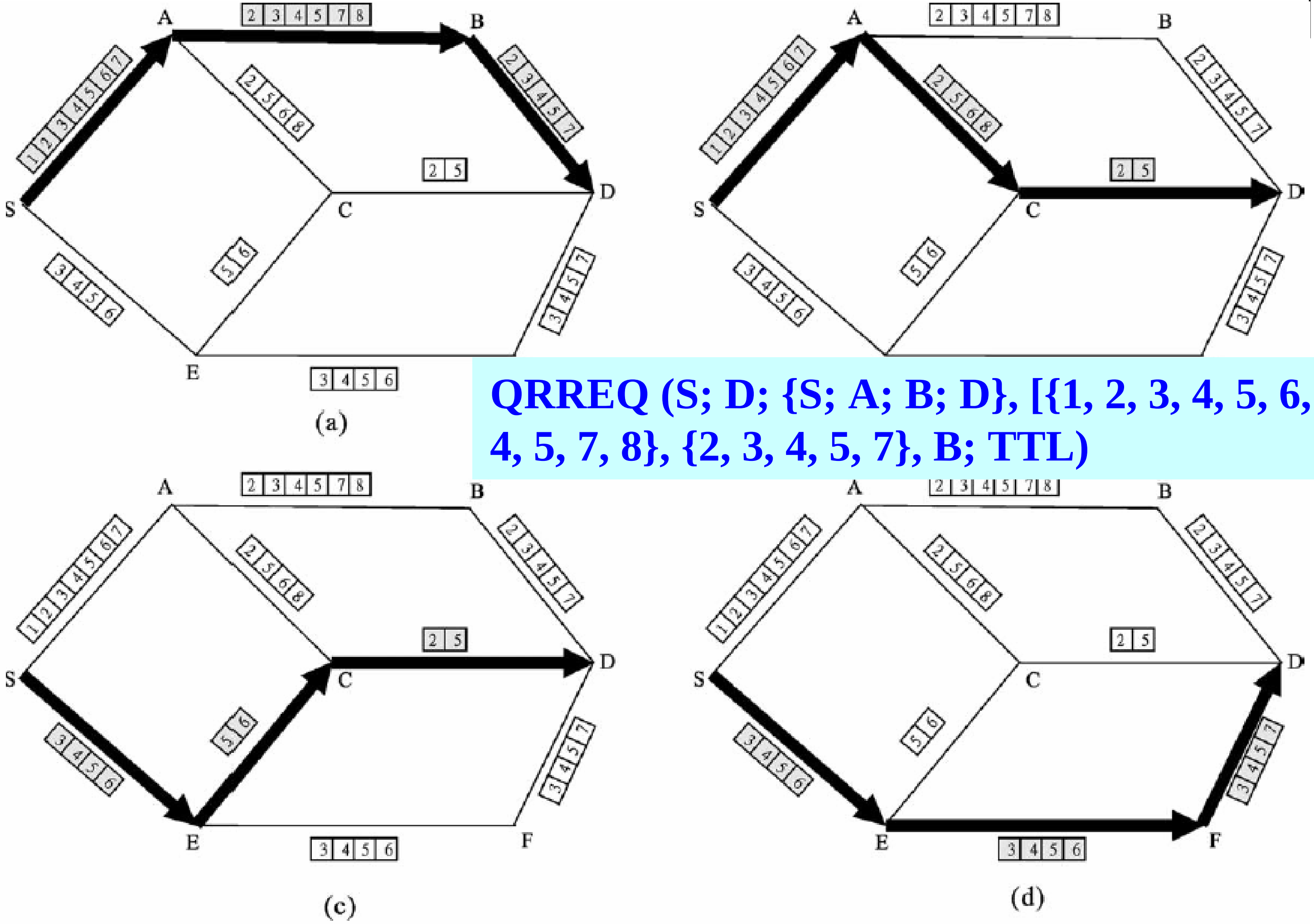
# Phase 1: on-demand, link-state delivery and collection

- Define the on-demand, link-state delivery/collection operation:

  (A1) Source node S initiates and floods a QRREQ packet into the MANET toward the destination node D if the given bandwidth requirement is B.

  (A2) If node e receives a QRREQ packet, add e into node_history and append the free time slots of node e and the last node recorded in the node_history into the free_time_slot list, and decrease the value of the TTL. If e is not the destination and TTL is not equal to zero, then we reforward the packet to all neighboring nodes whichdo not exist in node_history.

# Phase 1: on-demand, link-state delivery and collection

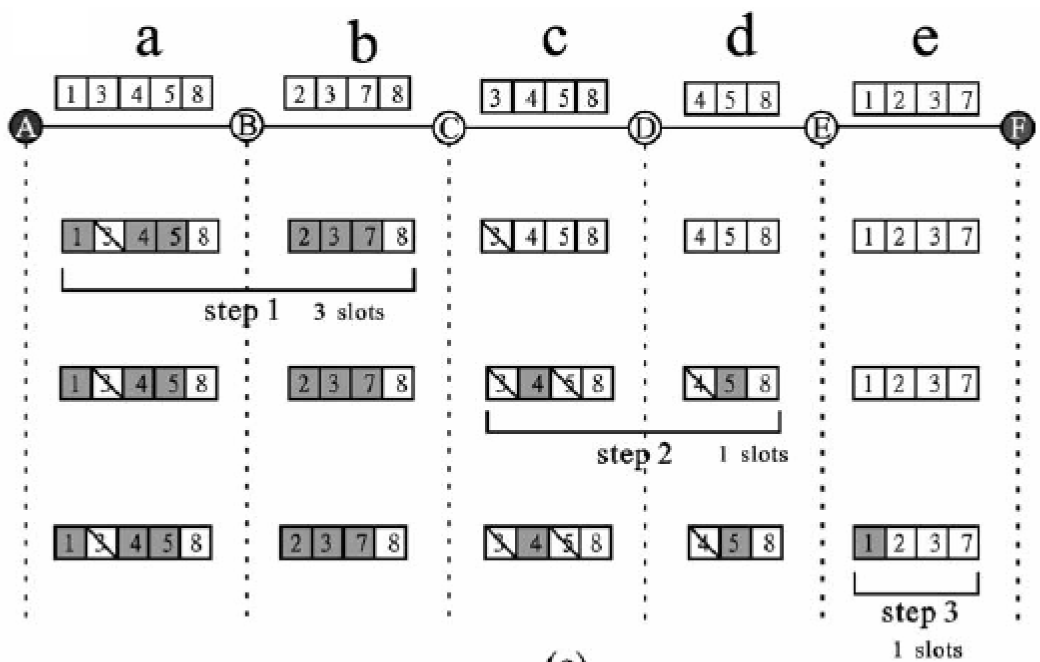



**QRREQ (S; D; {S; A; B; D}, [{1, 2, 3, 4, 5, 6, 7}, (2, 3, 4, 5, 7, 8}, {2, 3, 4, 5, 7}, B; TTL)**

Fig. 7. On-demand, link-state delivery and collection operation.

# Phase 2: uni-path discovery

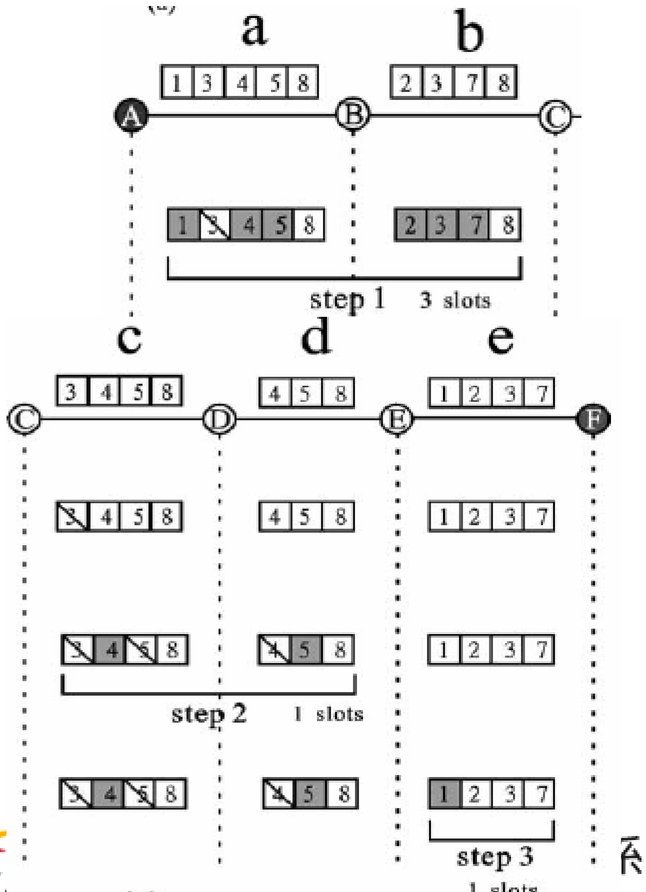
- The uni-path discovery operation is accomplished by constructing a least-cost-first time-slot reservation tree TLCF.
- Traditional hop-by-hop time slot reservation.




(c)

# Phase 2: uni-path discovery

- A maximal reserved time-slot number is denoted to reserve the largest number of time slots of a link in a path.




a={1,3,4,5,8}, b={2,3,7,8}

[1,4,5]→ AB, [2,3,7]→ BC

maximal reserved timeslot number=3.

the free time slot of c is thus updated

from [3,4,5,8] to [4,5,8]

[4]→ CD, [5]→ DE, [1]→ EF

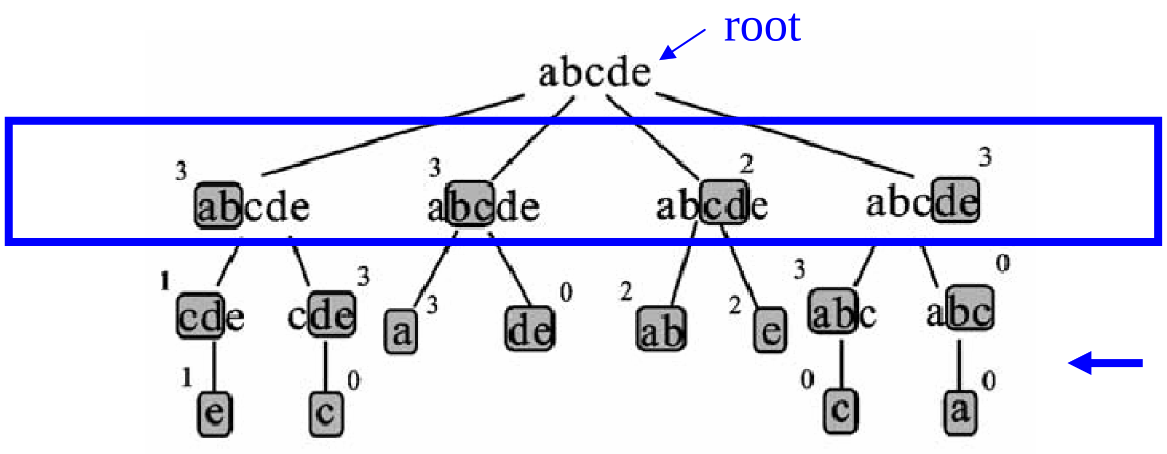
path bandwidth (A,B,C,D,E,F) is 1.

# Phase 2: uni-path discovery

- The new approach does not use traditional hop-by-hop slot reservation (in Fig. 6, the path bandwidth =2).
- The purpose of constructing tree $T_{LCF}$ is to identify a path with maximal path bandwidth.
- Trees T and $T_{LCF}$ are constructed to represent all possible conditions of time-slot reservation.
- The new time-slot reservation scheme does not follow the order of AB,BC,CD,…,EF.
- A time-slot reservation tree T is constructed by the breadth-first-searching approach.

# Phase 2: uni-path discovery

Definition 1. **Time-slot reservation tree T.**




First level

Recursively expends all children node of each node on each level of tree T.

- The maximal reserved time-slot numbers are 3, 3, 2, 3 from left to right in the first level.

# Phase 2: uni-path discovery

- The new uni-path time-slot reservation

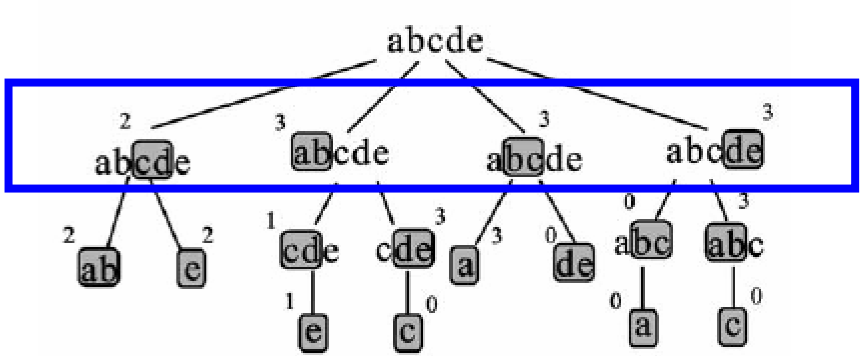
(B1)given T tree and path bandwidth B, by depth-first-search order. Each path from root to leaf nodes forms a time-slot reservation pattern. [ex. (ab, cd, e): reservation time slot=1, (ab, de,c): 0 ]

(B2)if a new reservation pattern exists to reserve a path bandwidth B', and B'<B, than we proceed to traverse tree T until identifying other reservation patterns, and than go to step B2. otherwise, if tree traversal is finished or B'>=B, than exits the procedure.

- All possible reservation patterns are identified, and a maximal path bandwidth is exploited.

# Phase 2: uni-path discovery

Definition 2. Least-cost-first time-slot reservation tree $T_{LCF}$.




Maximal reserved time-slot numbers from left to right are 2,3,3,3.

Uni-path time-slot reservation algorithm is the same for steps B1 and B2.

- (C1) the same as step B1, except for providing the least-cost-first time-slot reservation tree $T_{LCF}$ and bandwidth B.
- (C2) the same as step B2, except for traversing the least-cost-first time-slot reservation tree $T_{LCF.}$

# **Phase 3:** multi-path discovery and reply

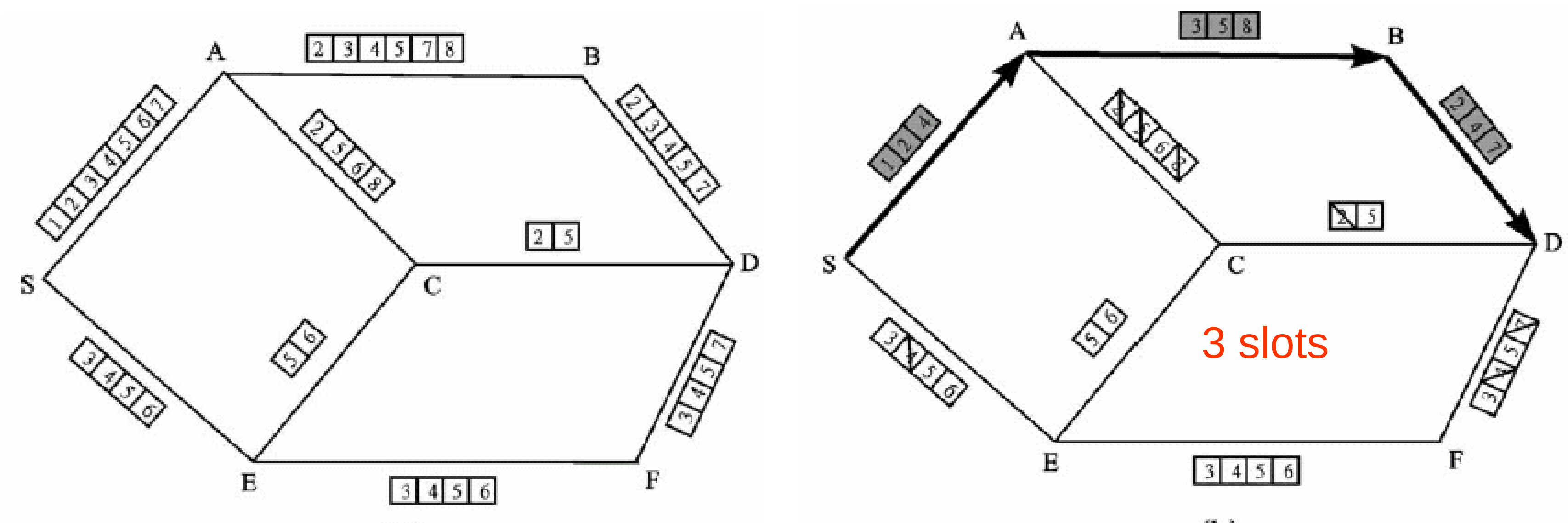
- A centralized algorithm is proposed at the destination to determine the multi-paths.

(D1) Let Bandwidth_Sum denote the total sum of multiple uni-paths. Initially, we set Bandwidth_Sum= 0.

(D2) The destination waits for a period of time to obtain a possible uni-path, while Bandwidth_Sum< B. Use a uni-path discovery procedure to acquire its maximal path bandwidth b. Let Bandwidth_Sum= Bandwidth_Sum+ b. If Bandwidth_ Sum <B, then modify all link-state information of the network topology according to the current constructed unipath and then go to step D2. If Bandwidth_ Sum >=B, then exits the procedure.

# **Phase 3:** multi-path discovery and reply

- The proposed multi-path discovery operation sequentially exploits multiple uni-paths.
- Continue to modify the link-state information in Fig. 9 (b), (c), (d).




(a) (b)

# **Phase 3:** multi-path discovery and reply

Original bandwidth requirement = 4 slots.

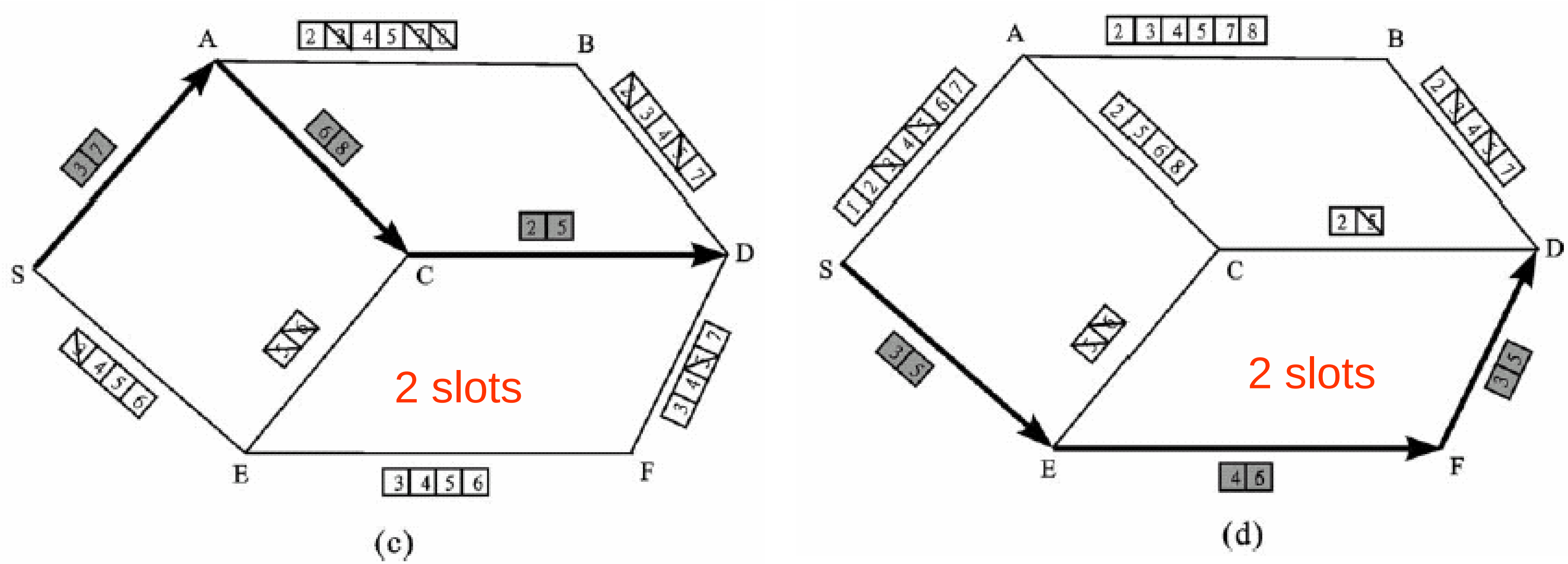



Fig. 9. The original network and found multi-paths.

- All identified uni-paths are also displayed in Fig. 10(a).

# Phase 3: multi-path discovery and reply

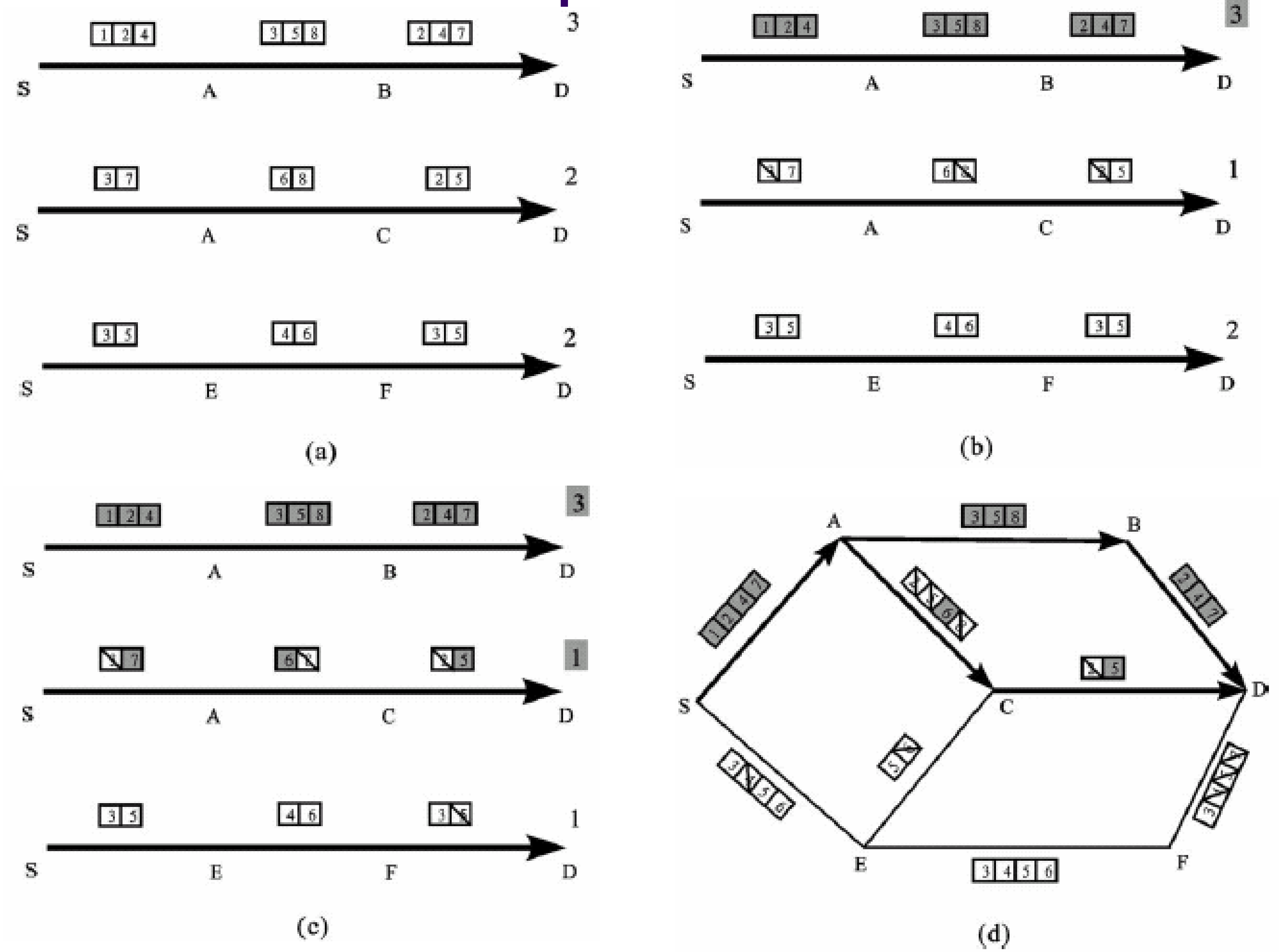
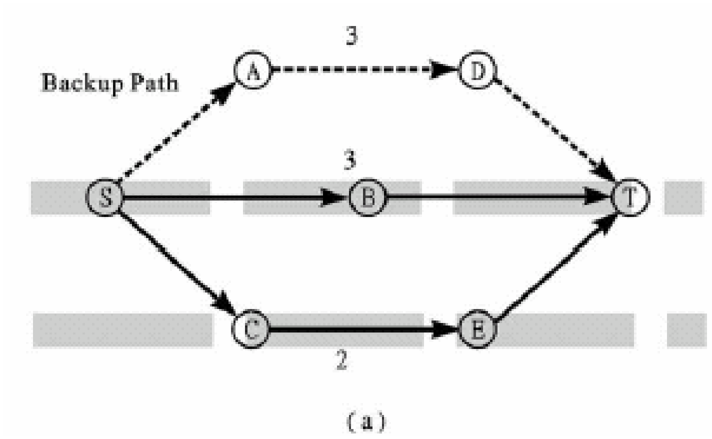



Fig. 10. Example of multi-path discovery.

# Phase 4: multi-path maintenance

- Single-path tolerance capability achieved by adding a backup path into the multi-path.
- The backup path must be a fully disjointed path from the identified multi-path, and the bandwidth must be large enough.



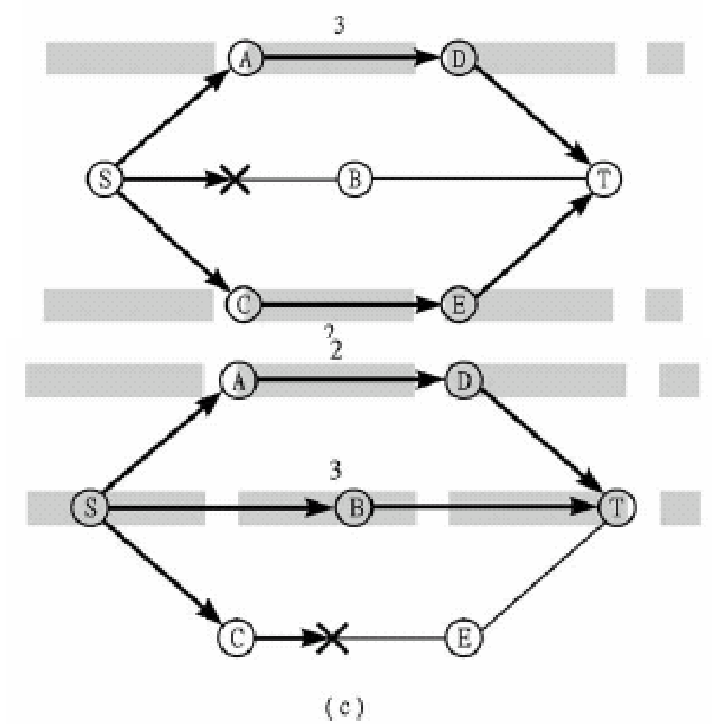




Fig. 11. Example of multi-path maintenance.

# Experimental results

- **MP1:** if the multi-path discovery operation adopts the constructed $T_{LCF}$ tree.
- **MP2:** if the multi-path discovery operation does not use the constructed $T_{LCF}$ tree.
- Three different bandwidth requirements are 1, 2 and 4 slots.
- **Success_Rate (SR):** (# of successful QRREQs)/ (total # of QRREQs from source to destination).
- **Slot_Utilization (SU)**
- **OverHead (OH):** the hop count of routing packets being transmitted divided by the total number of QoS request.
- **Incomplete (IR):**the number of broken connections divided by the number of success QoS requests.

# Experimental results

**Performance of Success Rate**

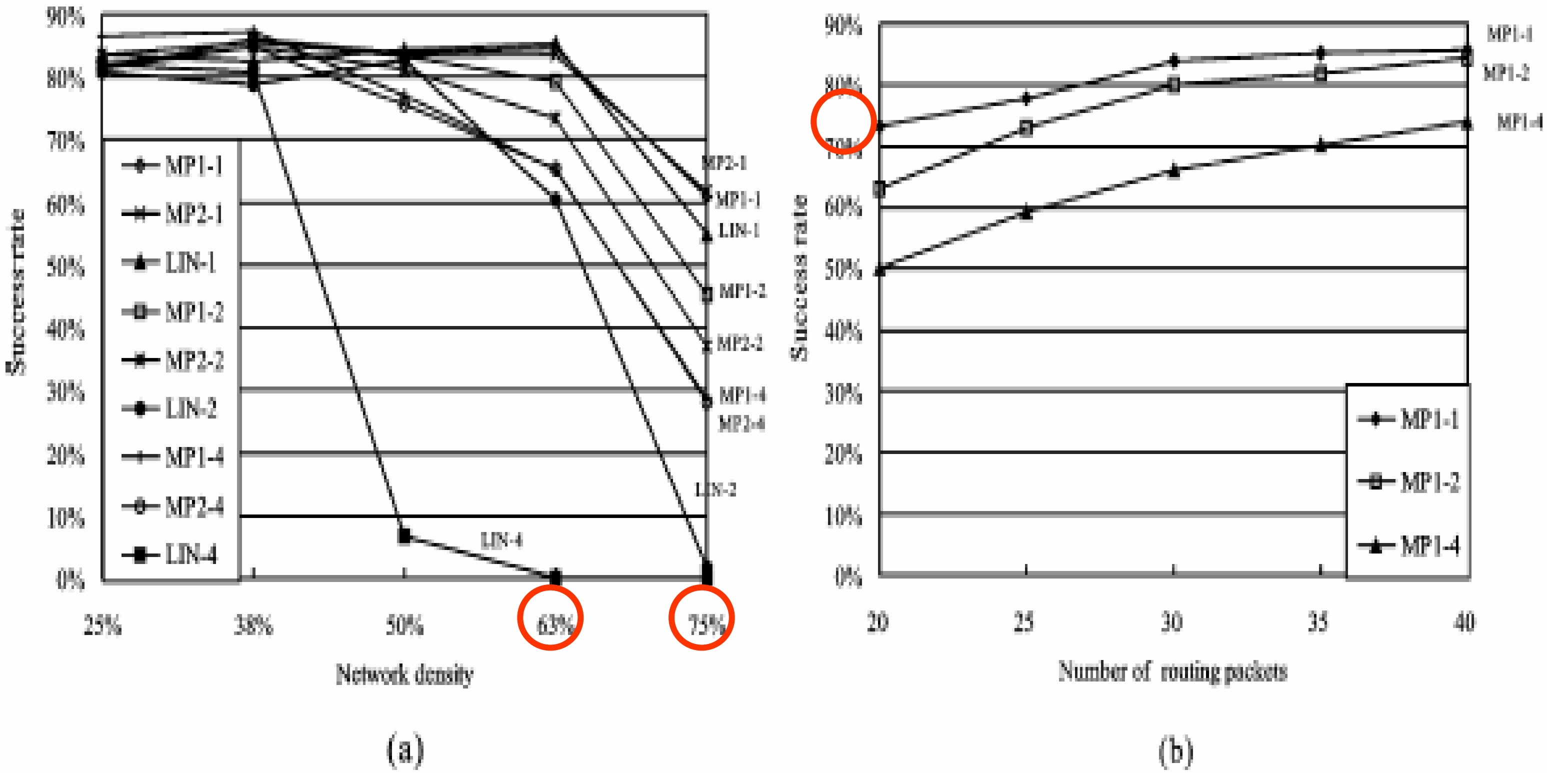
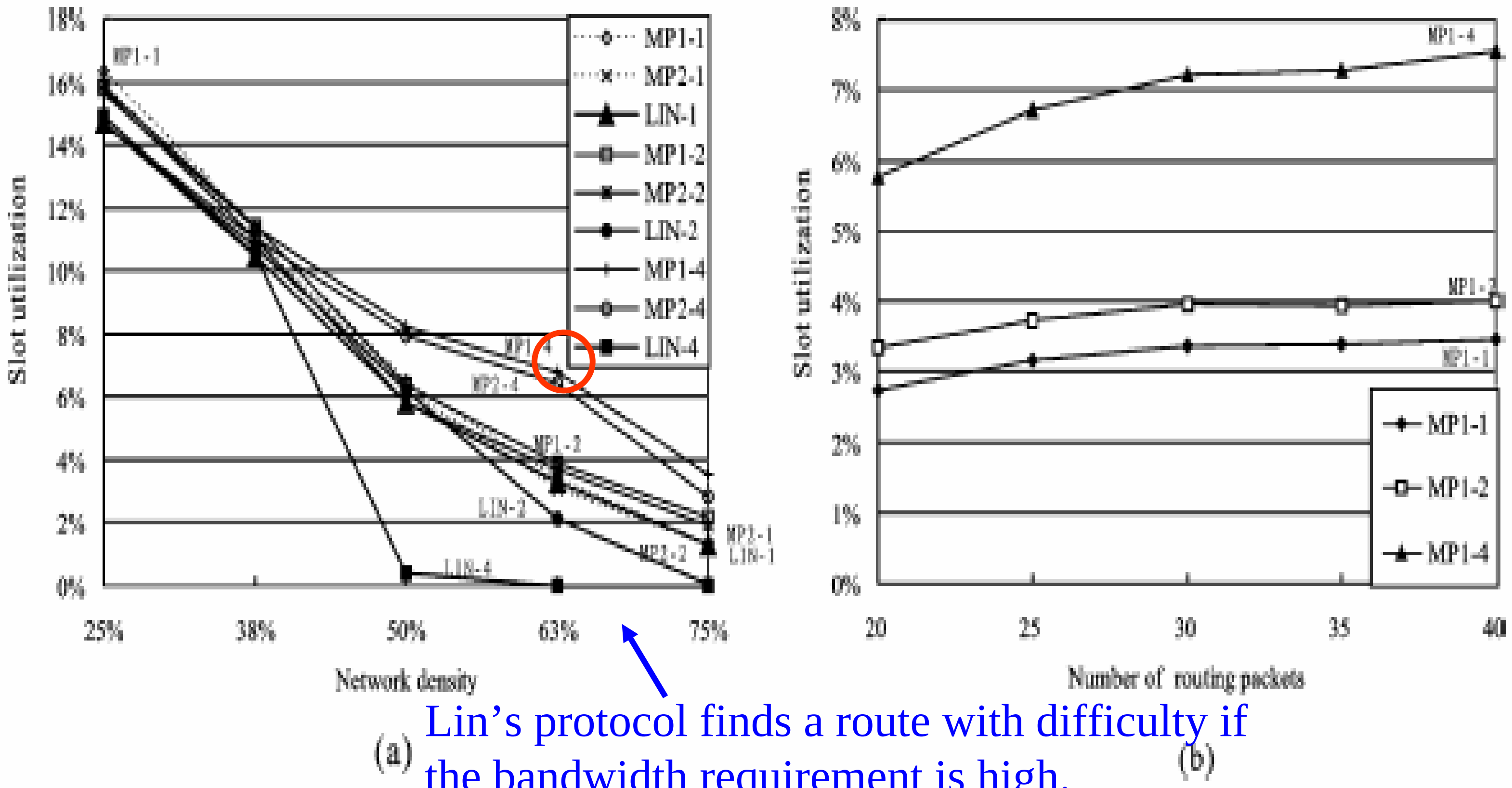



Fig. 12. Success rate vs. (a) network density (number of mobile hosts = 30 and number of routing packets = 30), (b) number of routing packets (number of mobile hosts = 30 and network density = 63).

# Experimental results




Lin's protocol finds a route with difficulty if the bandwidth requirement is high.

Fig. 13. Slot utilization vs. (a) network density (number of mobile hosts = 30 and number of routing packets = 30), (b) number of routing packets (number of mobile hosts = 30 and network density = 63).

# Experimental results

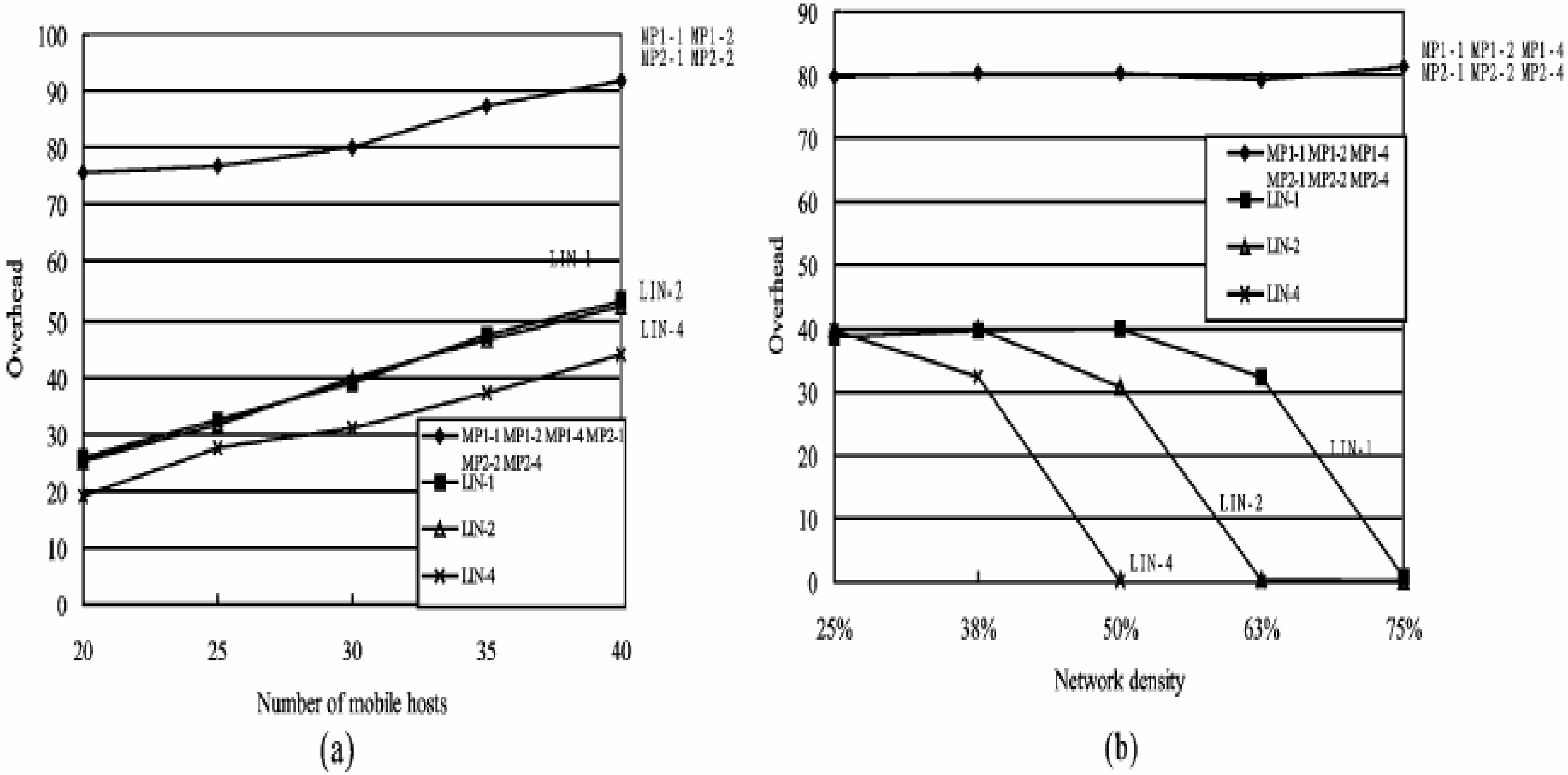



Fig. 14. Routing overhead vs. (a) network size (number of routing packets = 30 and network density = 38%), (b) network density (number of routing packets = 30 and number of mobile hosts = 30).

# Experimental results

- Effect of number of mobile hosts.
  - The proposed approach mainly concerns how many QRREQ packets are delivery/collection phase.
  - In Lin's approach, overhead is dependent on the bandwidth requirement.
  - The routing packet of new approach will be re-forwarded to the destination in an intermediate node even if this node does not have enough free time slots.
- Effect of network density.
  - Lin's protocol has a very low overhead for high network density.
  - When the density is high, the success rate is very low, few routing packets can reach the destination host. (Lin's)

# Experimental results

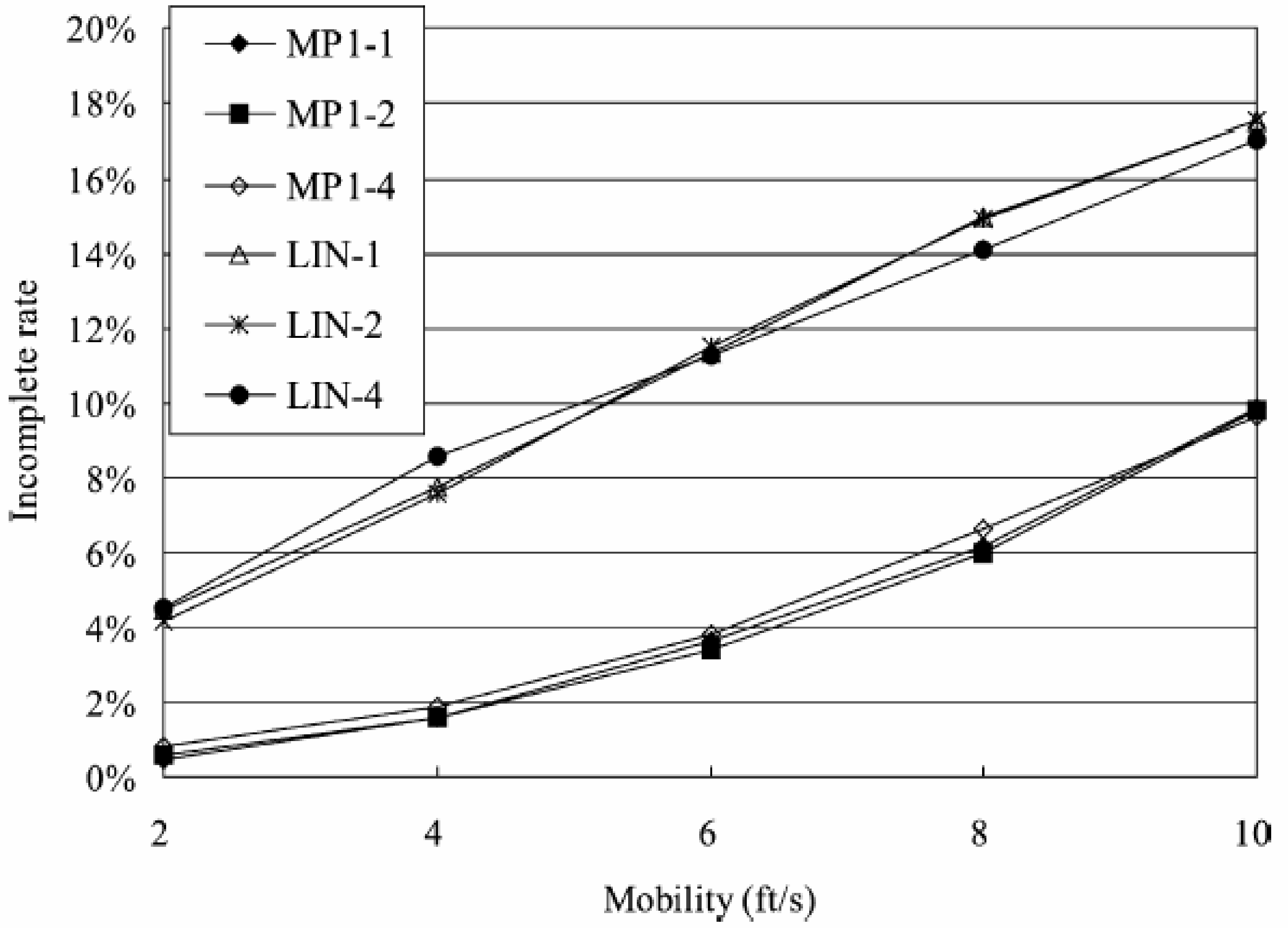



Fig. 15. Incomplete rate vs. mobility (number of mobile hosts = 30, number of routing packets = 30, and network density = 38%).

# Experimental results

- Effect of mobility.
  - A transmission connection might not be completely finished due to link breakage.
  - Proposed (1%- 10%), Lin's (4%-17%).
  - This because the backup path scheme improves the route robustness.

# Conclusions

- The proposed no-demand, link-state, multi-path routing approach has a higher success rate, higher slot utilization, higher overhead, and a lower incomplete rate.
- The proposed protocol is developed by searching uni-path or multipath route at the destination depending on the network bandwidth is sufficient or not.
- Performance analysis results demonstrate that the new proposed protocol outperforms existing QoS routing protocol.

# Homework #13:

1. How to design a QoS routing protocol in MANETs ?