Chapter 11 An On-Demand, Link-State, Multi-Path QoS Routing in a MANET

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Dec. 2006

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

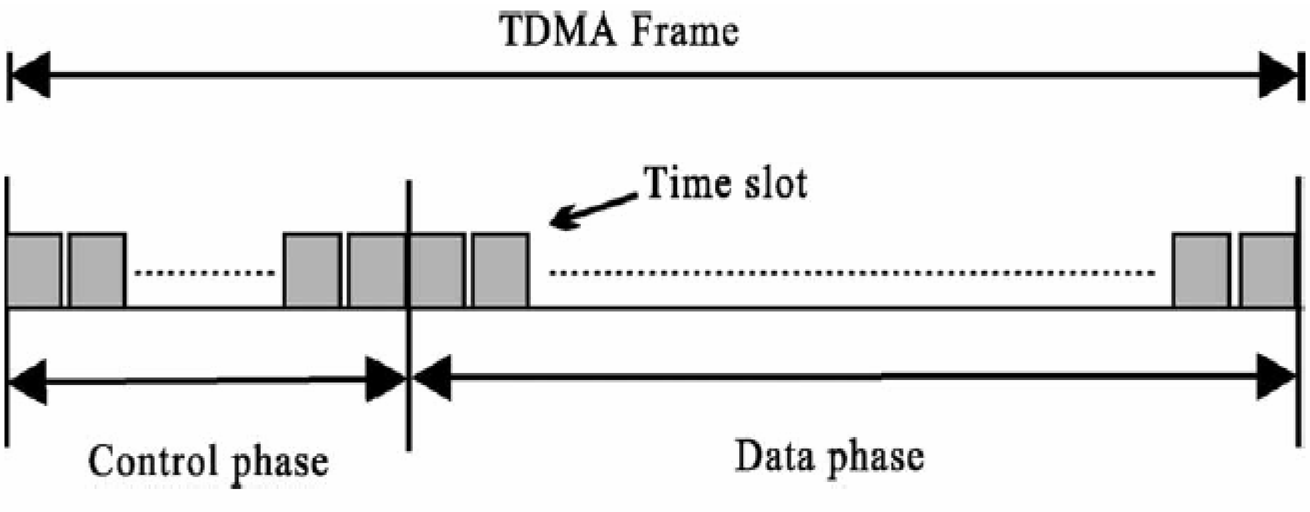


Fig. 1. TDMA frame structure.

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

Basic ideas and challenges

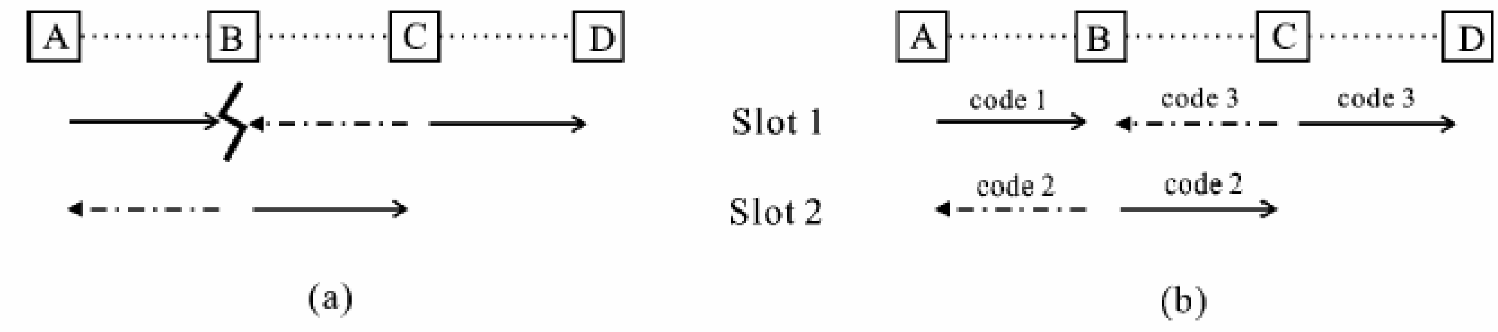


Fig. 2. (a) Hidden terminal problem, (b) CDMA-over-TDMA.

- 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

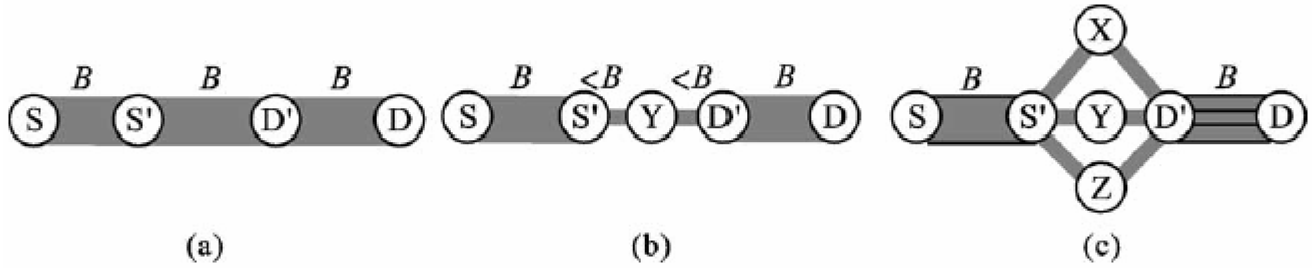


Fig. 3. Multi-path approach.

- 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.

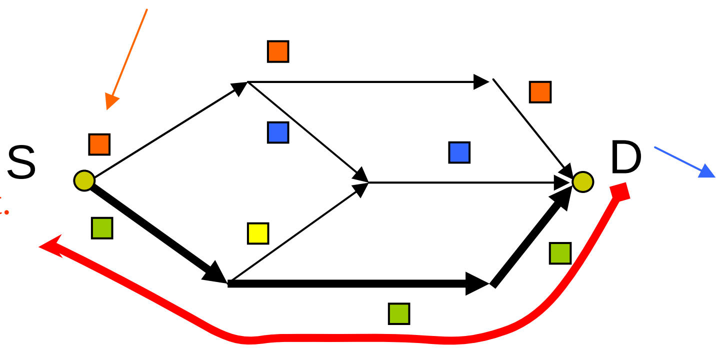
Route REQuest (RREQ) packet

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

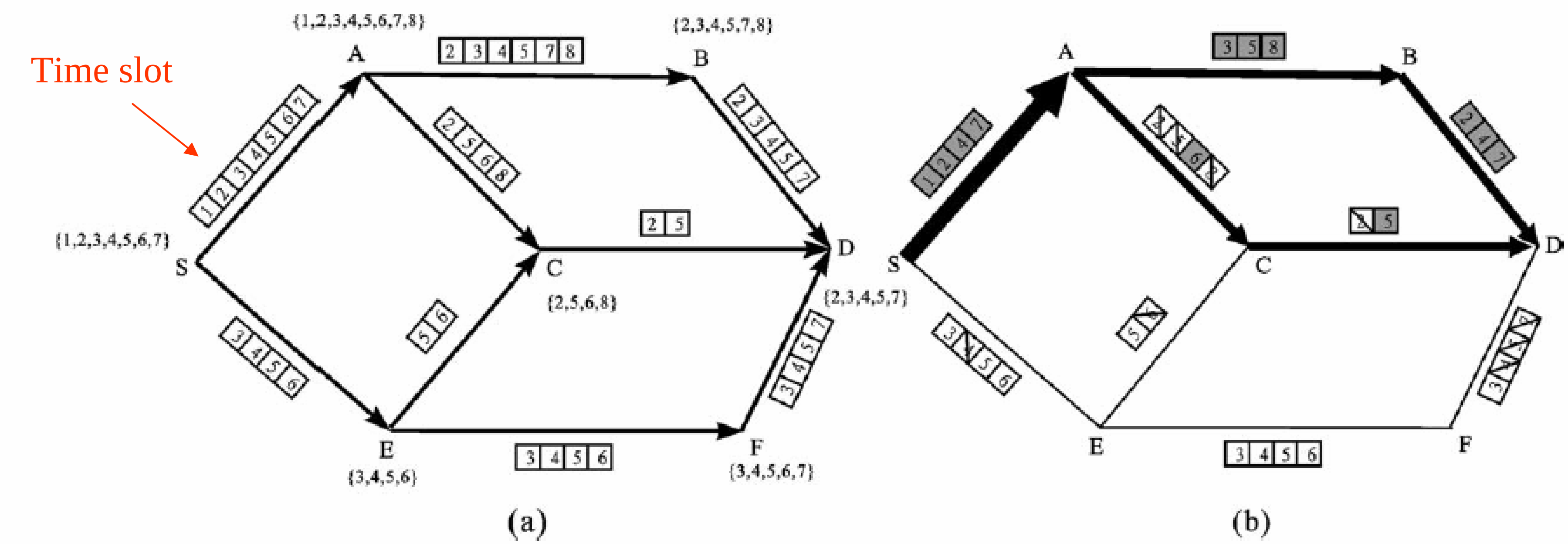


Fig. 4. Example of multi-paths in a CDMA-over-TDMA channel model.

- 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

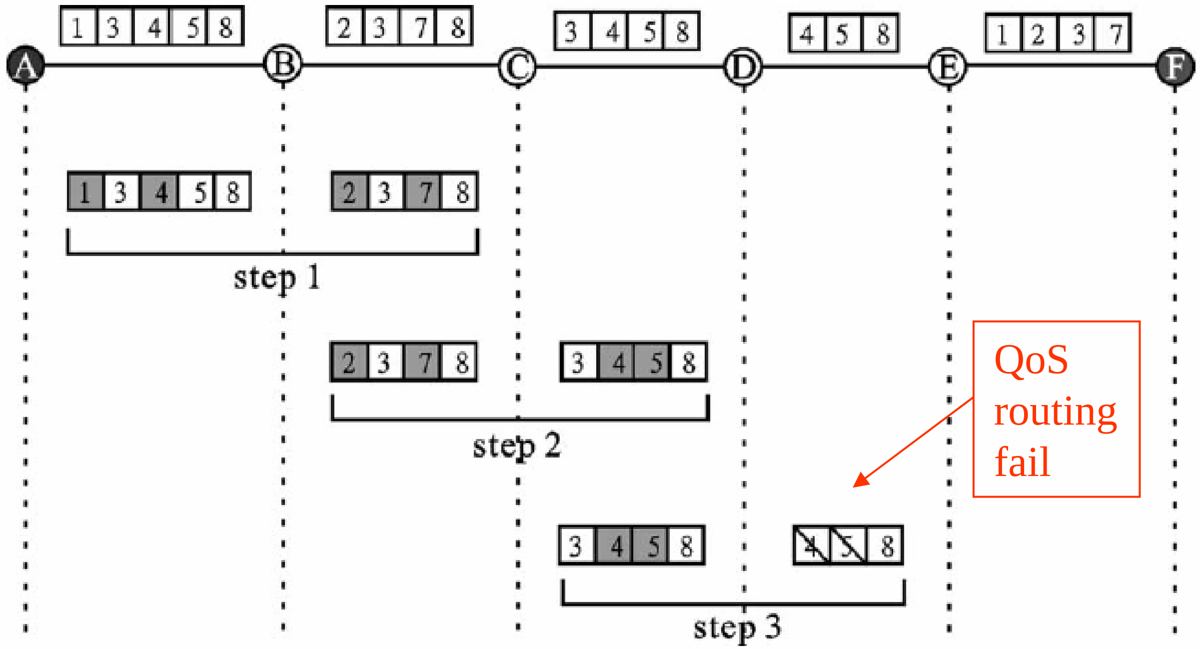


Fig. 5. Example of a hop-by-hop time slot reservation scheme.

QoS routing fail

Path requirement = two slots.

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

- 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

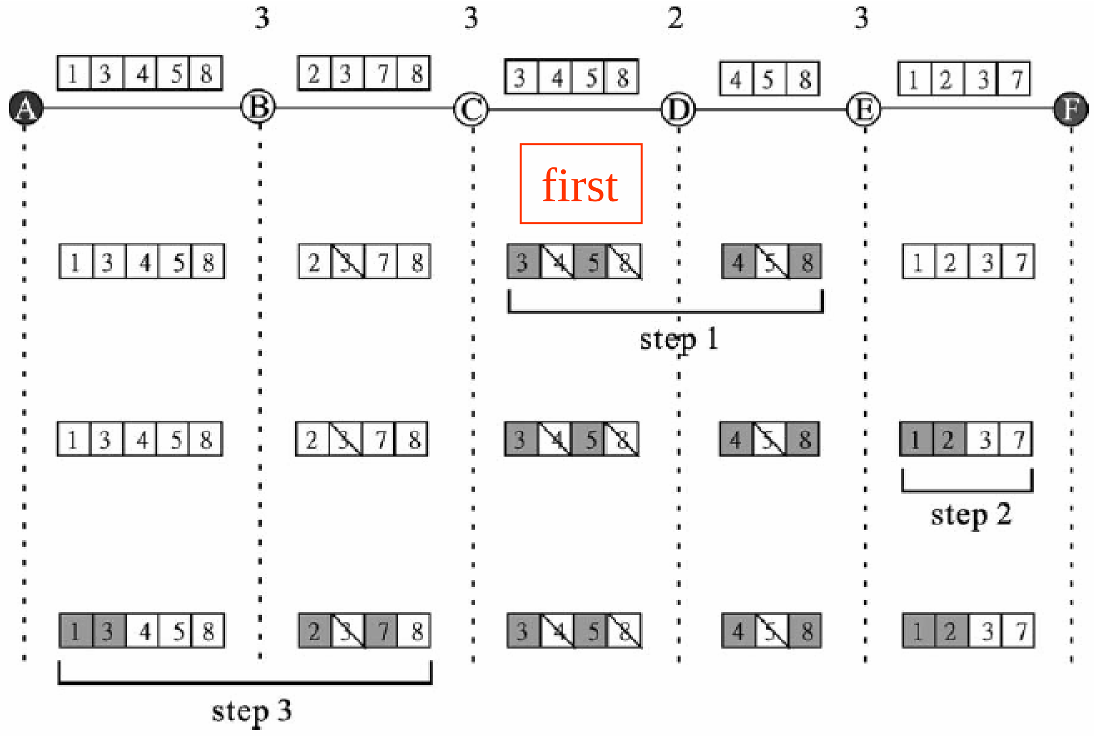


Fig. 6. Example of slot reservation by our QoS uni-path protocol.

- 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

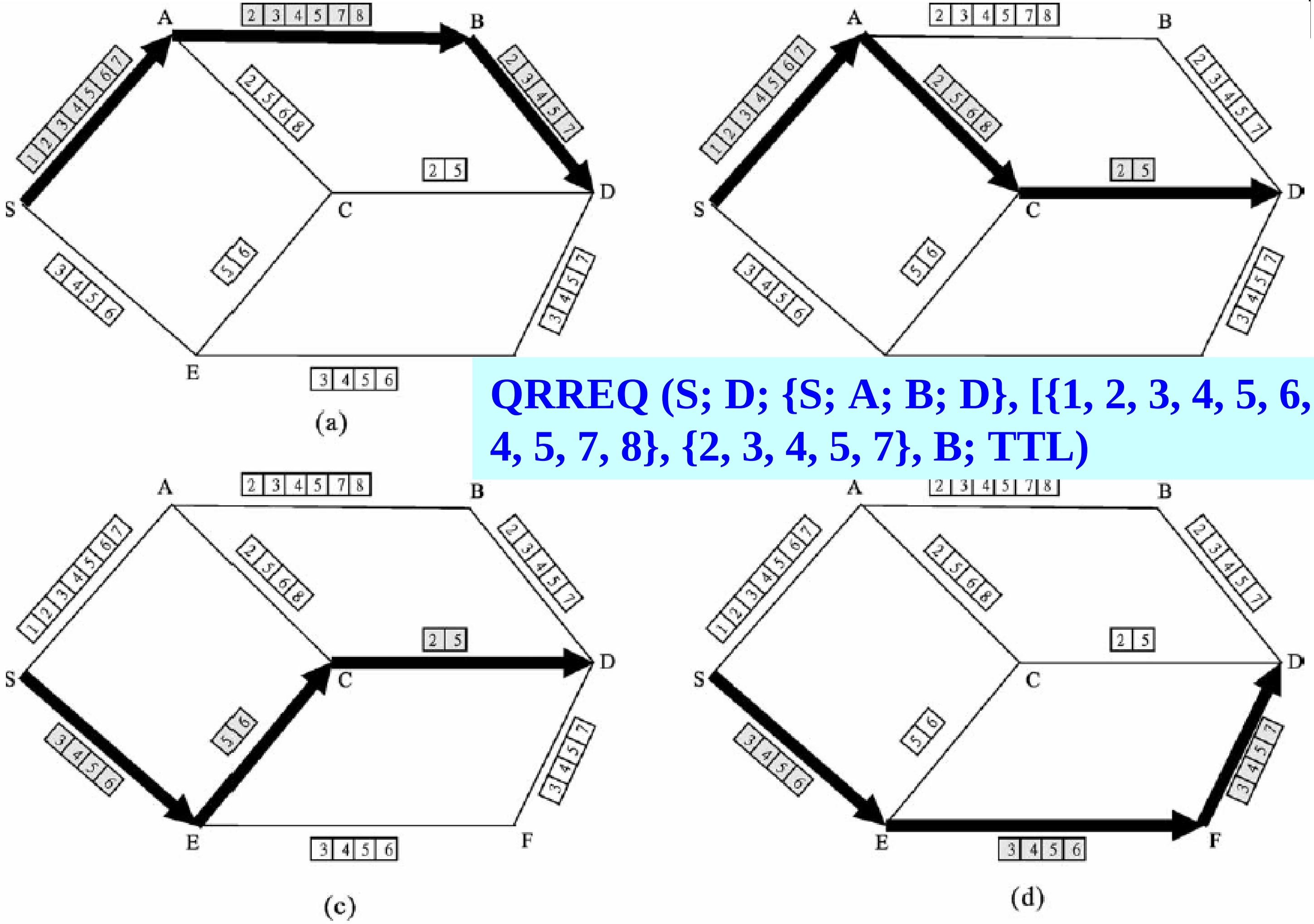
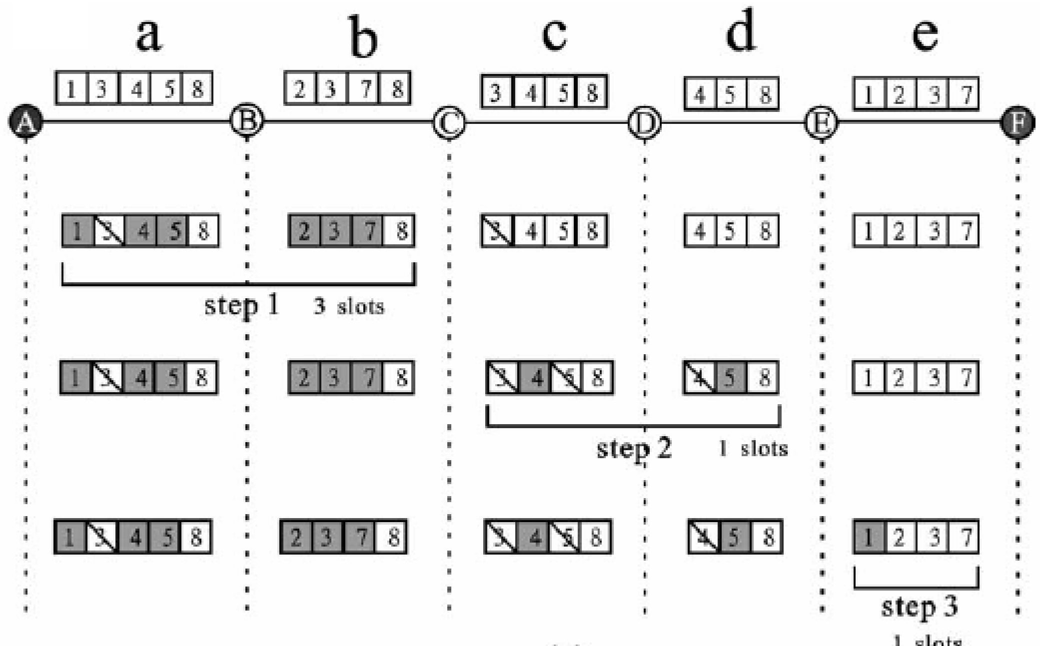


Fig. 7. On-demand, link-state delivery and collection operation.

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)

Phase 2: uni-path discovery

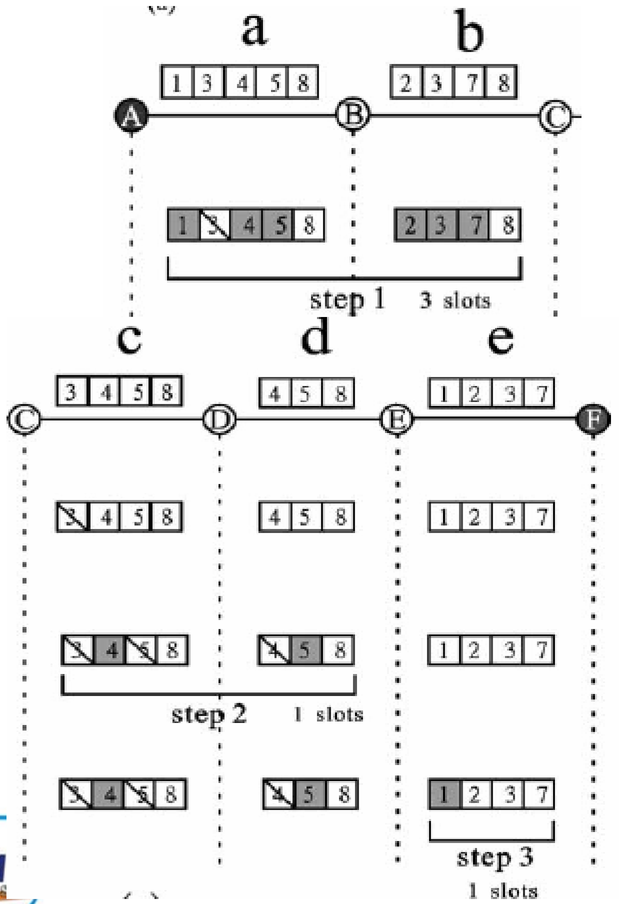
- The uni-path discovery operation is accomplished by constructing a least-cost-first time-slot reservation tree TLCF.
- Traditional hop-by-hop time slot reservation.



(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

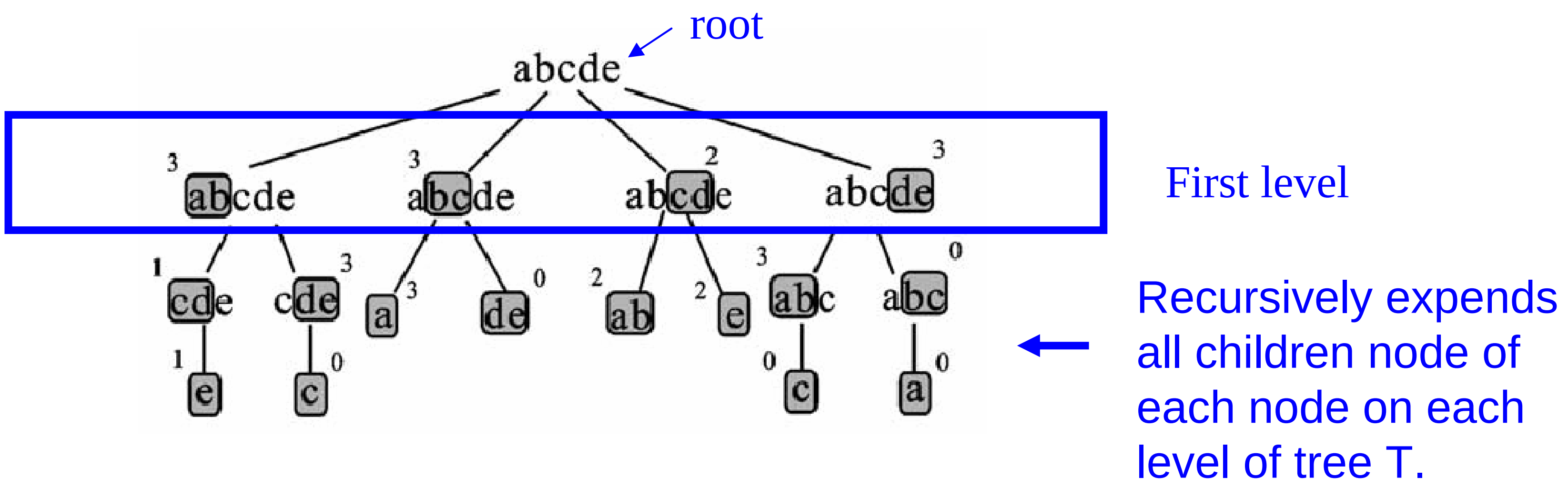
path bandwidth (A,B,C,D,E,F) is 1.

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.**



- 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

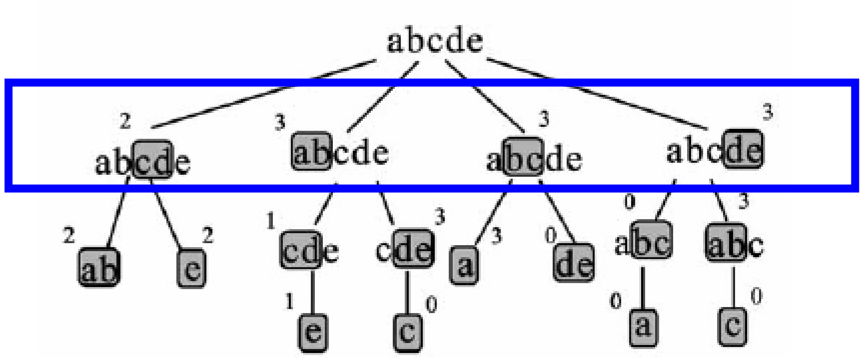
(B1)given T tree and path bandwidth B, by depth-first-search order. Each path from root to leaf nodes forms a time-slot reservation pattern. [ex. (ab, cd, e): reservation time slot=1, (ab, de,c): 0]

(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

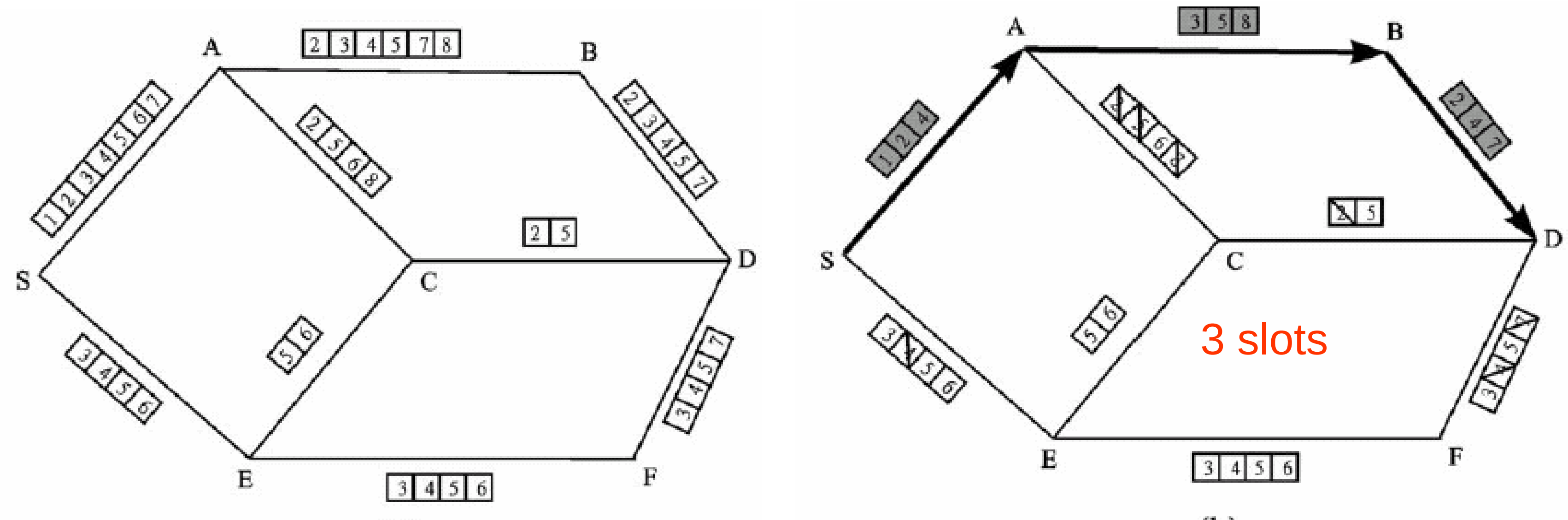
- A centralized algorithm is proposed at the destination to determine the multi-paths.

(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.

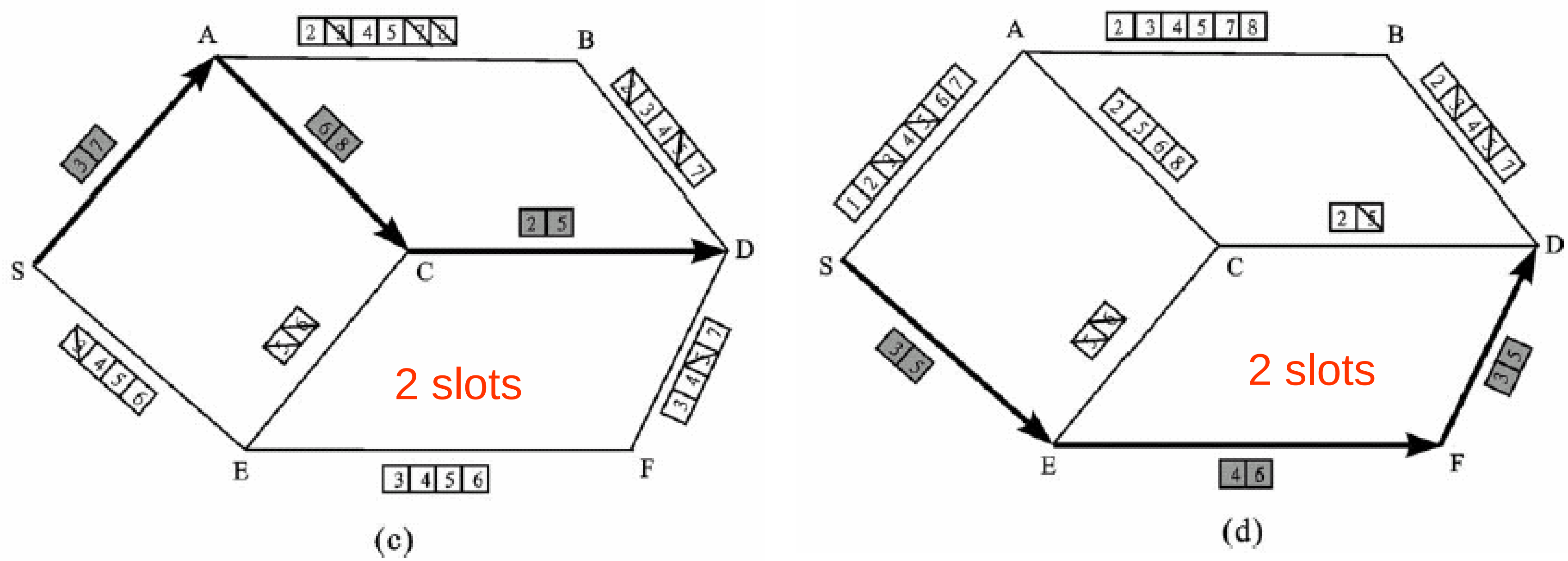


Fig. 9. The original network and found multi-paths.

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

Phase 3: multi-path discovery and reply

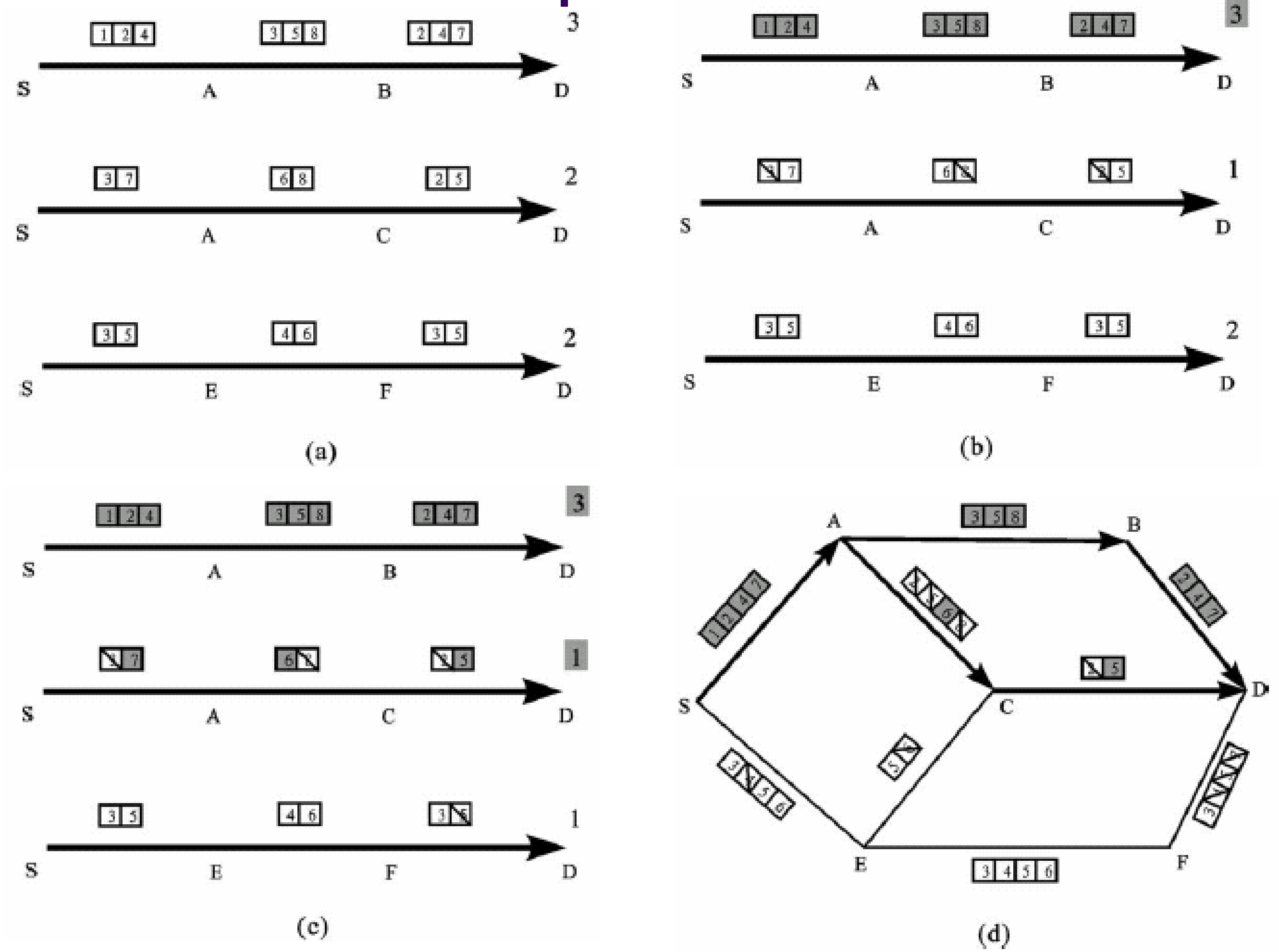


Fig. 10. Example of multi-path discovery.

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.

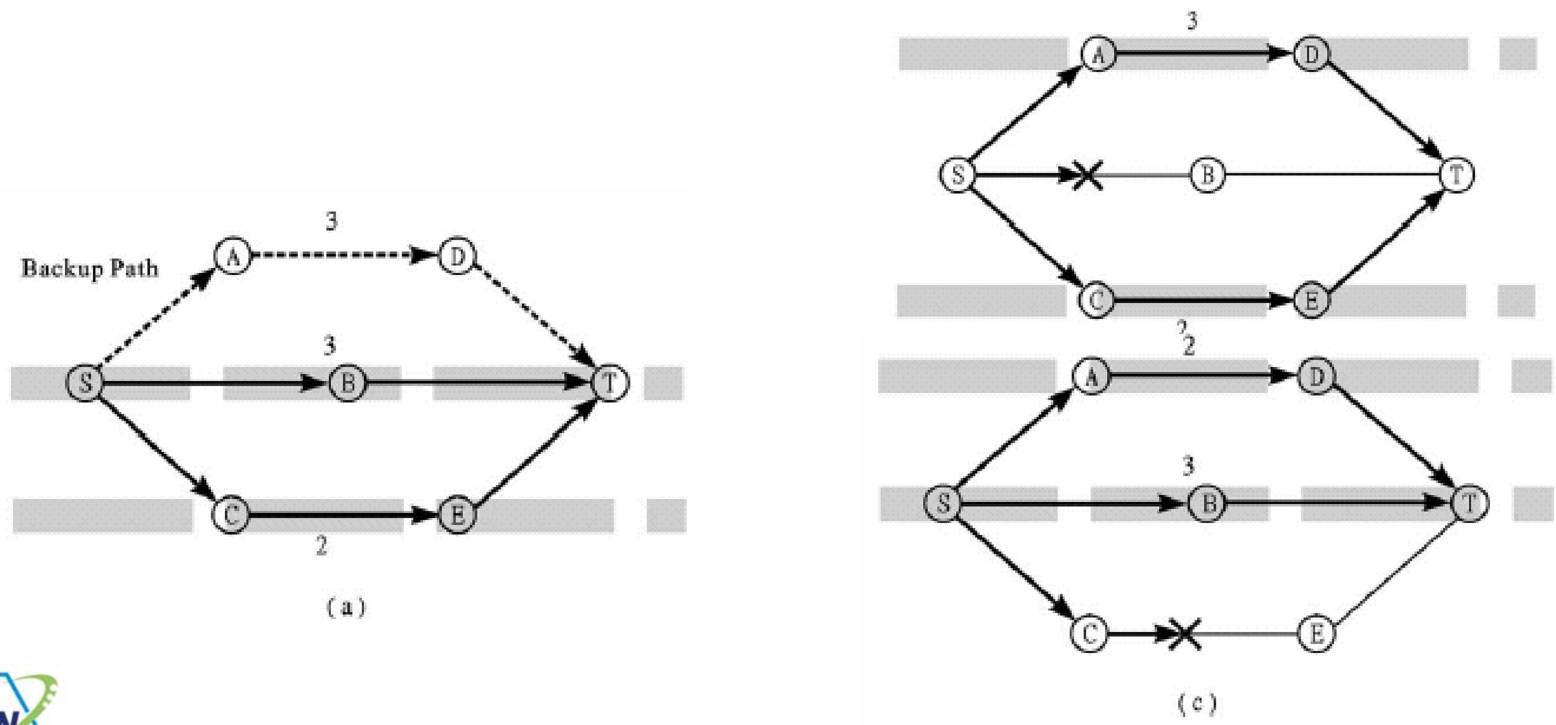


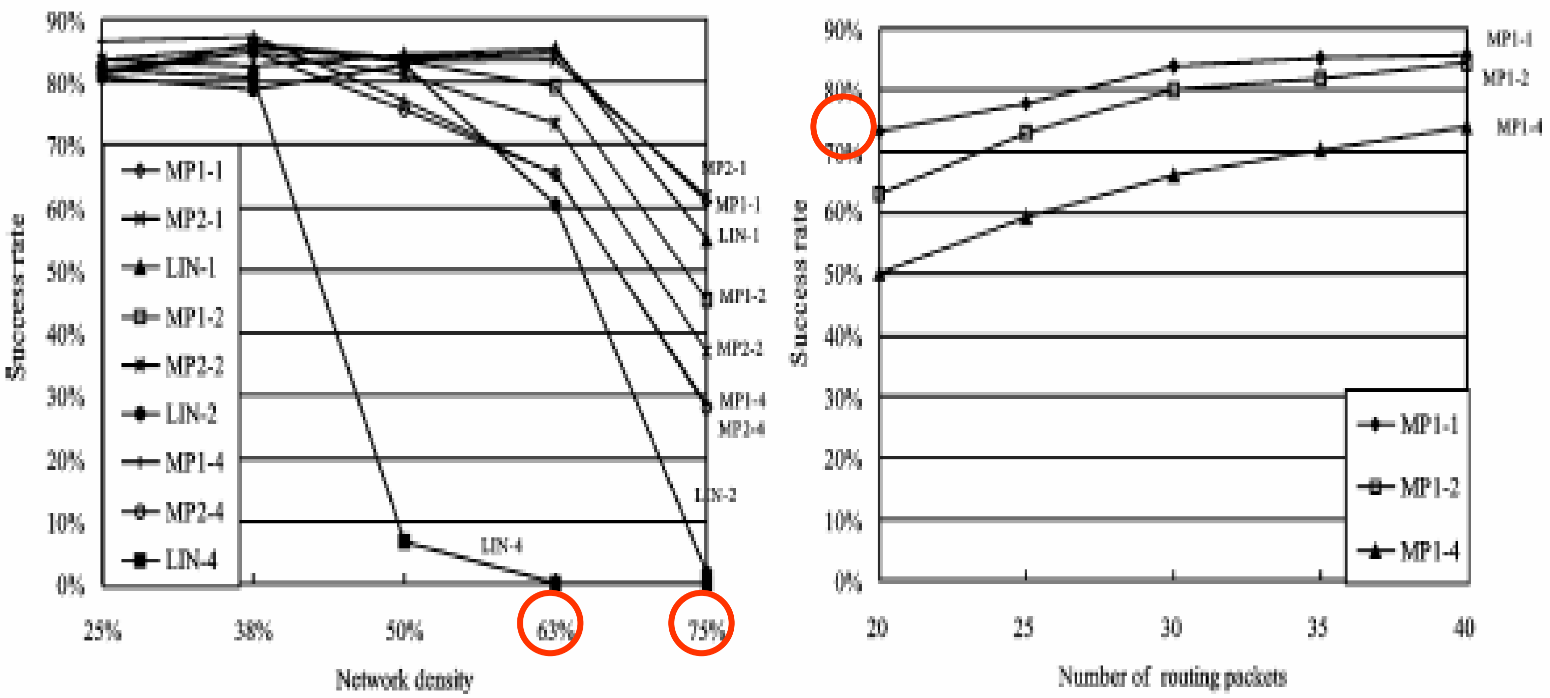
Fig. 11. Example of multi-path maintenance.

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



(a) (b)

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

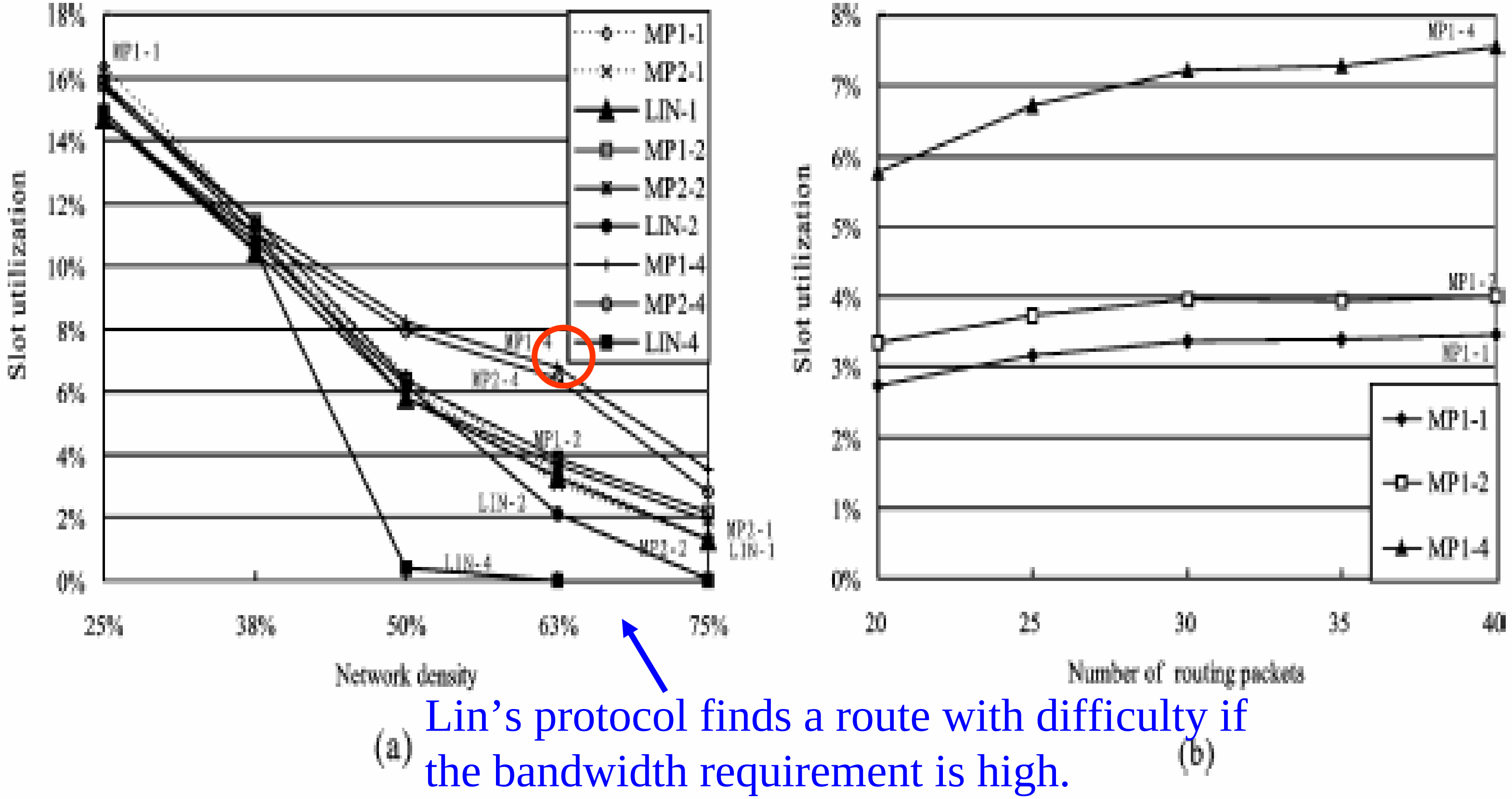


Fig. 13. Slot utilization vs. (a) network density (number of mobile hosts = 30 and number of routing packets = 30), (b) number of routing packets (number of mobile hosts = 30 and network density = 63).

Experimental results

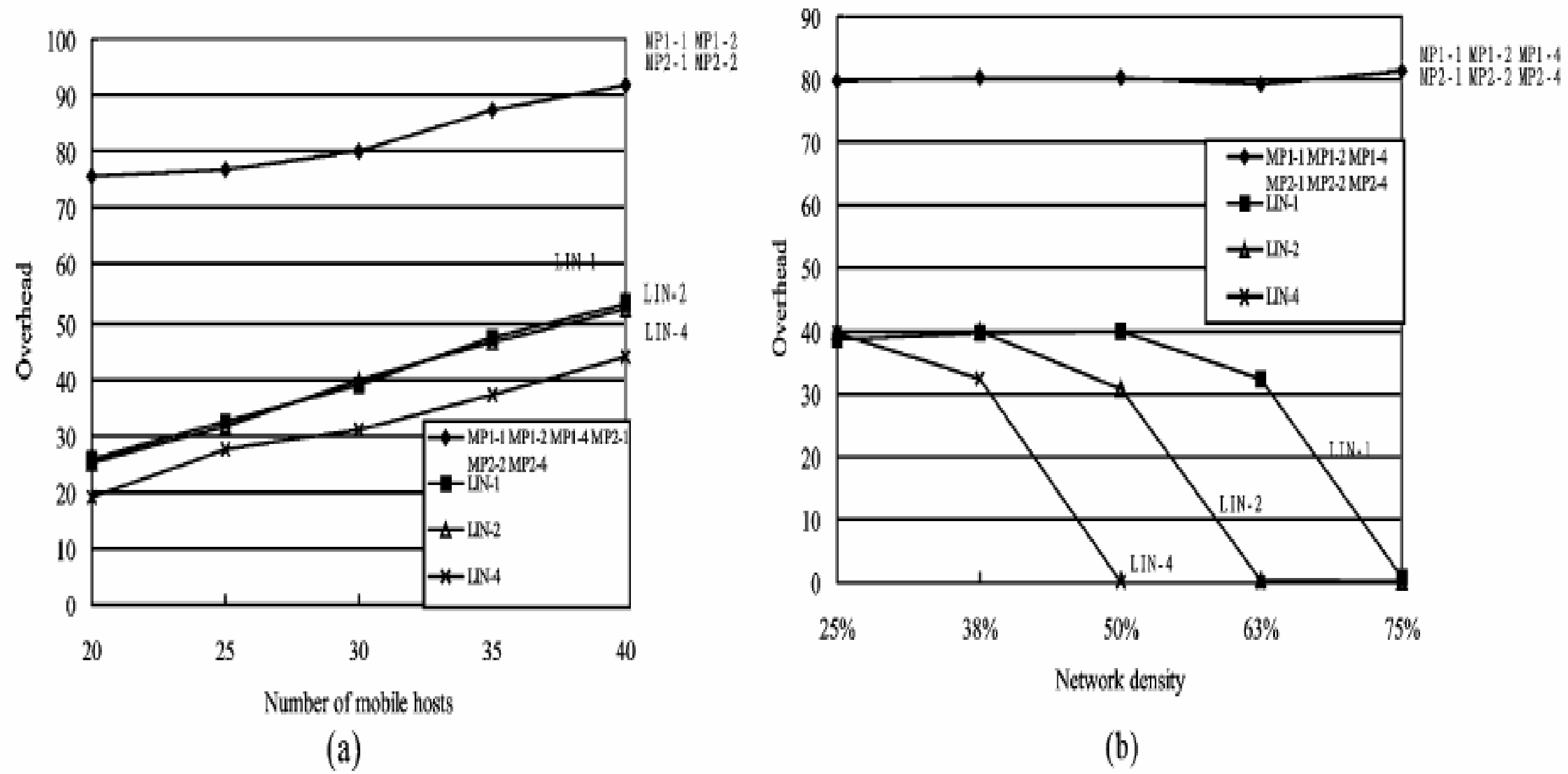


Fig. 14. Routing overhead vs. (a) network size (number of routing packets = 30 and network density = 38%), (b) network density (number of routing packets = 30 and number of mobile hosts = 30).

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

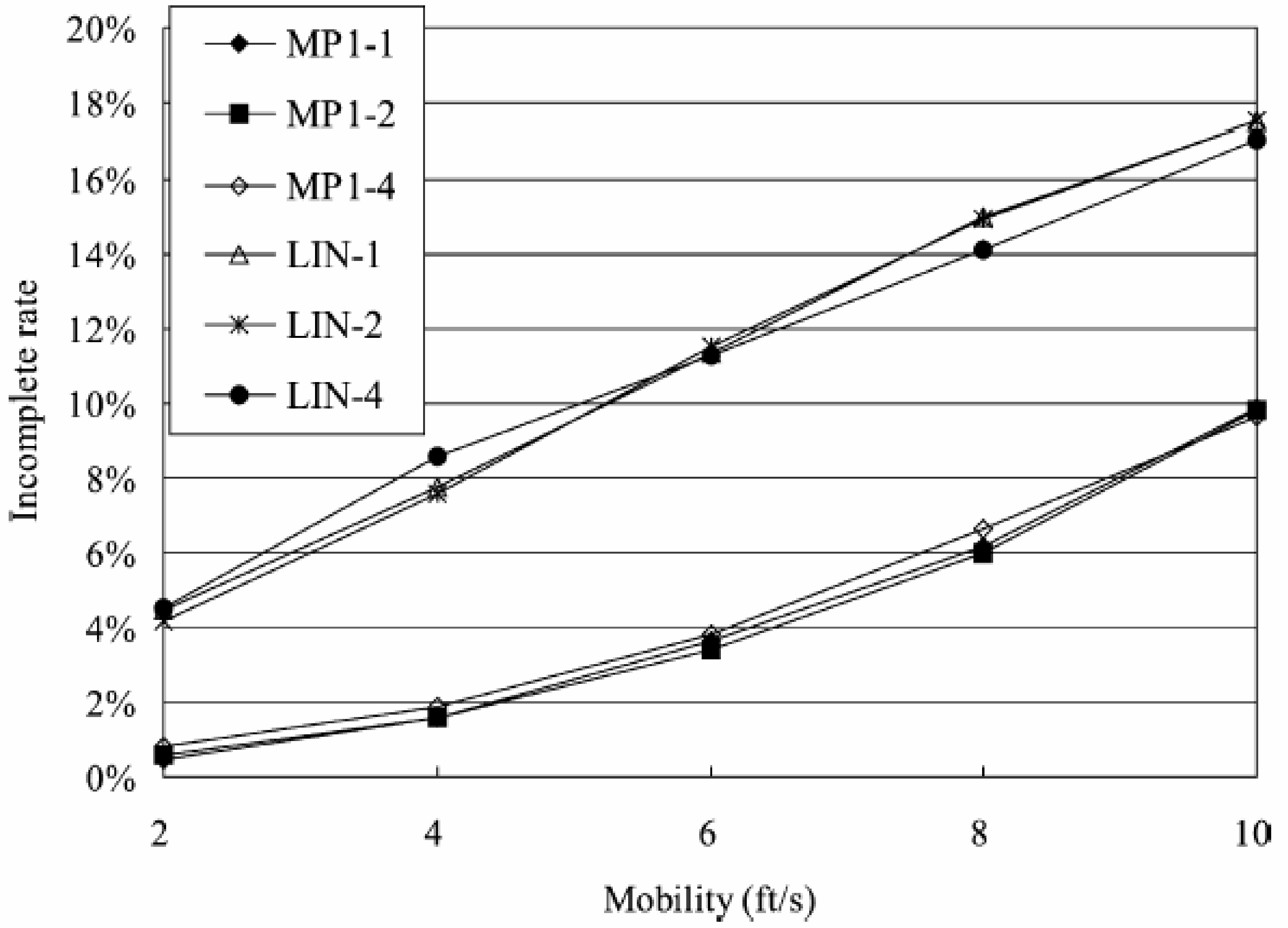


Fig. 15. Incomplete rate vs. mobility (number of mobile hosts = 30, number of routing packets = 30, and network density = 38%).

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.