Chapter 14. A Shoelace-Based QoS Routing Protocol for Mobile Ad hoc Networks Using Directional Antenna

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Outline

1. Introduction
2. Related work
3. System model and basic idea
4. Our shoelace-based QoS routing protocol
5. Simulation results
6. Conclusion

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Introduction

- This result offers a new QoS routing protocol in a MANET using directional antenna.
  - Some cross links with different sources and destination nodes, called as shoelace, are existed and identified.
    - These cross links can simultaneously transmit data with out any data interference.
    - Our shoelace-based routing is a multi-path routing.
  - By identifying shoelaces in a MANET, this result more easily constructs a QoS route which satisfied a given bandwidth requirement.

Introduction

- This scheme provides a dynamic routing path, which is depended on network environment.
  - The shoelace-based routing is a uni-path if the network bandwidth sufficient.
  - The shoelace-based routing is a multi-path if the network bandwidth insufficient.
- This new approach improves success rate, wireless medium utilization, throughput, and average latency.

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Existing results for QoS routing protocols using omni-directional antenna

- C. R. Lin and J-S. Lin, "QoS routing in ad hoc wireless networks," *IEEE Journal on Selected Areas in Communications (JSAC),* Vol. 17, No. 8, p.p. 1426-1438, Oct. 1999.
- W.-H. Liao, Y.-C. Tseng, S.-L. Wang, and J.-P. Sheu, "A Multi-Path QoS Routing Protocol in a Wireless Mobile Ad Hoc Network", *Telecommunication Systems*, Vol. 19, No. 3-4, pp. 329-347, 2002.

Cont.

- Y.-S. Chen, Y.-C. Tseng, J.-P. Sheu, and P.-H. Kuo, "An on-demand, link-state, multi-path QoS routing in a wireless mobile ad-hoc network," *Computer Communications,* Vol. 27, No. 1, p.p. 27-40, Jan. 2004.
  - This result is included in book, "Ad Hoc Wireless Networks Architectures and Protocols", edited by C. Siva Ram Murthy and B. S. Manoj, Prentice Hall, pp. 542-546, 2004.
- Y.-S. Chen and Y.-W. Ko, "A lantern-tree-based QoS on-demand multicast protocol for a wireless mobile ad hoc network," *IEICE Transaction Communications,* No. 3, p.p. 717-726, Mar. 2004.

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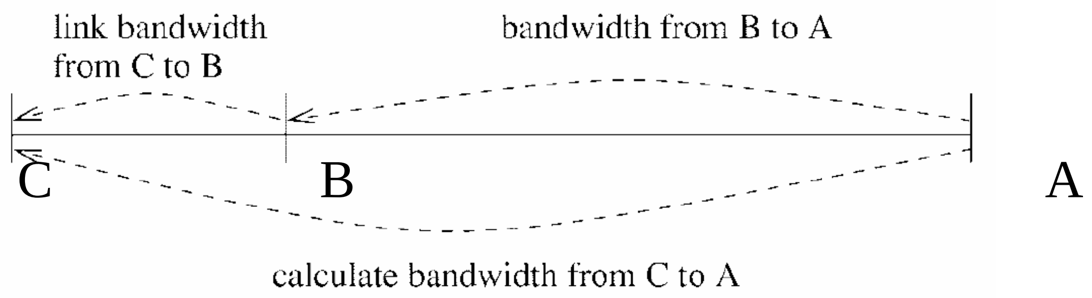
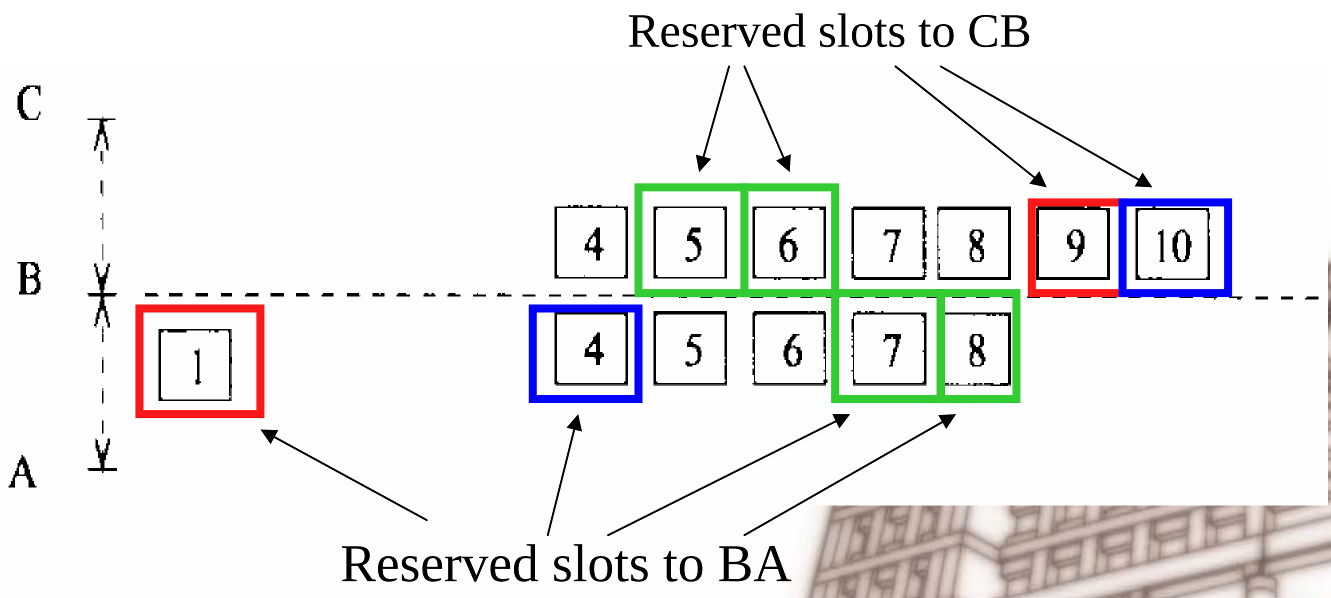
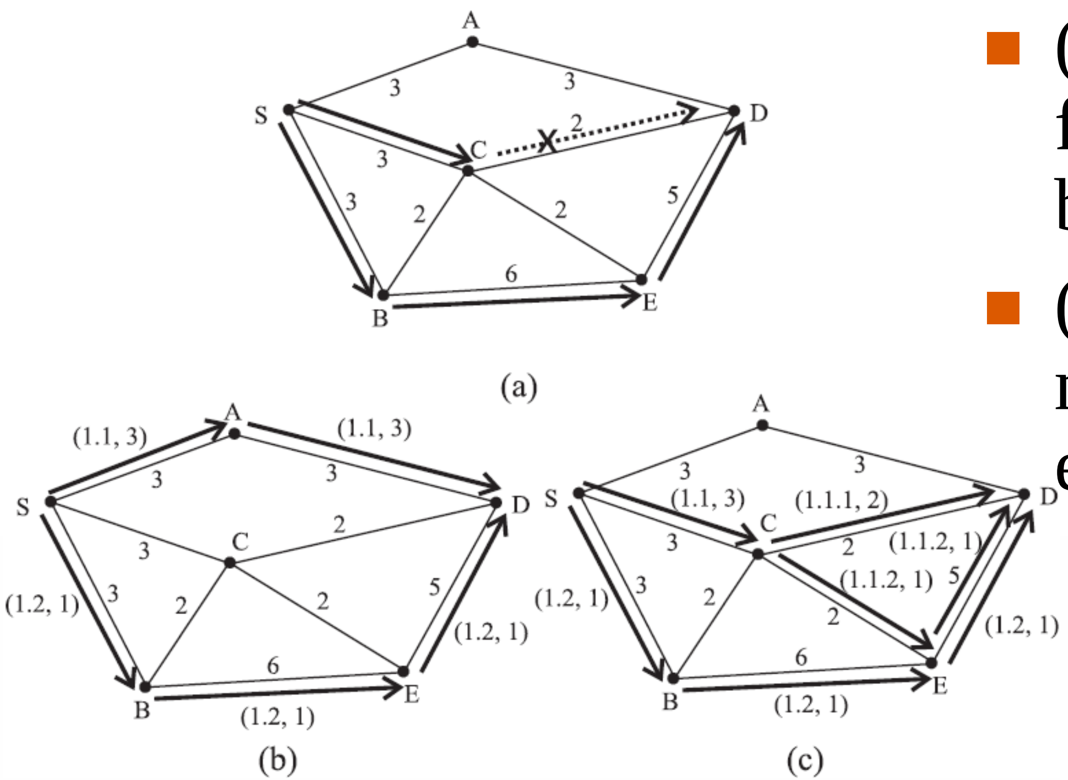


Bandwidth calculation

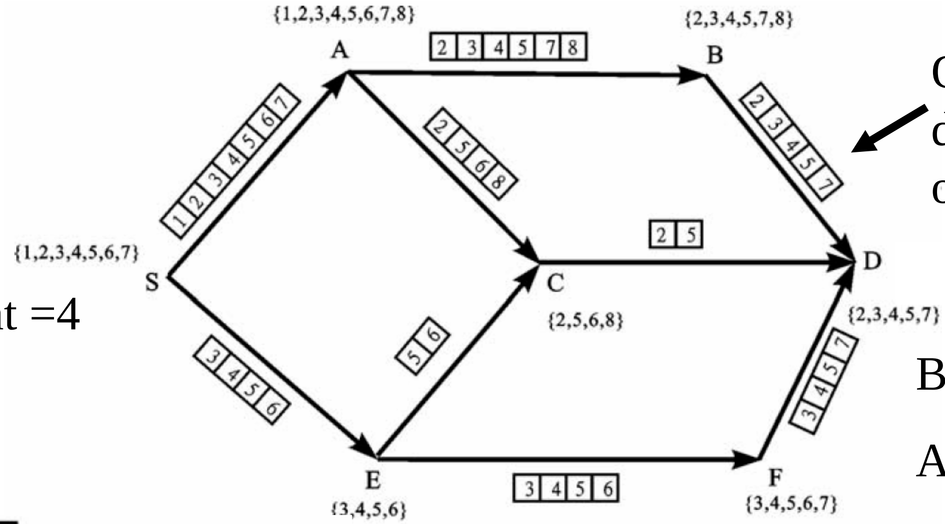


W.-H. Liao, Y.-C. Tseng, S.-L. Wang, and J.-P. Sheu, "A Multi-Path QoS Routing Protocol in a Wireless Mobile Ad Hoc Network", *Telecommunication Systems*, Vol. 19, No. 3-4, pp. 329-347, 2002.



- (a) Searching for a route from *S* to *D* with bandwidth 3
- (b)-(c) Two successful multi-path routing examples.
  - The 2-turple on each link means the ticket identity and the reserved bandwidth.

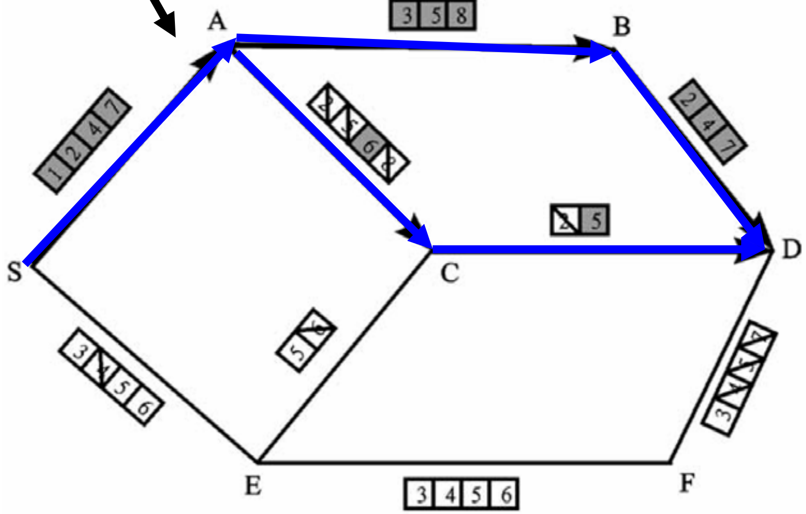
Y.-S. Chen, Y.-C. Tseng, J.-P. Sheu, and P.-H. Kuo, "An on-demand, link-state, multi-path QoS routing in a wireless mobile ad-hoc network," *Computer Communications*, Vol. 27, No. 1, p.p. 27-40, Jan. 2004.



On-demand, link-state delivery and collection operation

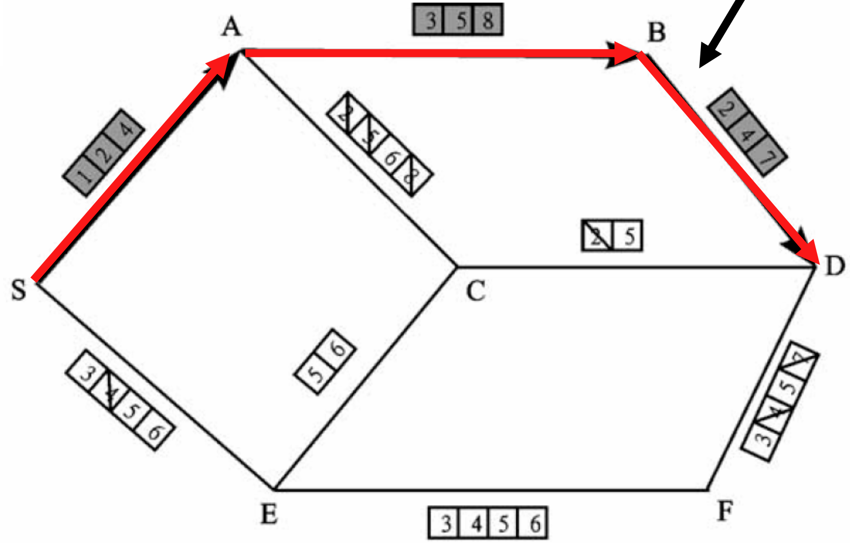
Bandwidth requirement =4

Adapting multi-path



Bandwidth requirement =3

Adapting uni-path



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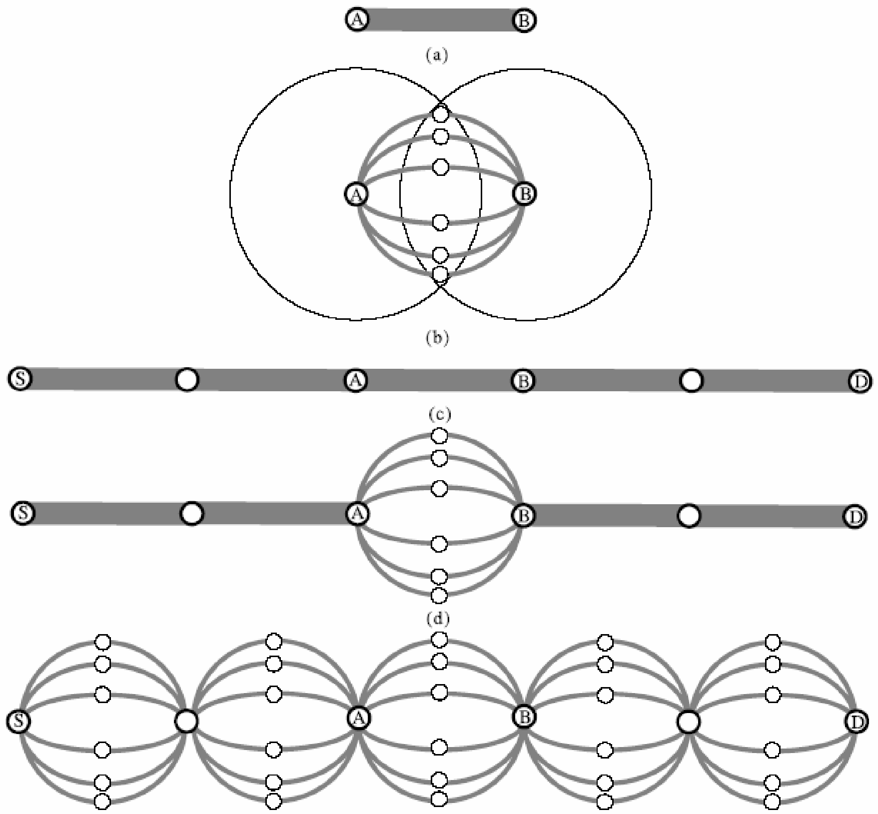


(a): A link

(b): Lantern which the total bandwidth of one or more sub-path is equal Br.

(c): Uni-path which satisfies a bandwidth requirement B_r..

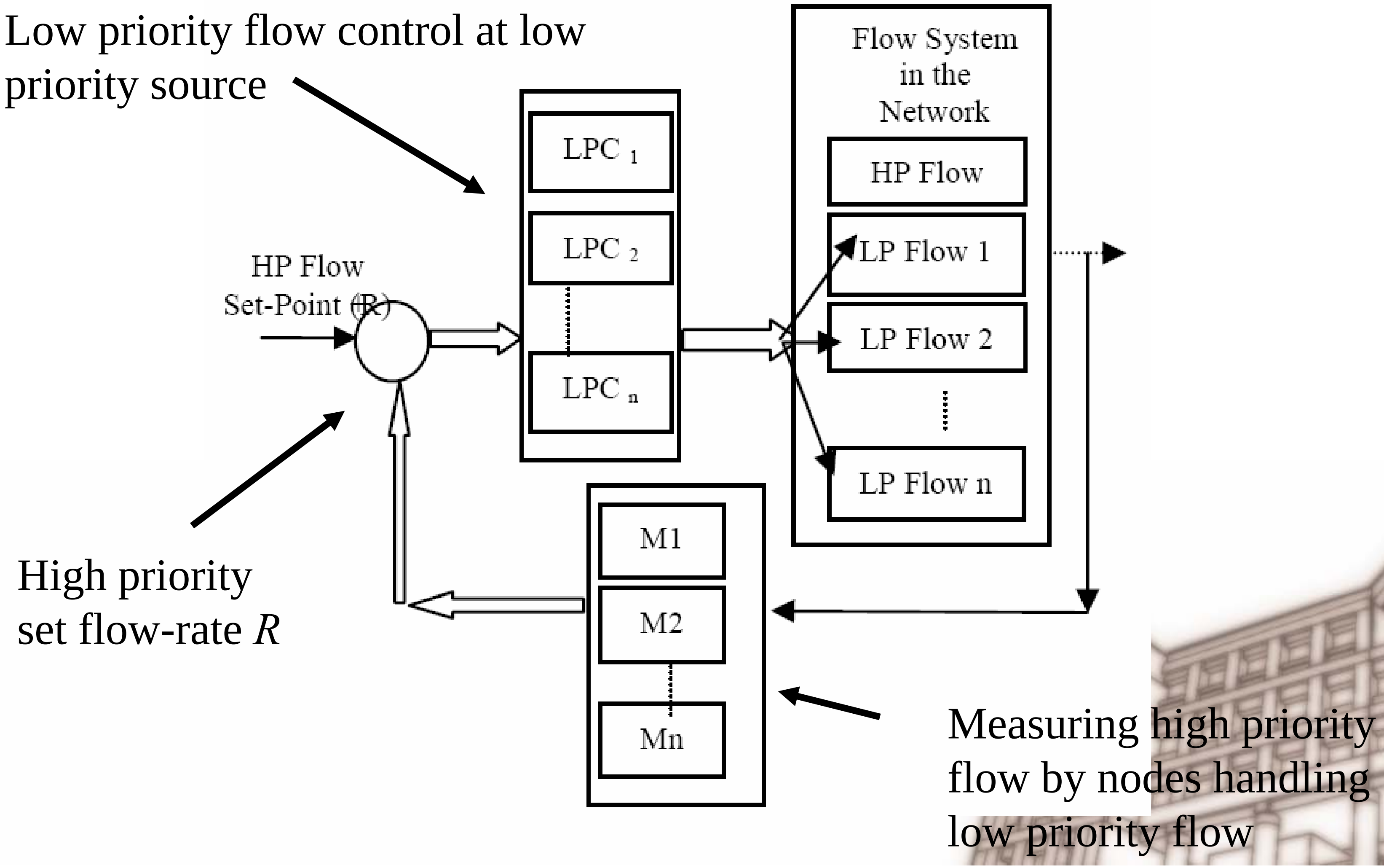
(d): Lantern-path.

(e): Worst-cast situation of a lantern-path.

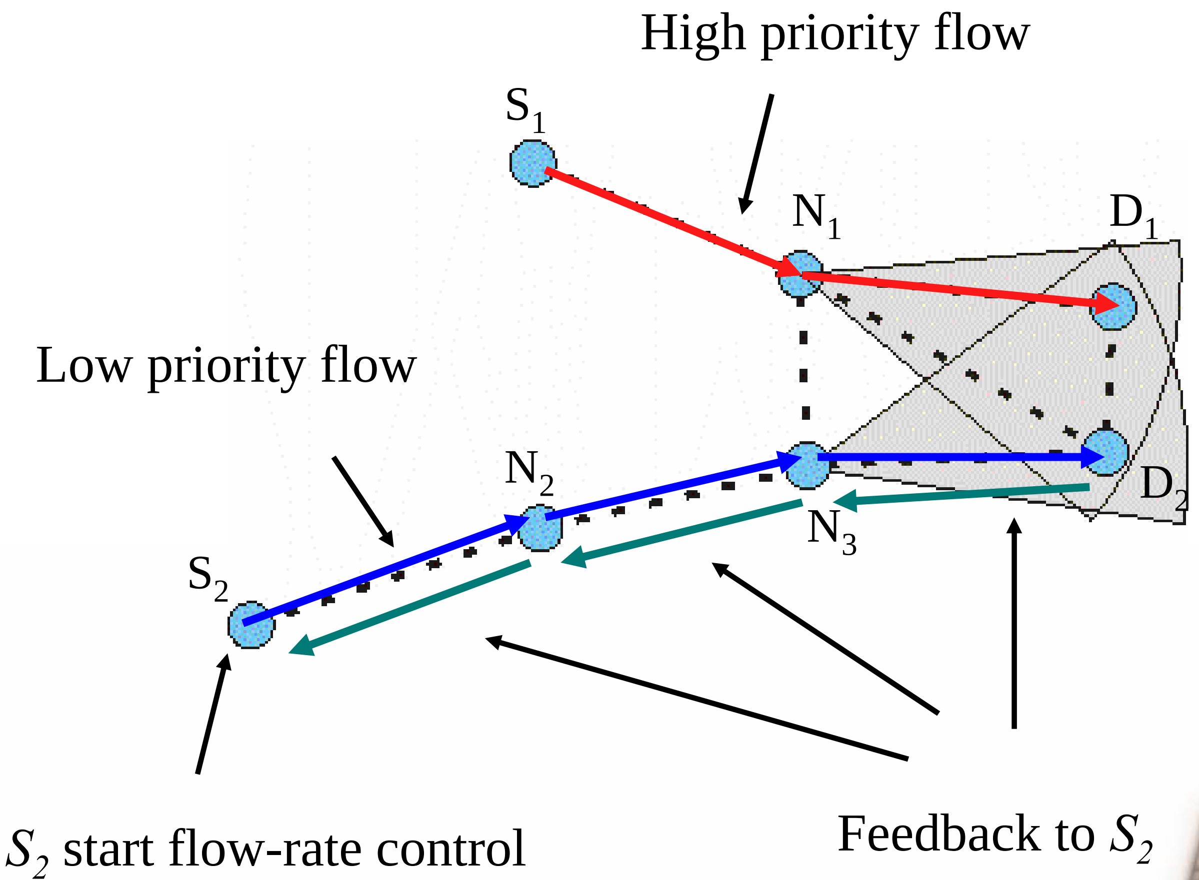
Existing results for QoS routing using **directional antenna**

- D. Saha, S. Roy, S. Bandyopadhyay, T. Ueda, and S. Tanaka,"A distributed feedback control mechanism for priority-based flow-rate control to support QoS provisioning in ad hoc wireless networks with directional antenna," *IEEE International Conference on Communications* (*IEEE ICC* 2004), Vol. 7, p.p. 4172-4176, 2004.
- T. Ueda, S. Tanaka, S. Roy, D. Saha, and S. Bandyopadhyay, "A priority-based QoS routing protocol with zone reservation and adaptive call blocking for mobile ad hoc networks with directional antenna," *IEEE Global Telecommunications Conference Workshops* (*GLOCOMW*), p.p. 50-55, Nov. 2004.

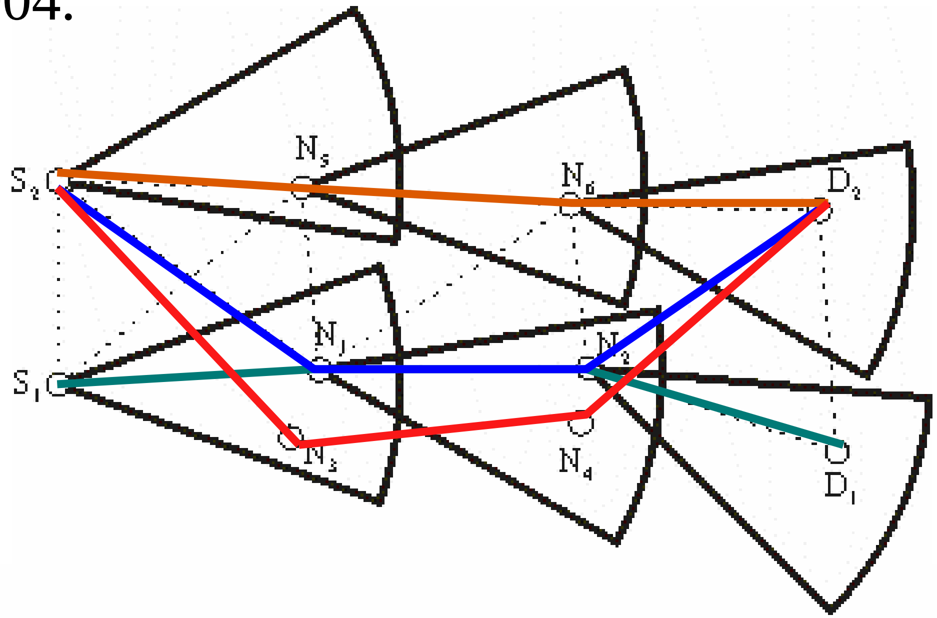
D. Saha, S. Roy, S. Bandyopadhyay, T. Ueda, and S. Tanaka,"A distributed feedback control mechanism for priority-based flow-rate control to support QoS provisioning in ad hoc wireless networks with directional antenna," *IEEE International Conference on Communications* (IEEE ICC 2004), Vol. 7, p.p. 4172-4176, 2004.



Example


High priority flow
S1
N1
D1
Low priority flow
N2
D2
N3
S2
S2 start flow-rate control
Feedback to S2

T. Ueda, S. Tanaka, S. Roy, D. Saha, and S. Bandyopadhyay, "A priority-based QoS routing protocol with zone reservation and adaptive call blocking for mobile ad hoc networks with directional antenna," *IEEE Global Telecommunications Conference Workshops* (GLOCOMW), p.p. 50-55, Nov. 2004.



Path

$\{S_1, N_1, N_2, D_1\}$

$\{S_2, N_1, N_2, D_2\}$

$\{S_2, N_3, N_4, D_2\}$

$\{S_2, N_5, N_6, D_2\}$

zone disjoint

- Two routes are located close enough to interfere with each other during data communication.

Motivation

- Using omni-directional antenna easily produces interference problem.
  - Two nodes closed in different routing path interfering with each other.
  - This leads to the problem of the lower wireless medium utilization.
- It is hard to identify a QoS route if only using uni-path, especially if the network bandwidth is insufficient.

Contribution

- This shoelace-based protocol significantly improves success rate, wireless medium utilization, throughput, and average latency, but with higher overhead.
  - Multi-path approach

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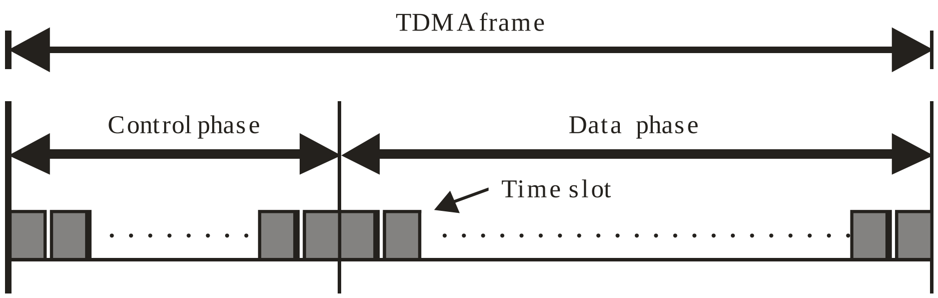
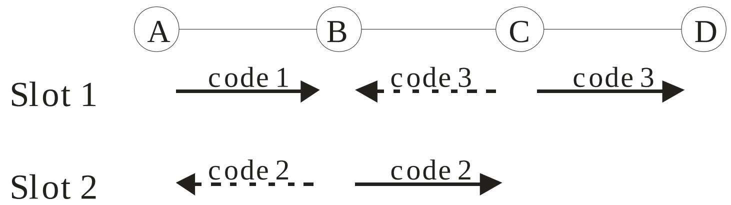
System model

- This work investigates a QoS routing protocol in mobile ad hoc network using directional antenna .
  - MAC sub-layer adopts the CDMA-over-TDMA channel model.
  - Each node equips with directional antenna.
  - In the idle mode, the node hears using omni-directional antenna.
    - The same model is in existing results [Saha. et al., IEEE ICC 2004, Ueda. et al., GLOCOMW 2004].

The CDMA-over-TDMA



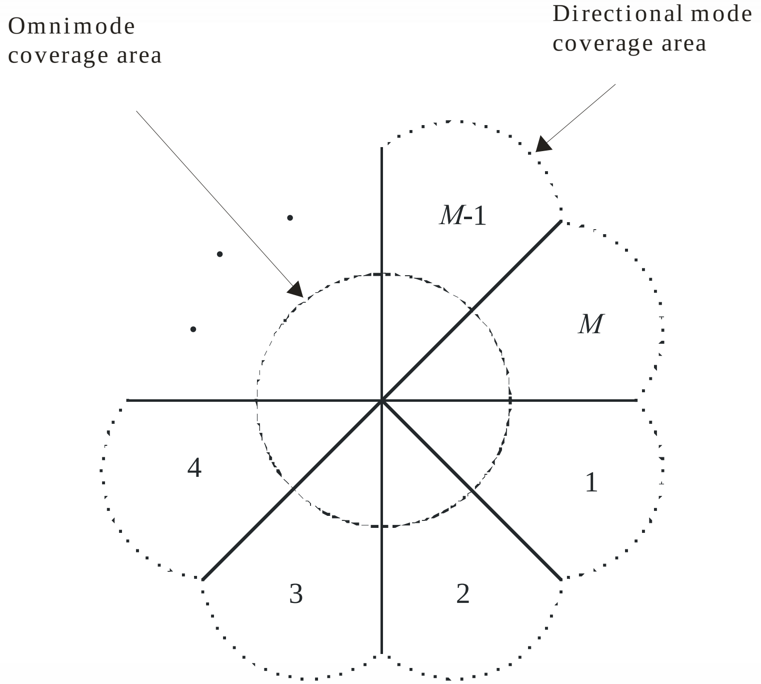
(a)



(b)

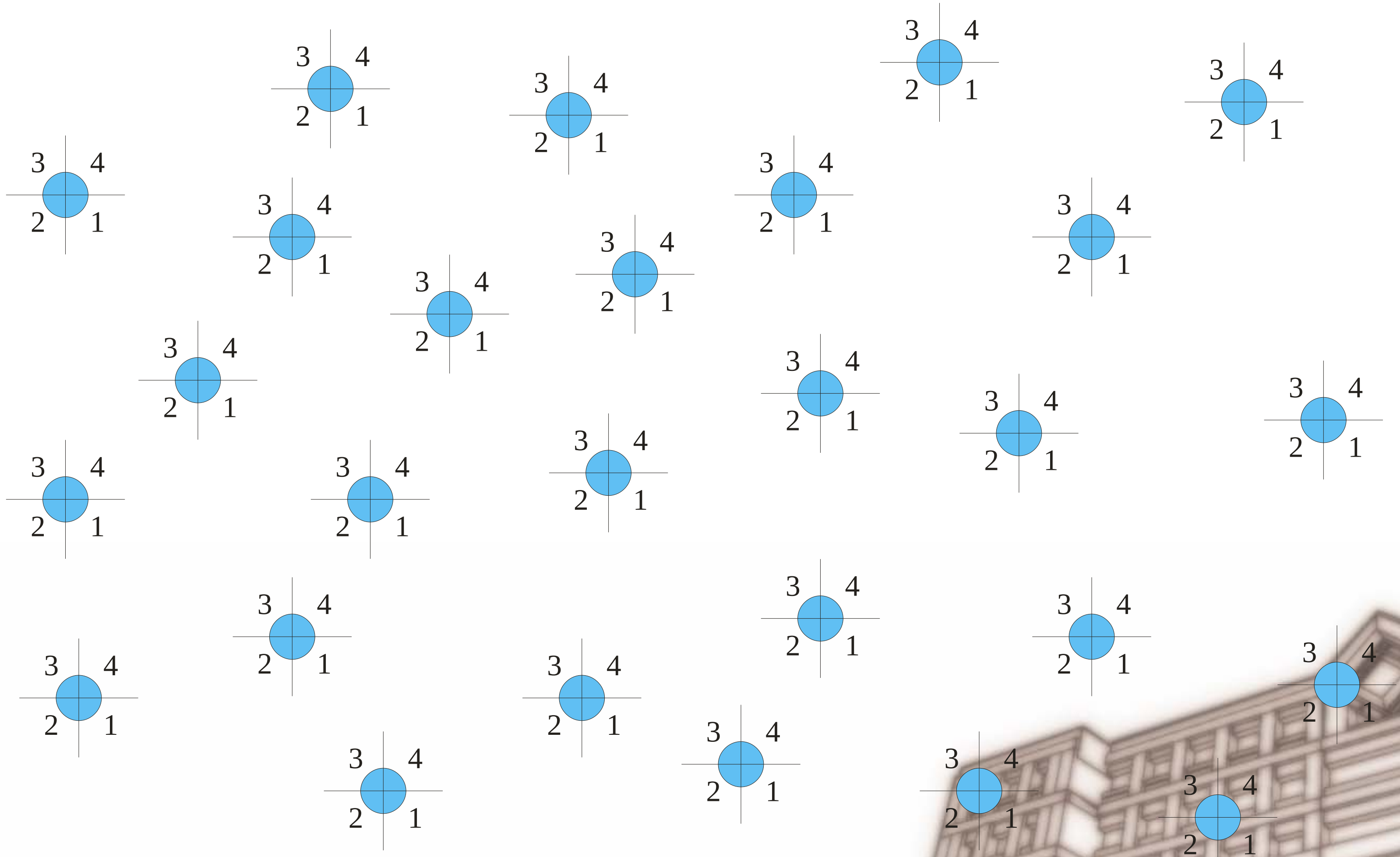
- The CDMA is overlaid on top of the TDMA infrastructure and multiple sessions can share a common TDMA slot via CDMA.
- The use of time slots on link dependent on the status of its one-hop neighboring links.

Directional antenna model



- A node with *M* sectors.
- The sectors are not overlapping.
- Sectors from 1 to *M* starting from right of the 3 o' clock position.

MANET using directional antenna

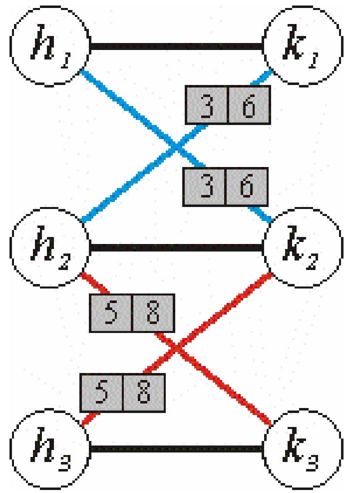


Basic idea

- Shoelace-based QoS routing protocol.
  - A multi-path result.
  - Cross links can simultaneously transmit data without any data interference.
  - To provide dynamic routing path, which is depended on the real network environment.
    - Our shoelace-based routing is a uni-path if the network bandwidth sufficient.
    - Our shoelace-based routing is a multi-path if the network bandwidth insufficient.

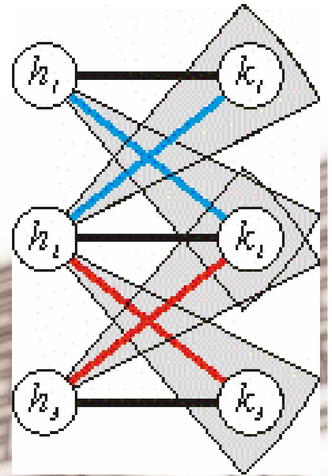
The shoelace-based routing

- Give a group of one-hop neighboring nodes



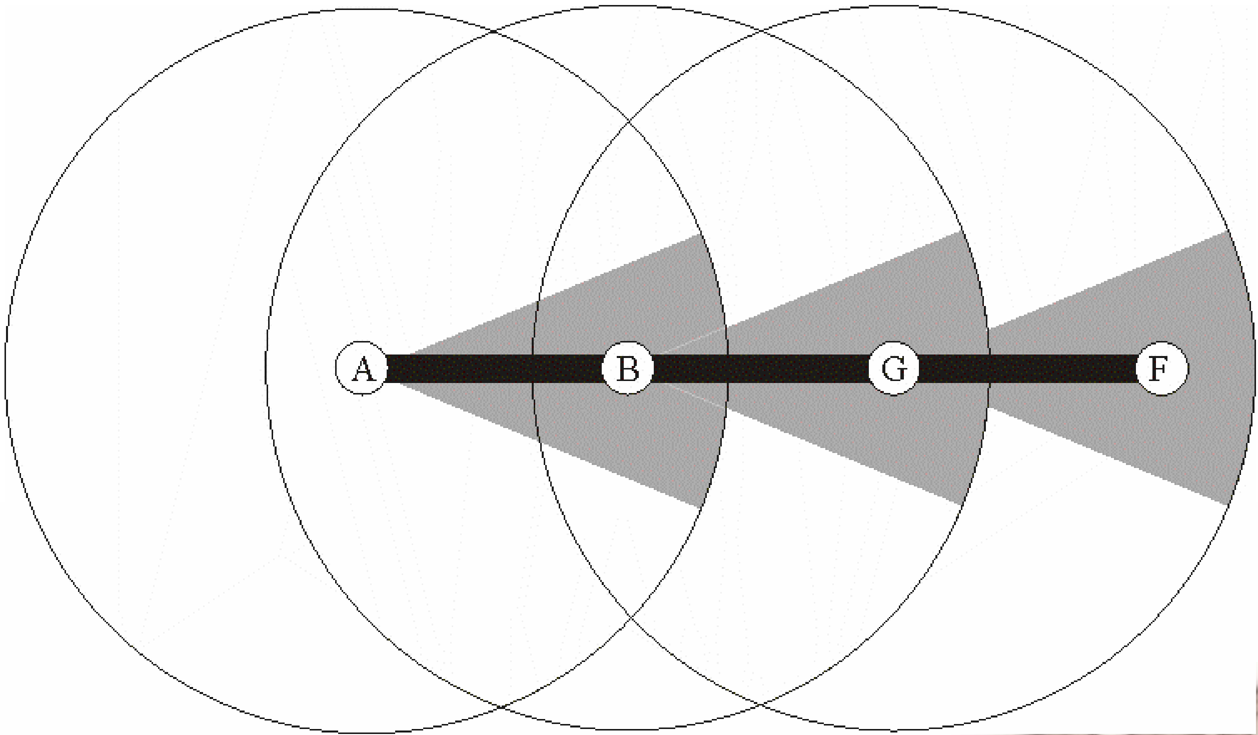
$$\begin{bmatrix} h_1 & k_1 \\ h_2 & k_2 \\ \vdots & \vdots \\ h_m & k_n \end{bmatrix}$$

- The link $h_i k_{j+1}$ and $h_{i+1} k_j$, where $i = 1, \ldots, m$, $j = 1, \ldots, n$, from a cross link, can use the same times slots.



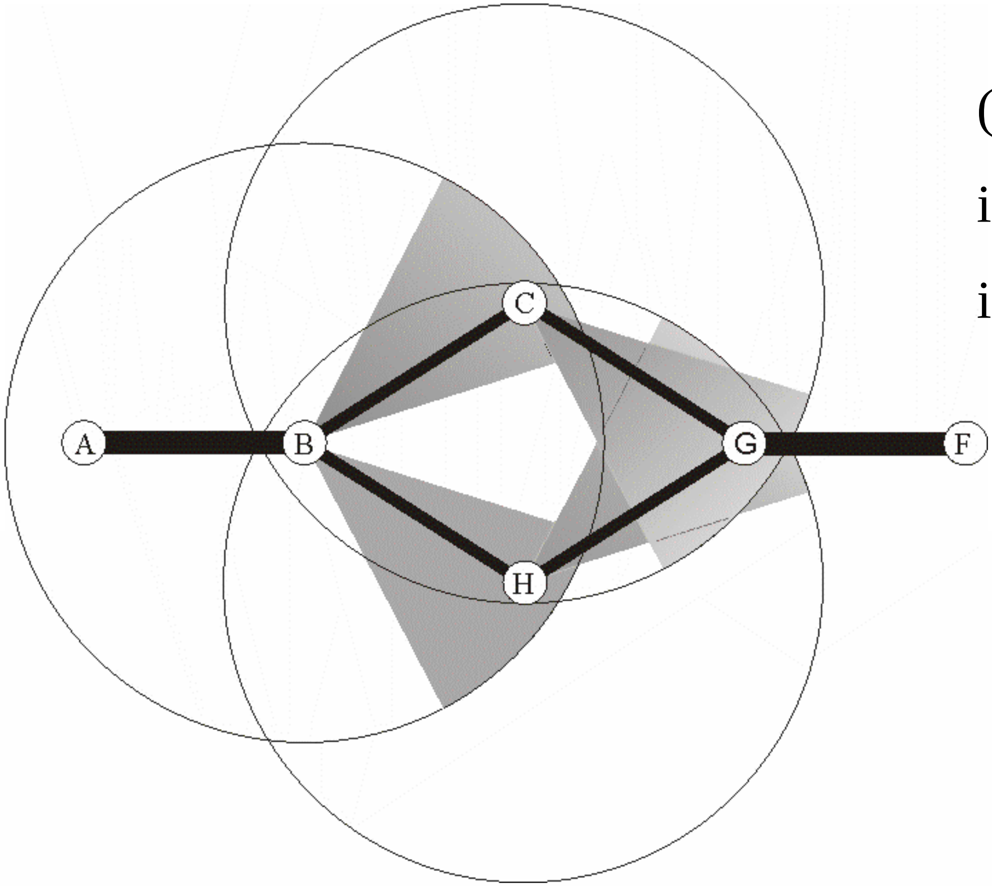
- The total bandwidth of all links between nodes h_i and k_j is equal to B_r (bandwidth requirement).

Our result under different QoS situations



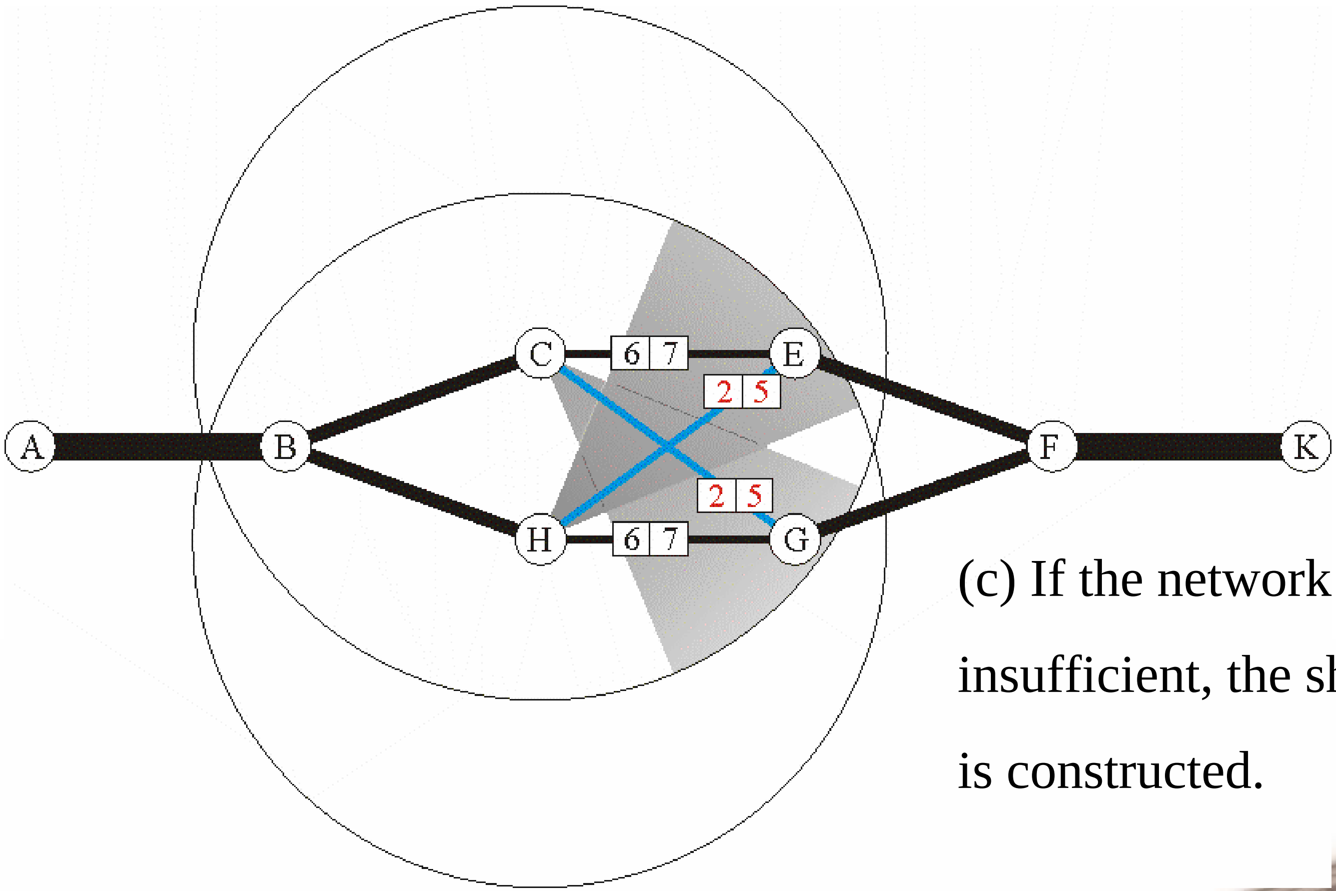
(a) If the network bandwidth is sufficient, a uni-path: [A B G F] is used.

Cont.



(b) If the network bandwidth is insufficient, the multi-path $\left[B \ \begin{matrix} C \\ H \end{matrix} \ G \right]$ is used.

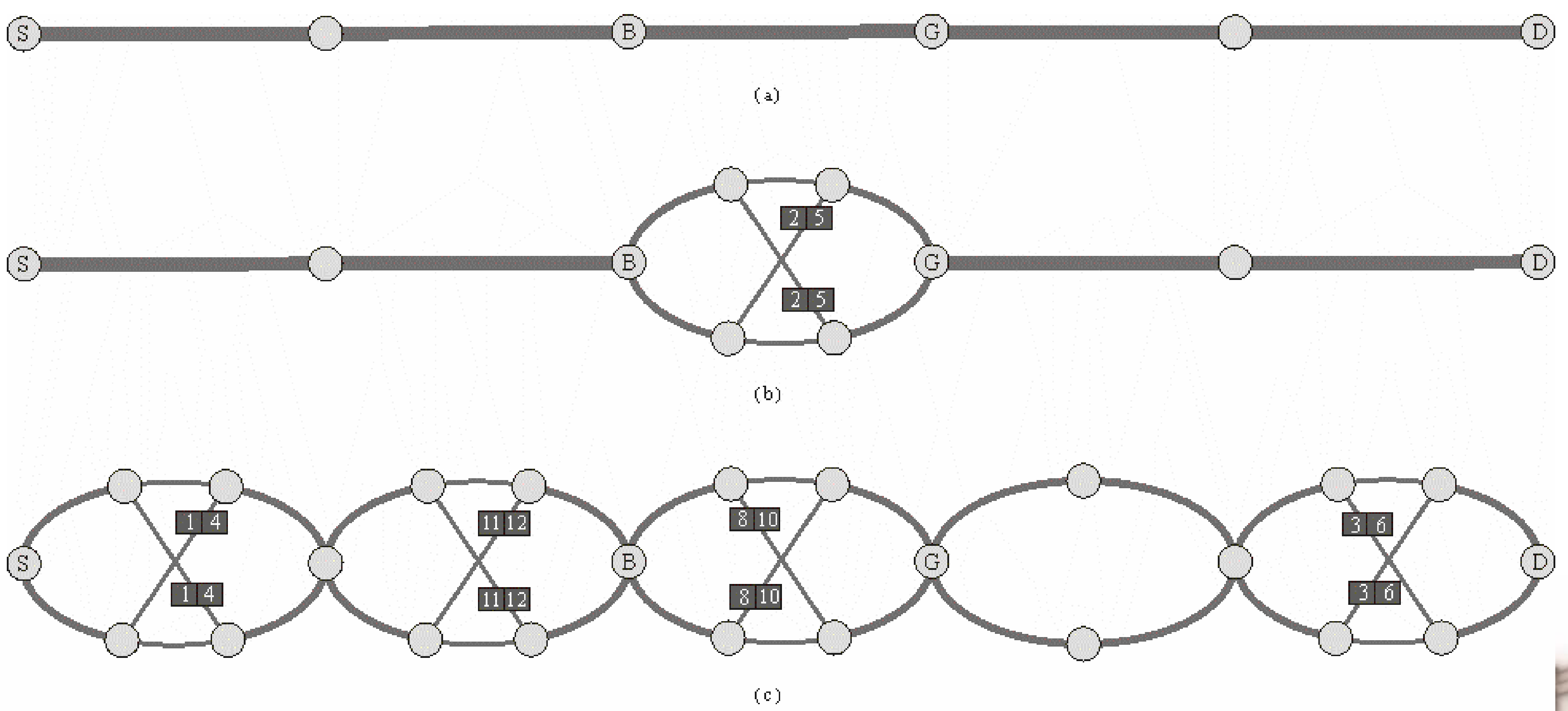
Cont.



(c) If the network bandwidth is strictly insufficient, the shoelace-path $\begin{bmatrix} B & \begin{matrix} C \\ G \end{matrix} & \begin{matrix} E \\ F \end{matrix} & H \end{bmatrix}$ is constructed.

• The links CG and GE can simultaneously transmit data using same time slots.

Other examples



(a) uni-path, (b) shoelace-path, and (c) worst-case shoelace-path

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Shoelace-based QoS routing protocol

- **Phase I:** Shoelace identification
- **Phase II:** Shoelace-path construction
- **Phase III:** Shoelace-path maintenance

Phase I: Shoelace identification

- Each node maintains the beacon message to collect link-state information for constructing shoelace.
- The beacon lifetime is two-hop, each node can acquire two-hop neighboring information.

Time slot reservation rule

- Let $\begin{bmatrix} & h_1 & k_1 & \\ & h_2 & k_2 & \\ \alpha & \vdots & \vdots & \beta \\ & h_m & k_n & \end{bmatrix}$ denotes a shoelace-based sub-path between α and β.

- Since MAC layer adopts CDMA-over-TDMA model, the time slot reservation rule is given as follows.

Time slot reservation rule

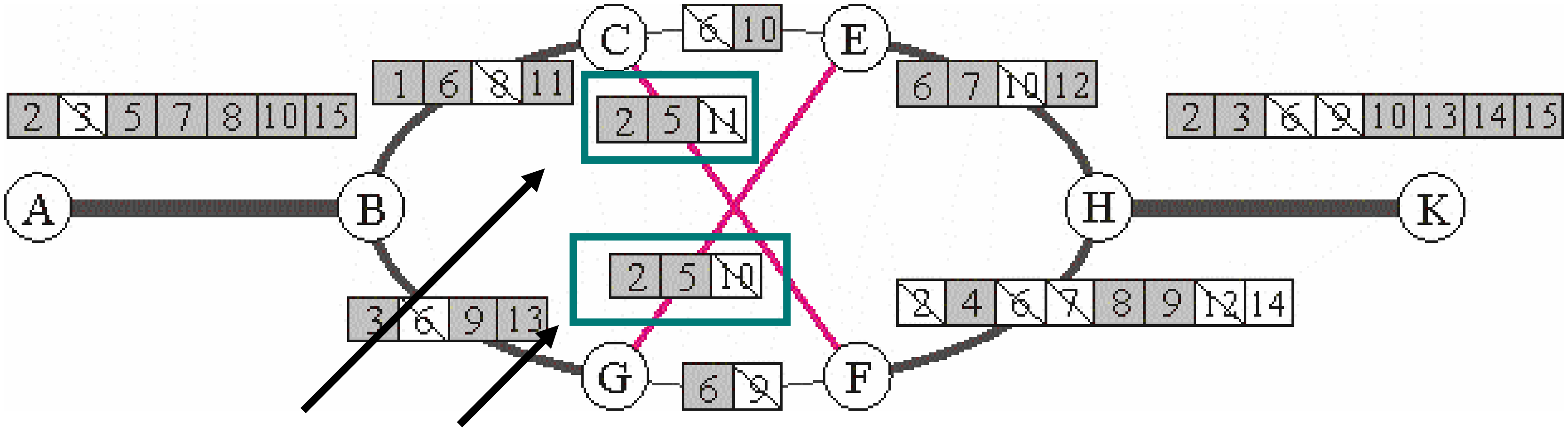
- **R1.** Time slots reserved on all links $\overline{\alpha h_i}$ must be differed, where $1 < i < n$.
- **R2.** Time slots reserved on all links $\overline{k_i \beta}$ must be differed, where $1 < i < m$.
- **R3.** Time slots reserved on link $\overline{\alpha hi}$ and $\overline{h_i k_j}$ must be differed, where $1 < i < n$, $1 < j < m$.
- **R4.** Time slots reserved on link $\overline{h_i k_j}$ and $\overline{k_j \beta}$ must be differed, where $1 < i < n$, $1 < j < m$.
- **R5.** Time slots reserved on link $\overline{h_i k_j}$ and $\overline{h_x k_y}$ must be differed, where $i = x$ or $j = y$.

The determination rule of reserved time slots for a shoelace

- $F[i]$: a set of free time slot of node i. $F[i] = t_1, t_2, t_3, \ldots, t_k$, where t_k is time slot.
- $SF[i, j]$: a set of share free time slot of nodes i and j. $SF[i, j] = F[i] \cap F[j]$.
- $ASF[i, j]$: a set of available share free time slot of nodes i and j.

  $ASF[i, j] = SF[i, j] - RSF[x, i] - RSF[y, j]$, where x is node i other neighbors and y is node j other neighbors.
- $RSF[i, j]$: a set of reserved share free time slot of nodes i and j. $RSF[i, j] = \{t_k, t_k \in ASF[i, j]\}$.

Example



After calculating, the cross links transmit data using the same time slots {2, 5} without interfering each other

- $SF[G, E] = \{2, 5,10\}$
- $ASF[G, E] = SF[G, E] - SF[B, G] - RSF[C, E]$
  $= \{2, 5, 10\} - \{1, 6, 10\} - \{10\} = \{2, 5\}$
- $RSF[F, H] = \{2, 5\}$

Phase II: Shoelace-path construction

- Employing beacon to find neighbors' location and free time slots
- Calculating the reserved time slots of link
- The source initiates a bandwidth requirement packet SL_REQ and transmit this packet
- Each packet record the bandwidth requirement B_r and link-state information

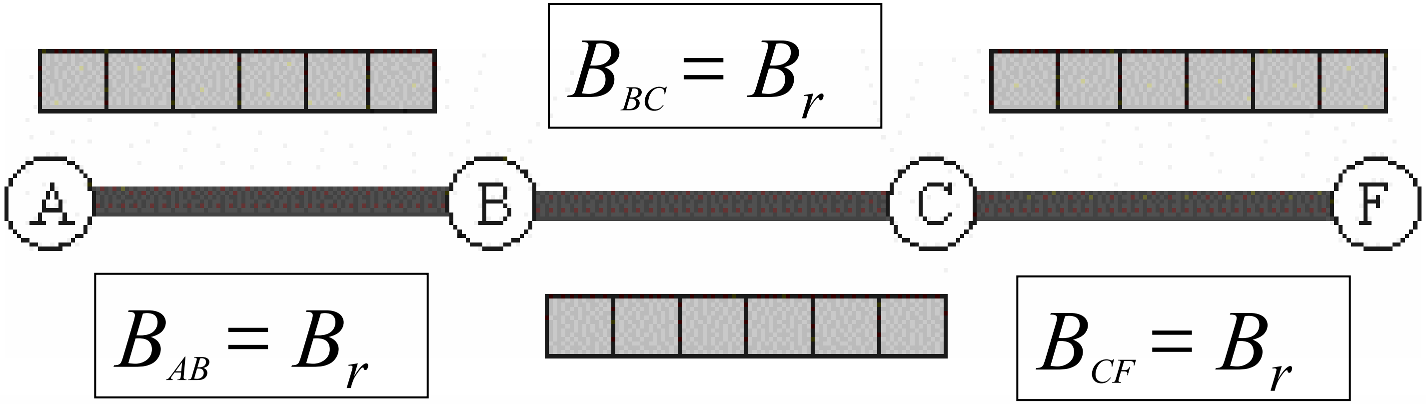
Packet format

- *S*: the source node;
- *D*: the destination node;
- *NH*: the node which the neighbor of the source and received a SL_REQ packet.
- *TH_NEI*: the common neighbors of the next hop.
- *NL*: a list of nodes, which denotes the through nodes from source to current traversed node;
- *RSF*: a list of reserved time slot. This field records reserved time slot between current node and next hop node ;
- B_r: the bandwidth requirement from source to destination.
- *B*: the total bandwidth from current node to its neighbors .

Shoelace-path construction

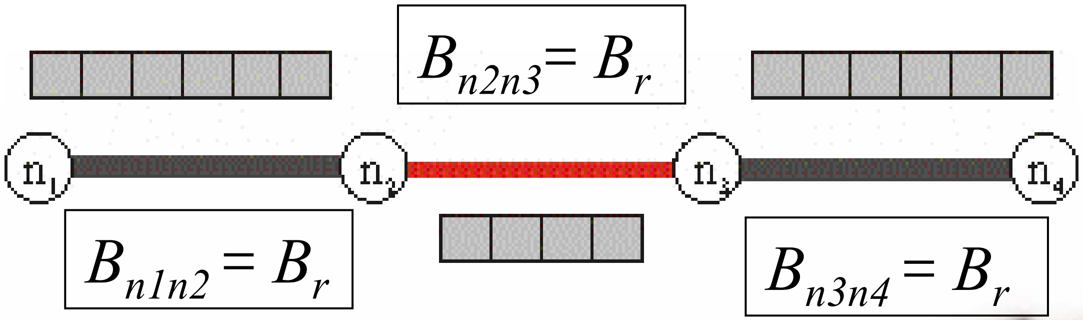
- **Case I:** uni-path if the network bandwidth is sufficient
- **Case II:** multi-path if the network bandwidth is insufficient
- **Case III:** shoelace-path if the network bandwidth is strictly insufficient

Case I: uni-path if the network bandwidth is sufficient



Case II: multi-path if the network bandwidth is insufficient

Give a path [n_1 n_2 n_3 n_4], the bandwidth on n_1n_2 is equal to B_r and the bandwidth on n_2n_3 is less then B_r



If the uni-path is unsuitable

Procedure II

- **Step 1:**
  - The node n_2 fines other nodes n'_i, where $i = 1, 2, ..., m,$ such as the total bandwidth on $\begin{bmatrix} & n'_1 \\ n2 & \vdots \\ & n'_m \end{bmatrix}$ is equal to B_r
  - The n_2 calculates the $RSF[n_2, n'_3]$, $RSF[n_2, n'_1]$, $RSF[n_2, n'_2]$, ..., and $RSF[n_2, n'_m]$.
  - node n_2 record the beam ID which n_2 uses to connect with nodes n'_i and n_3
  - The n_2 updates the SL_REQ(S, D, $n'_i(n_3)$, n_4, {[n_1 n_2], RSF[n_2, n'_i], B_r, B) and sends routing packet to notify nodes n_3 and n_i the reserved share free time slots and two hop neighboring n_4 information.

Cont.

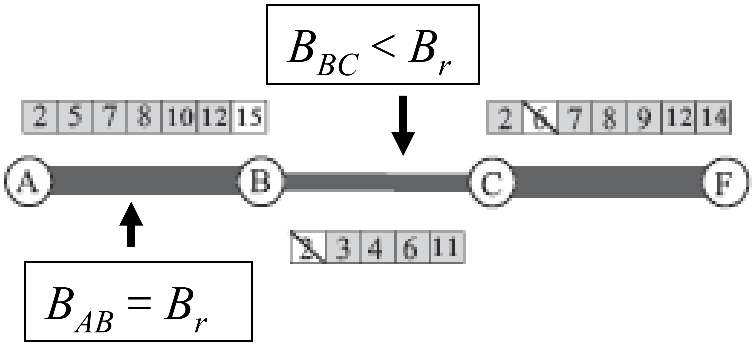
- **Step 2:**
  - When node n_3 and n_i received the routing packet from node n_2, they respectively calculate $RSF = \{t_1, t_2, \ldots, t_k\}$, where $k \geqq 1$, with their common neighbor n_4 which node n_2 notified and
  - Updating the SL_REQ(S, D, n_4, TH_NEI = {two hop neighbors of node $n'_i(n_3)$, {[n_1 n_2 $n'_i(n_3)$]}, RSF[n'_i, n_4], B_r, B = |$RSF[n'_i, n_4]$|) and forwarding the routing packet to the next hop.
  - The nodes n_3 and n_i record the beam ID which they use to connect next hop and receive from preceding hop.

Cont.

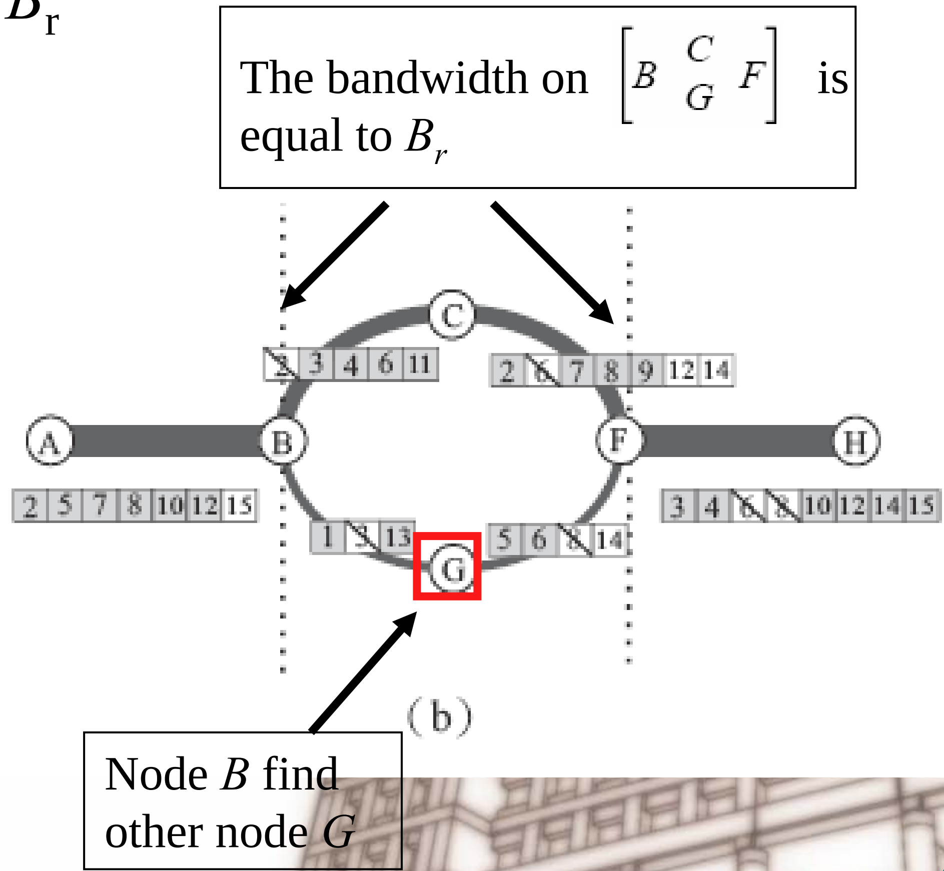
- **Step 3:**
  - Node n_4 received routing packet from n_3 and n_i and the bandwidth on $\begin{bmatrix} n_3 & \\ n'_1 & n4 \\ \vdots & \\ n'_m & \end{bmatrix}$ is equal to B_r.
  - The uni-path is suitable and the multi-path $\begin{bmatrix} & n_3 & \\ & n'_1 & \\ n_2 & & n_4 \\ & \vdots & \\ & n'_m & \end{bmatrix}$, where $m \geqq 1$, is constructed.

Example

In node *B*, the bandwidth on AB is equal to B_r and the bandwidth on BC is less then B_r



(a)



(b)

Case III: shoelace-path if the network bandwidth is strictly insufficient

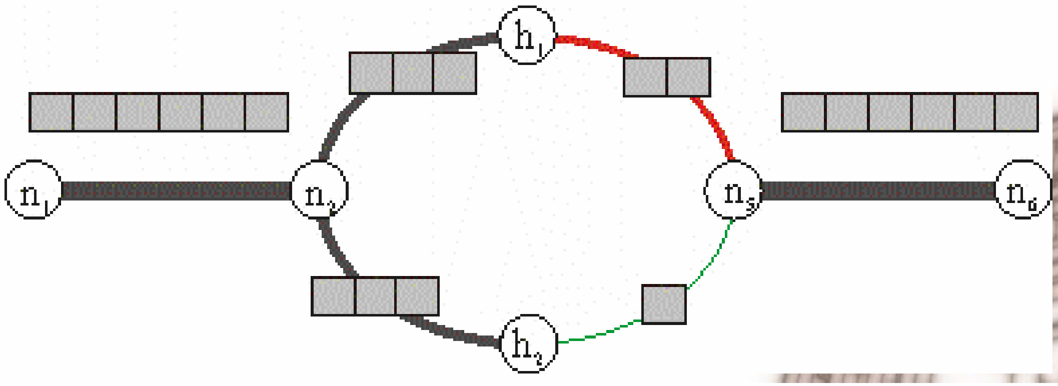
- Procedure III-A
  - The post of multi-path bandwidth is not satisfied bandwidth requirement. The $\sum B_{pre} = B_r$, and $B_{pre} > B_{post}$.
- Procedure III-B
  - The front and post of multi-path bandwidth is not satisfied bandwidth requirement and there be more bandwidth on one or more links of front of multi-path. The $\sum B_{pre} < B_r$, and $B_{post} < B_{pre}$.
- Our shoelace-based protocol

Procedure III-A

Let $\begin{bmatrix} & h_1 & \\ n_1\ n_2 & \vdots & n_5\ n_6 \\ & h_n & \end{bmatrix}$, where $n \geq 2$, denote multi-path. The post of multi-path bandwidth is not satisfied bandwidth requirement.

Now the total bandwidth on $\begin{bmatrix} h_1 & \\ \vdots & n_5 \\ h_n & \end{bmatrix}$ is less then Br and the

$B_1 = |RSF[n_2\ h_i]| < B_r$, $B_2 = |RSF[h_i\ n_5]| < B_1$



Cont.

- **Step 1:**
  - Node h_i , where i =1, 2, ..., n, finds other node k_j , where j = 1, 2, ..., m, which node n_2 notified such as the bandwidth on h_i k_j is equal to on [n_2 h_i] and calculates $RSF[h_i, k_1]$, $RSF[h_i, k_2]$, ..., and $RSF[h_i, k_m]$, respectively.
  - Node *hi* updates the SL_REQ(S, D, $k_j(n_5)$, n_6, {[n_1 n_2 h_i]}, $RSF[h_i\ k_j]$, B_r, B=|$RSF[h_i\ k_j]$|) and sends routing packet to next hop
  - Node h_i records beam ID which node h_i uses to connect with node k_j and received from preceding hop.

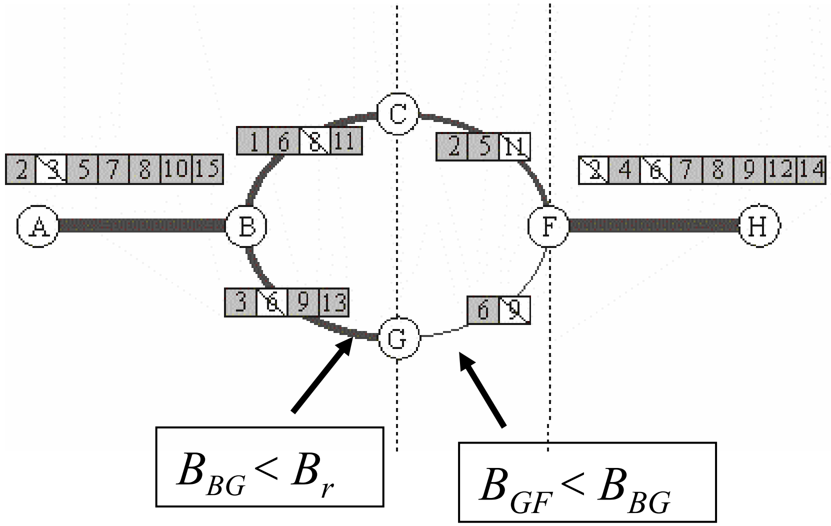
Cont.

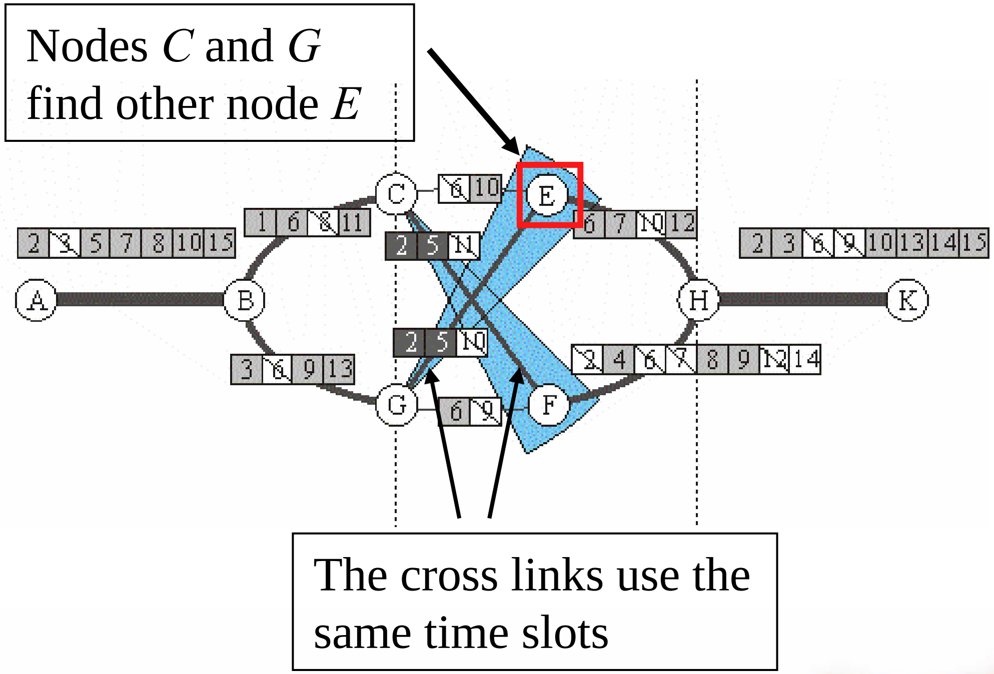
- **Step 2:**
  - When node k_j received the routing packet from node h_i, k_j calculates $RSF[k_j, n_6] = \{t_1, t_2, . . . , t_m\}$, where $m \geq 1$.
  - The node n_5 calculates the $RSF[n_5, n_6] = \{t_1, t_2, . . . , t_m\}$, where $m \geq 1$, again due to the change of the traffic from node h_i.
  - Nodes n_5 and k_j update the SL_REQ(S, D, n_6, TH_NEI = {two hop neighbors of node $k_j(n_5)$}, $\{[n_1\ n_2\ h_i\ k_j(n_5)]\}$, $RSF[k_j(n_5), n_6]$, B_r, $B = |RSF[k_j, n_6]|$forward routing packet to next hop
  - The node n_5 and k_j record the beam ID which node n_5 and k_j use to connect with next hop and receive from preceding hop.

Cont.

- **Step 3:**
  - Node n_6 received the routing packets from node n_5 and nodes k_j and the total bandwidth on $\begin{bmatrix} n_5 & \\ k_1 & \\ \vdots & n_6 \\ k_m & \end{bmatrix}$ is equal to B_r.
  - The shoelace $\begin{bmatrix} & & n_5 & \\ & h_1 & k_1 & \\ n_2 & \vdots & & n_6 \\ & h_n & \vdots & \\ & & k_m & \end{bmatrix}$, where n $\geq$2, m $\geq$1 is constructed.

Example

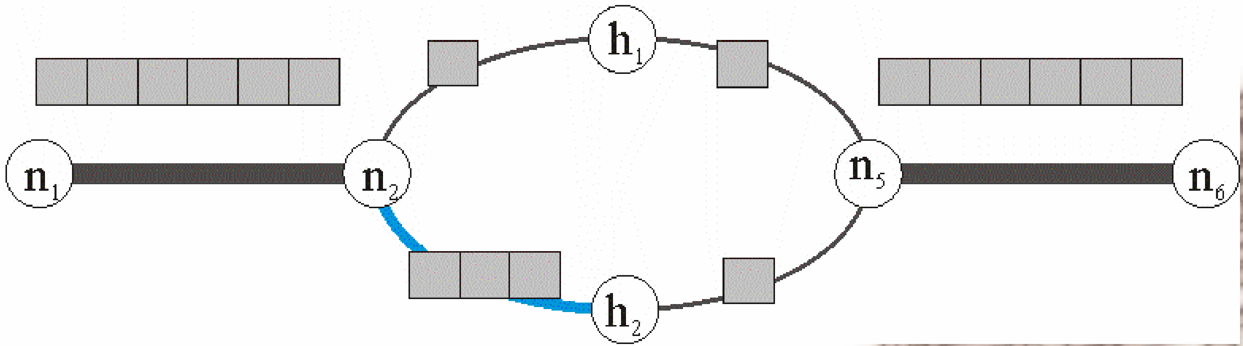




- The shoelace $\left[B \begin{smallmatrix}C\\G\end{smallmatrix} \begin{smallmatrix}E\\F\end{smallmatrix} H\right]$ is constructed
- The total bandwidth on $\left[B \begin{smallmatrix}C\\G\end{smallmatrix} \begin{smallmatrix}E\\F\end{smallmatrix} H\right]$ is equal to B_r

Procedure III-B

Let $\begin{bmatrix} & & h_1 & & \\ n_1 & n_2 & \vdots & n_5 & n_6 \\ & & h_n & & \end{bmatrix}$, where $n \geq 2$ denote multi-path. The bandwidth on $\begin{bmatrix} & h_1 \\ n_2 & \vdots \\ & h_n \end{bmatrix}$ and $\begin{bmatrix} h_1 & \\ \vdots & n_5 \\ h_n & \end{bmatrix}$ is not satisfied bandwidth requirement. There are more bandwidth on one or more link. Now let there be more bandwidth on link $n2h1$.



Procedure III-B

- **Step 1:**
  - The node n_2 finds other nodes h'_i, where $i = 1, 2, \ldots, x$, $x \geq 1$, such as the total bandwidth on $\begin{bmatrix} & h'_1 \\ & \vdots \\ & h'_x \\ n_2 & h_1 \\ & \vdots \\ & h_n \end{bmatrix}$ is equal to B_r and calculates $RSF[n_2, h_1], RSF[n_2, h_2], \ldots, RSF[n_2, h_x]$.
  - The node n_2 updates SL_REQ(S, D, h_i, TH_NEI = {two hop neighbors of node n_2}, {[n_1 n_2]}, $RSF[n_2, h'_i]$, B_r, B = {|$RSF[n_2, h'_i]$|}) and sends routing packet to next hop
  - The node n_2 records the beam ID which node n_2 uses to connect with node h_i and receive from preceding hop

Cont.

- **Step 2:**
  - When the node h'_i received the packet from node n_2, the node h'_i calculates the $RSF[h_i, n_5] = \{t_1, t_2, \ldots, t_m\}$, where $m \geq 1$.
  - The node h_1 find other node k_j, where $j = 1, 2, \ldots, m$,

    $m \geq 1$ such as the bandwidth on $\begin{bmatrix} & k_1 \\ h_1 & \vdots \\ & k_m \end{bmatrix}$ is equal to on $[n_2\ h_1]$

    and calculates $RSF[h_1, k_i] = \{t_1, t_2, \ldots, t_m\}$, where $m \geq 1$.
  - The nodes h_1 and h'_i update the SL_REQ(S, D, k_j, TH_NEI = {two neighbors of node $h'_i(h_1)$}, $RSF[h'_i(h_1), k_j]$, B_r, $B=|RSF[h'_i(h_1)|$) and forward the routing packet to next hop
  - The node h_1 and h'_i record the beam ID which nodes h_1 and h'_i use to connect with next hop and receive from preceding hop.

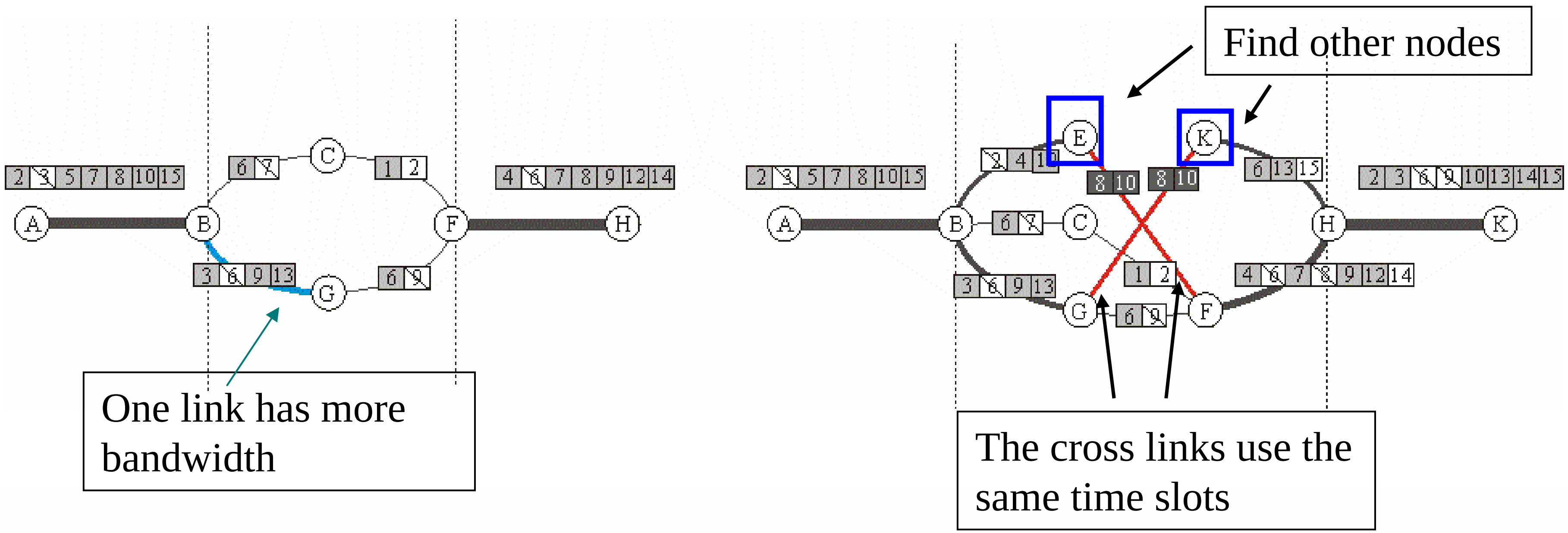
Cont.

- **Step 3:**
  - When the nodes n_5 and k_j received the routing packet from nodes hi and $h1$, the nodes $n5$ and kj calculate $RSF[n_5, n_6]$ and $RSF[k_j, n_6]$, respectively.
  - The node n_5 and k_j update the SL_REQ(S, D, n_6, TH_NEI = {two neighbors of node $k_j(n_5)$}, $RSF[k_j(n_5), n_6]$, B_r, $B = |RSF[k_j(n_5), n_6]|$) and forward the routing packet to next hop
  - The nodes n_5 and k_j record the beam ID which nodes n_5 and k_j uses to connect with next hop and receive from preceding hop.

Cont.

- **Step 4:**
  - The node n_6 received the routing packet form nodes n_5 and k_j and the total bandwidth on $\begin{bmatrix} k_1 & \\ \vdots & \\ k_m & n_6 \\ n_5 & \end{bmatrix}$ is equal to Br.
  - The shoelace $\begin{bmatrix} & h'_1 & & \\ & \vdots & k_1 & \\ & h'_x & \vdots & \\ n_2 & h_1 & k_m & n_6 \\ & \vdots & n_5 & \\ & h_n & & \end{bmatrix}$ is constructed.

Example



- The shoelace $\begin{bmatrix} & E & & \\ & & K & \\ B & C & & H \\ & & F & \\ & G & & \end{bmatrix}$ is constructed
- The total bandwidth on $\begin{bmatrix} & E & & \\ & & K & \\ B & C & & H \\ & & F & \\ & G & & \end{bmatrix}$ is equal to B_r

Our shoelace-based protocol

- **Step 1:**
  - The source node *S* calculates *RSF*[*S*, *j*], where *j* is its neighbor ID
  - *S* chooses one or more nodes such as the total bandwidth of the links between *S* and its neighbors is equal to *Br*.
  - The source node initiates and transmits a SL REQ (*S*, *D*, *NH, TH NEI*, *NL*={[*S*]}, *RSF*, *Br*, *B*) packet to the next hop node.
  - The source node records the beam ID which it uses to connect with node *j*.

Cont.

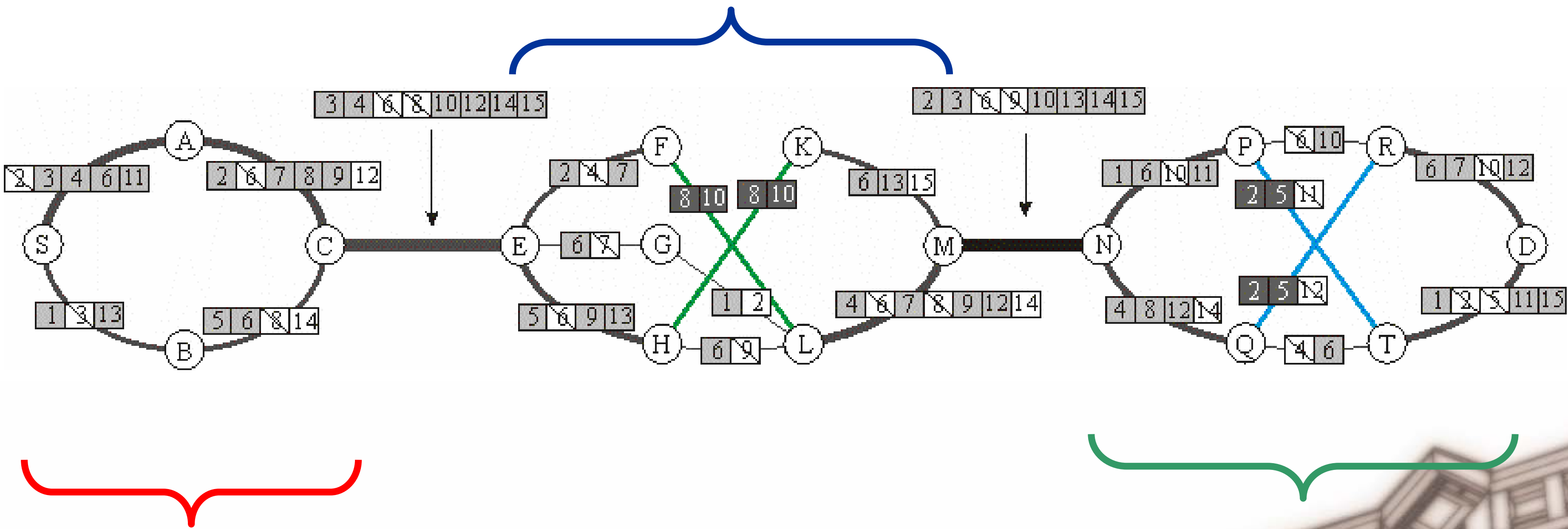
- **Step 2:**
  - If node *e* receives a number of SL REQ packet from node N_i, i =1, . . . , n, the node *e* adds its ID into the NL, and four cases are considered.
    - (1) if the $\sum B = B_r$ and the bandwidth on *ek*, where *k* is next hop of *e*, is less then *Br*, then run procedureII;
    - (2) if the $B < B_r$ and the bandwidth on *ek*, where *k* is next hop of *e*, is less then *B*, then run procedure III-A;
    - (3) if the $\sum B = B_r$ and the bandwidth on ek_i, where k_i is next hop of *e*, is less then *B* and one link ek_j has more bandwidth, then run procedure III-B;
    - (4) if the node *e* is destination node, then go to step 3;

Cont.

- **Step 3:**
  - Destination node *D* waits for a period of time to receive one or more SL REQ.
  - After a period of time, the *D* responds to source node and the QoS routing path are constructed.

Example

Procedure III-B



Procedure II

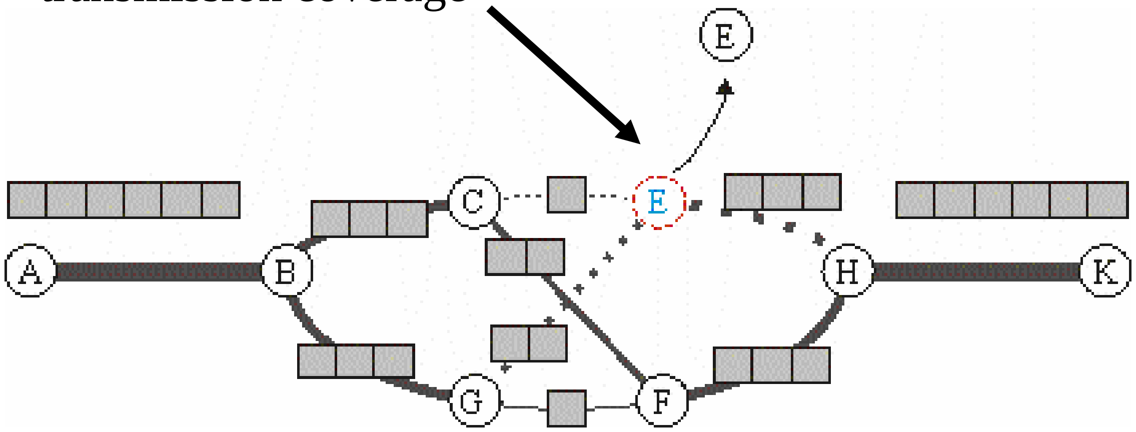
Procedure III-A

Phase III: Shoelace-path maintenance

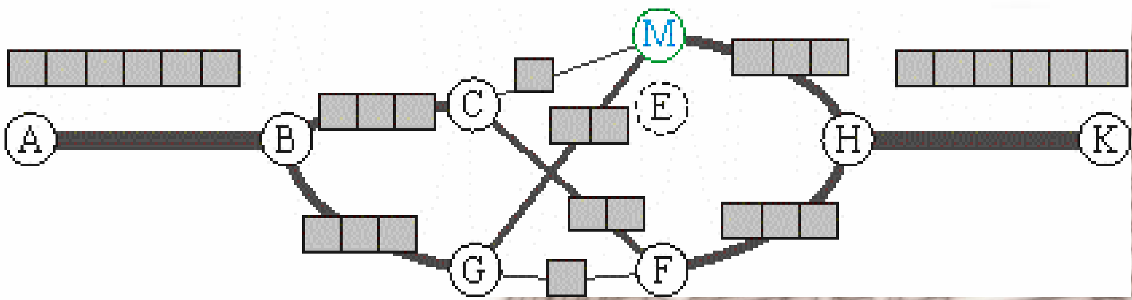
- When some node is failed or leaves off its transmission coverage, this shoelace-path maintenance phase is performed.
- The preceding nodes of the failed node try to search other node to replace the failed node.

Example

Node *E* leaves off path's transmission coverage



Nodes *C* and *G* find other node *M* to replace node *E*



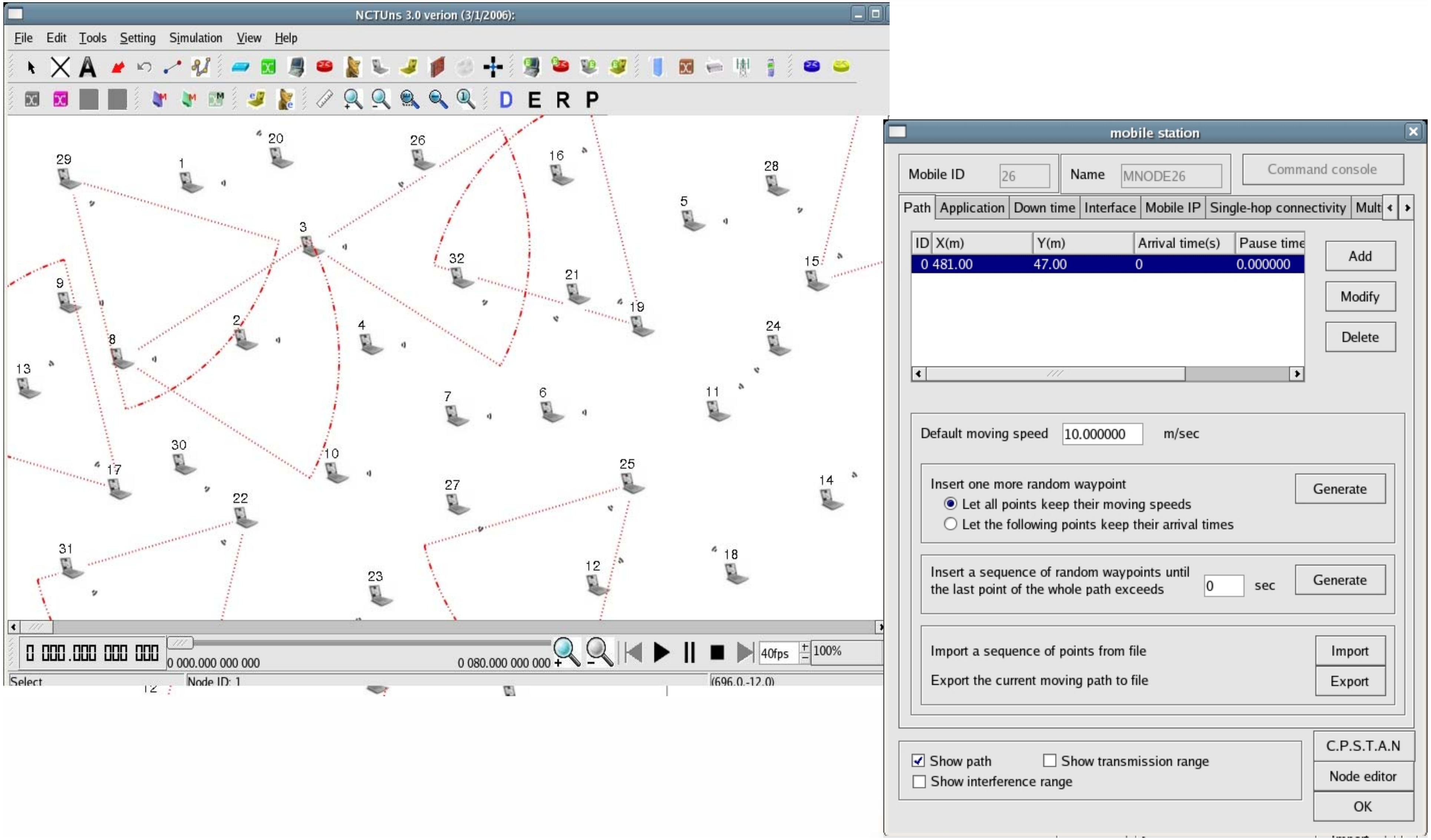
Outline

1. Introduction
2. Related work
3. System model and basic idea
4. Our shoelace-based QoS routing protocol
5. Simulation results
6. Conclusion

Simulation results

- All protocols are implemented using NCTUns 3.0.
  - Flow-control (ICC2004), zone-disjoint (GLOCOMW 2004), our shoelace-based.
- System parameters
  - mobility speed is from 0 to 50 km/h
  - numbers of time slots is 16 slots
  - data rate is 2 Mb/s
  - bandwidth requirement is 1 to 8 slots
  - The average network bandwidth is 6.25 to 50 percentage
  - the beam number is 4, 6, 8, and 12
  - the transmission range is 60, 70, 80, and 100 meters
  - the simulation runs in a 1000x1000 m^2 using 500 nodes

NCTUns 3.0


NCTUns 3.0 verion (3/1/2006):
File Edit Tools Setting Simulation View Help
D E R P
0 000.000 000 000
0 080.000 000 000
40fps
100%
Select
Node ID: 1
(696.0,-12.0)
mobile station
Mobile ID 26
Name MNODE26
Command console
Path Application Down time Interface Mobile IP Single-hop connectivity Mult
ID X(m) Y(m) Arrival time(s) Pause time
0 481.00 47.00 0 0.000000
Add
Modify
Delete
Default moving speed 10.000000 m/sec
Insert one more random waypoint
Let all points keep their moving speeds
Let the following points keep their arrival times
Generate
Insert a sequence of random waypoints until the last point of the whole path exceeds
0 sec
Generate
Import a sequence of points from file
Import
Export the current moving path to file
Export
Show path
Show transmission range
Show interference range
C.P.S.T.A.N
Node editor
OK

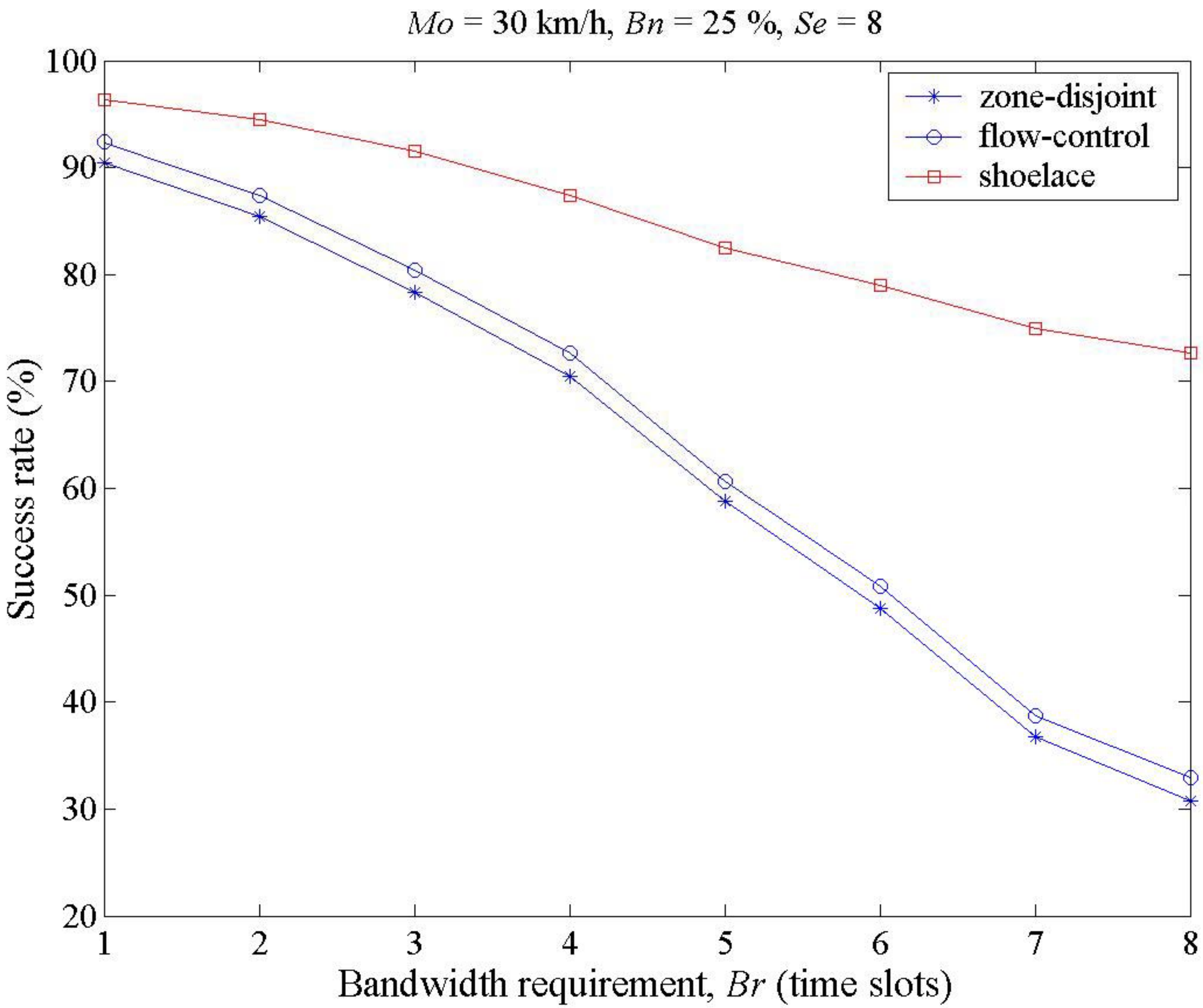
Performance metrics

- Success rate:
  - The number of successful QoS routes divided by the total number of QoS request from source to destination.
- Throughput:
  - The number of received data packets for all destination hosts divided by the total number of data packets sent from the source host.

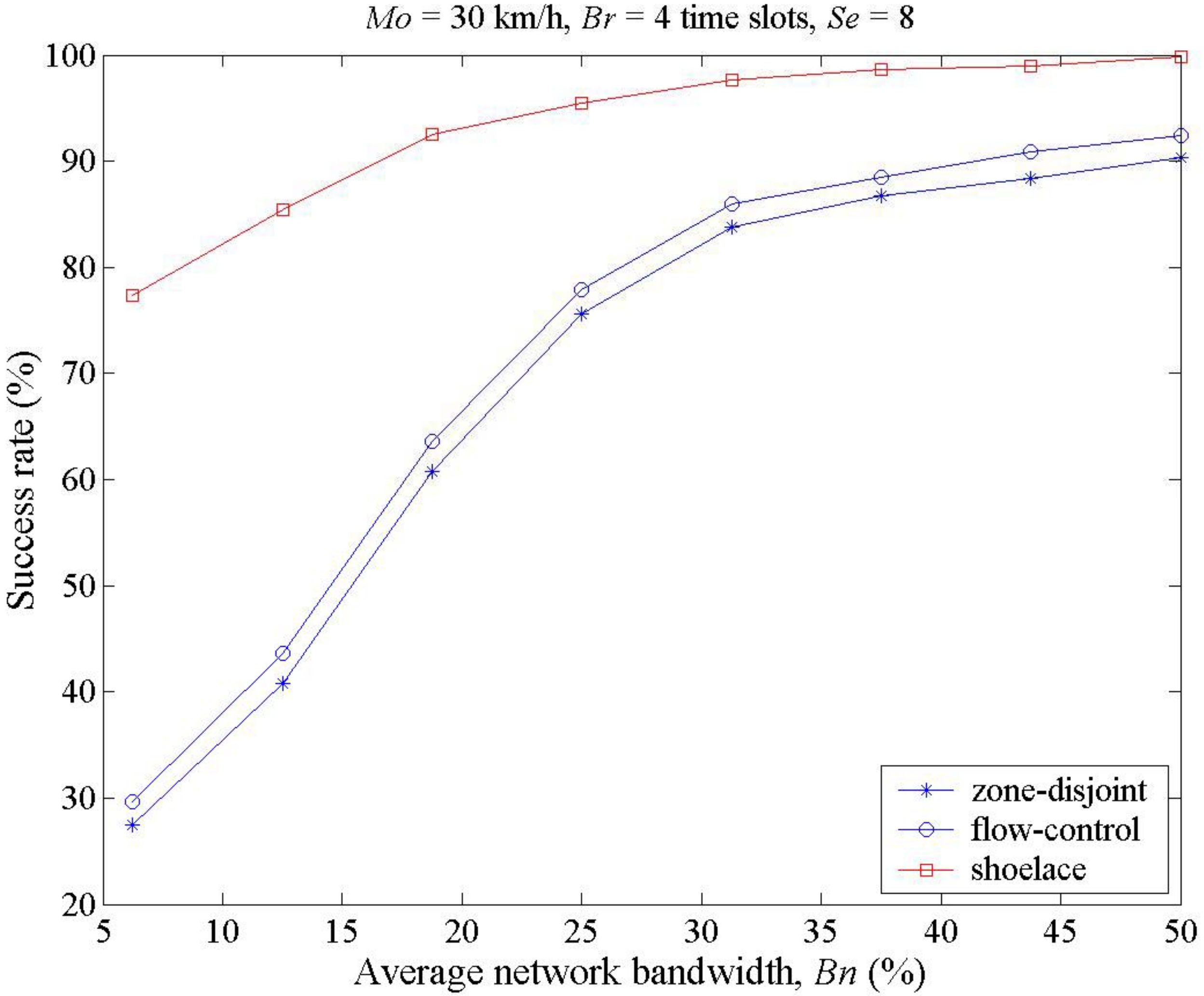
Cont.

- Wireless medium utilization:
  - The number of received data packets for all destination hosts divided by the simulation area
- Overhead:
  - The total numbers of transmitted packets, including the control packets.
- Average latency:
  - The interval from the time the transmission is initiated to the time the last host finishes its received.

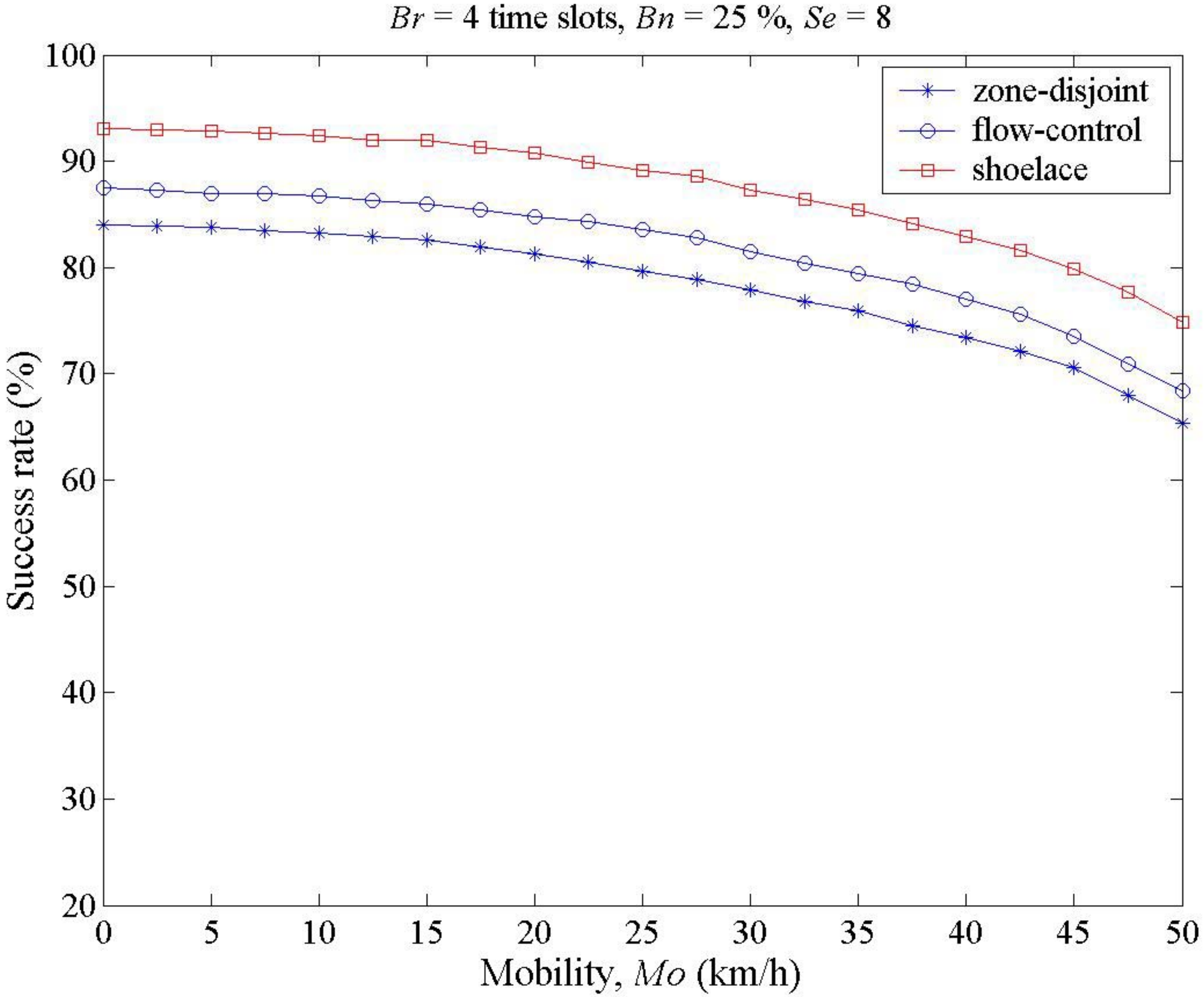
Success rate vs. bandwidth requirement



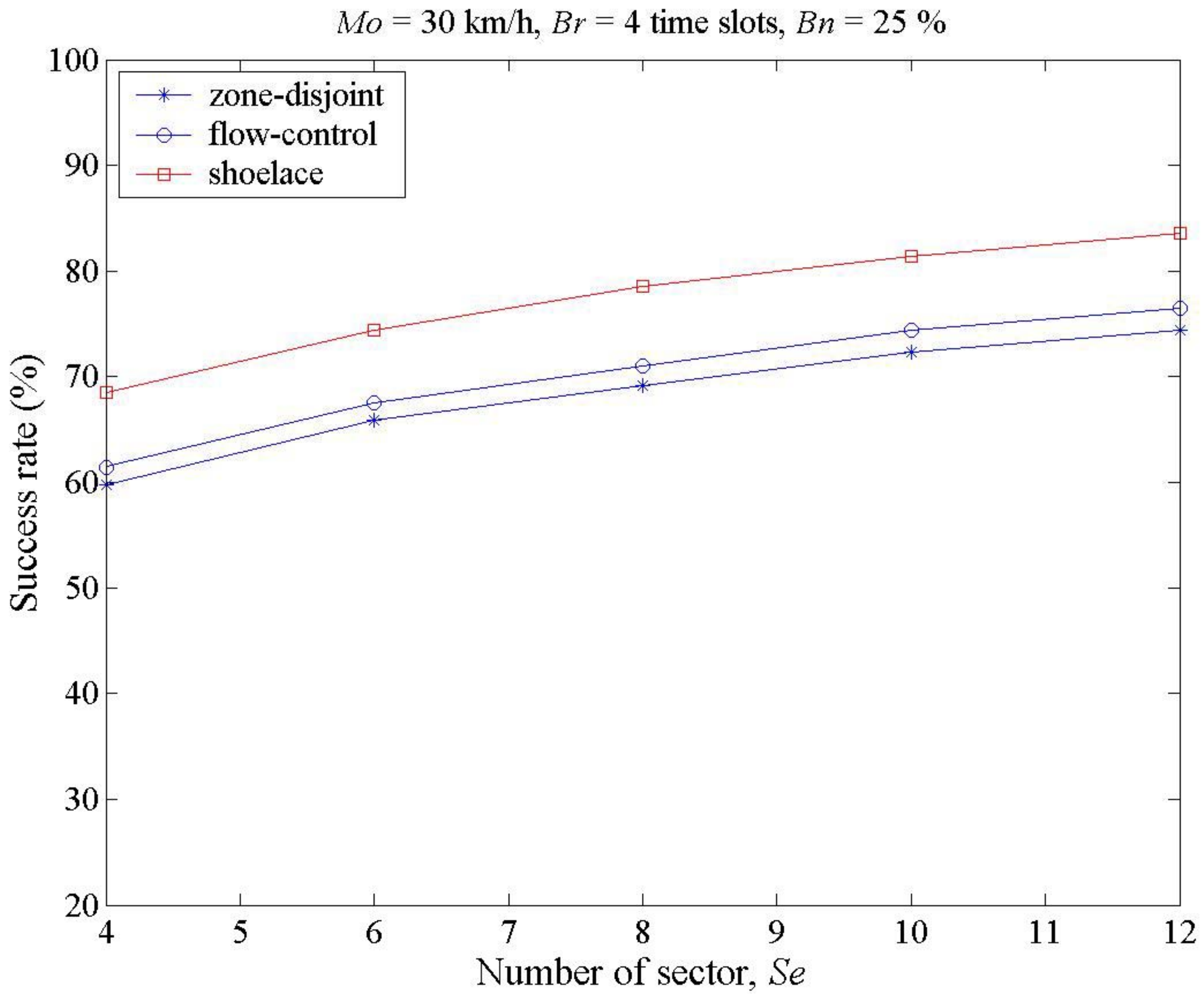
Success rate vs. average network bandwidth



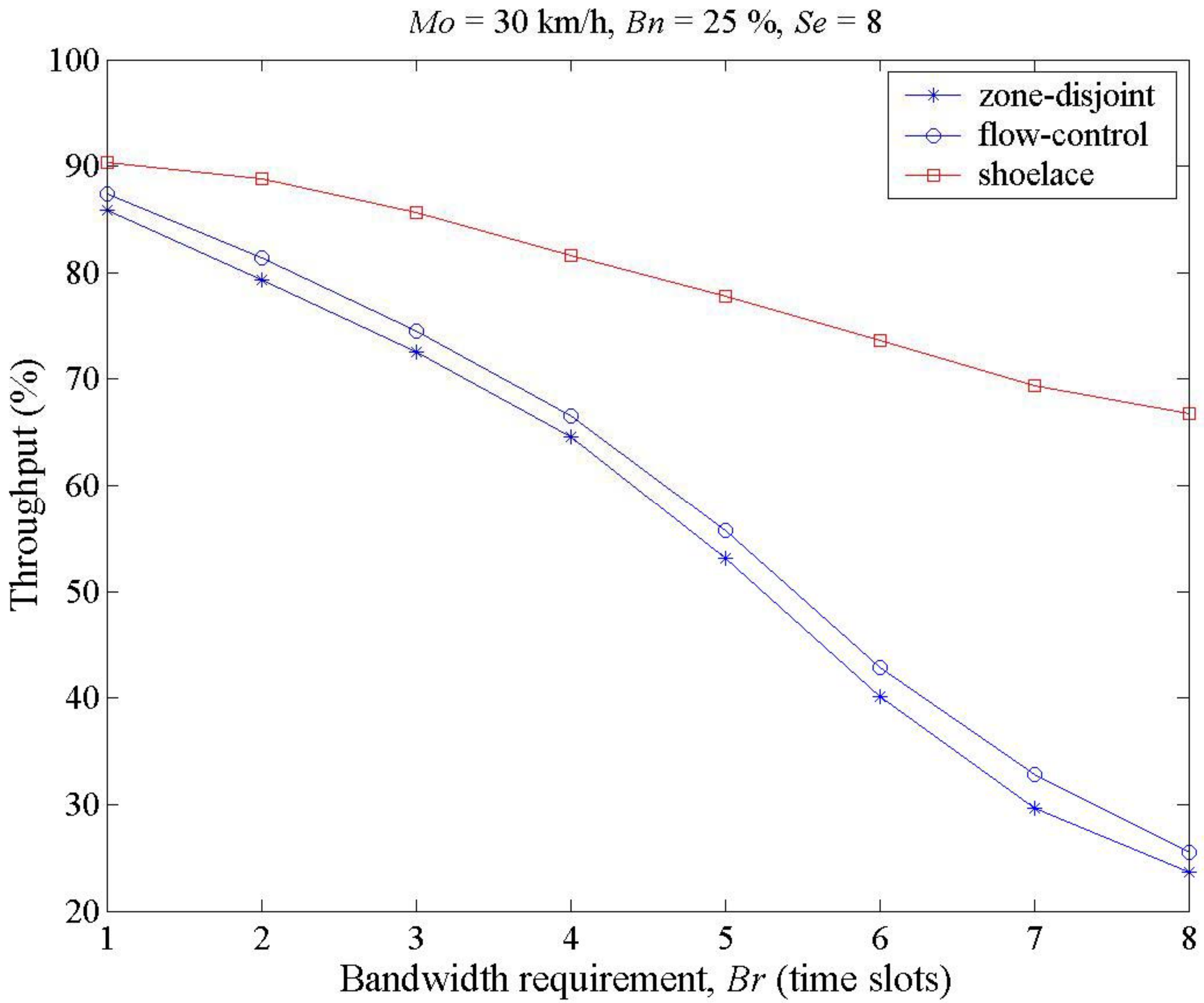
Success rate vs. mobility



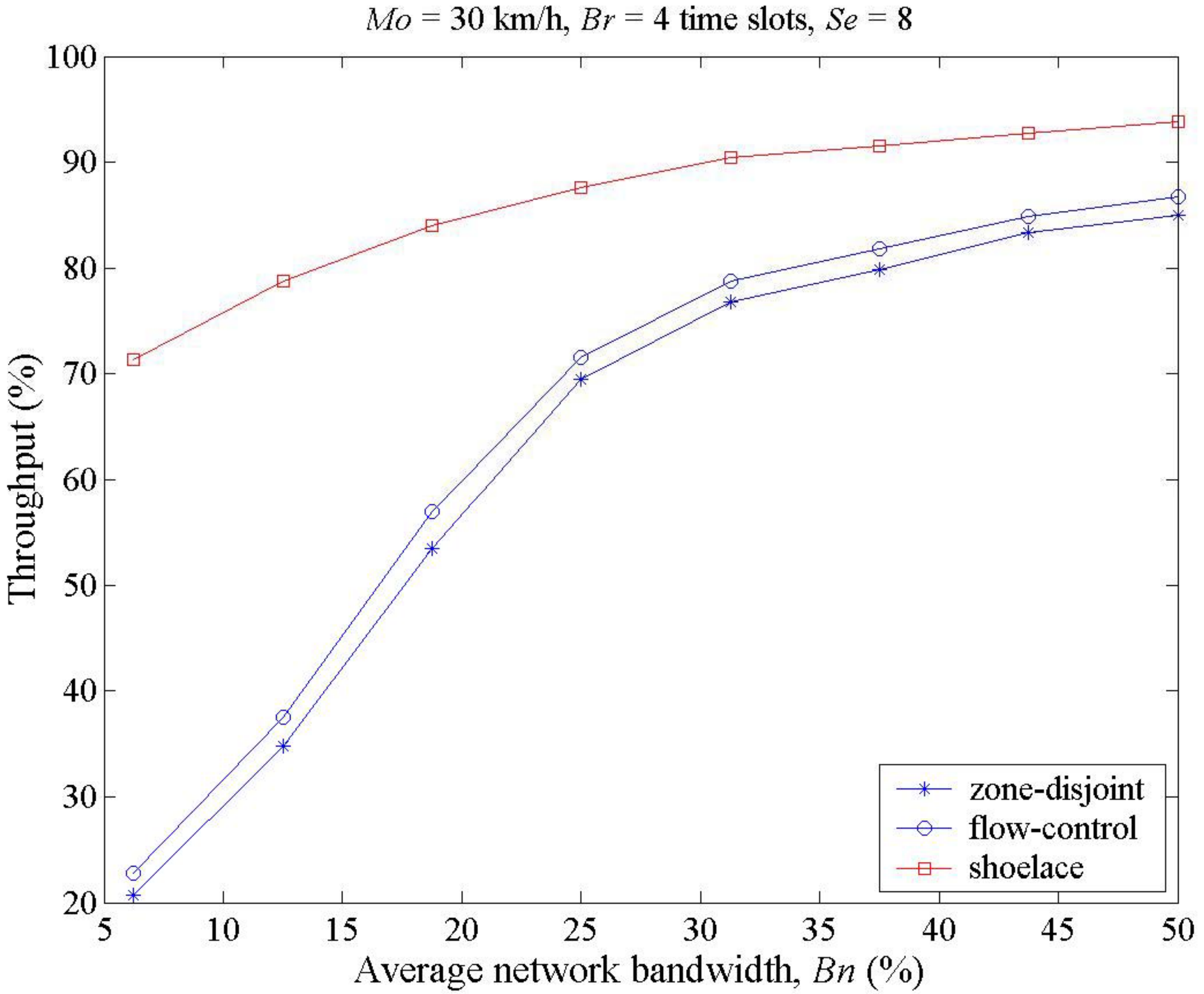
Success rate vs. number of sector



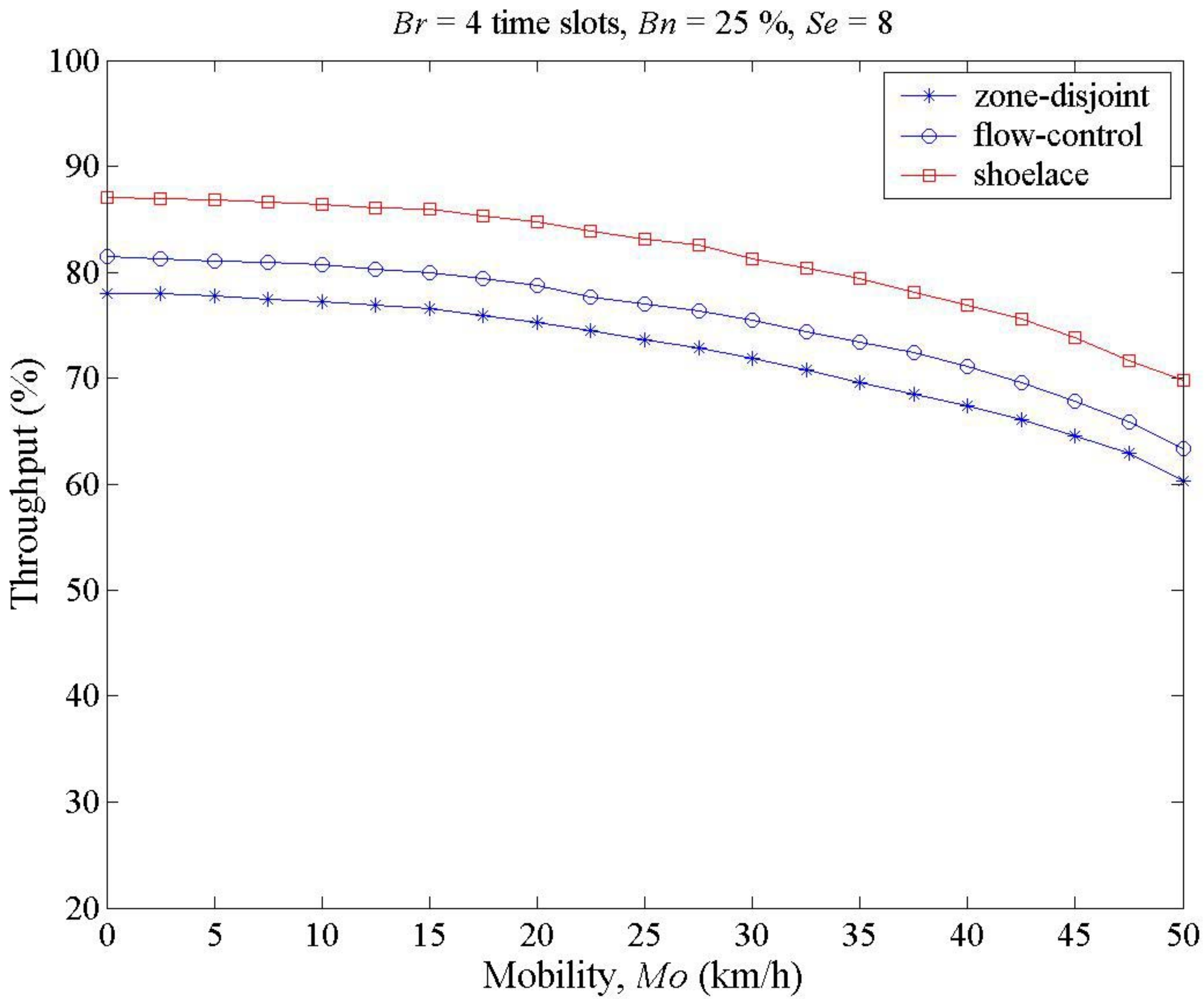
Throughput vs. bandwidth requirement



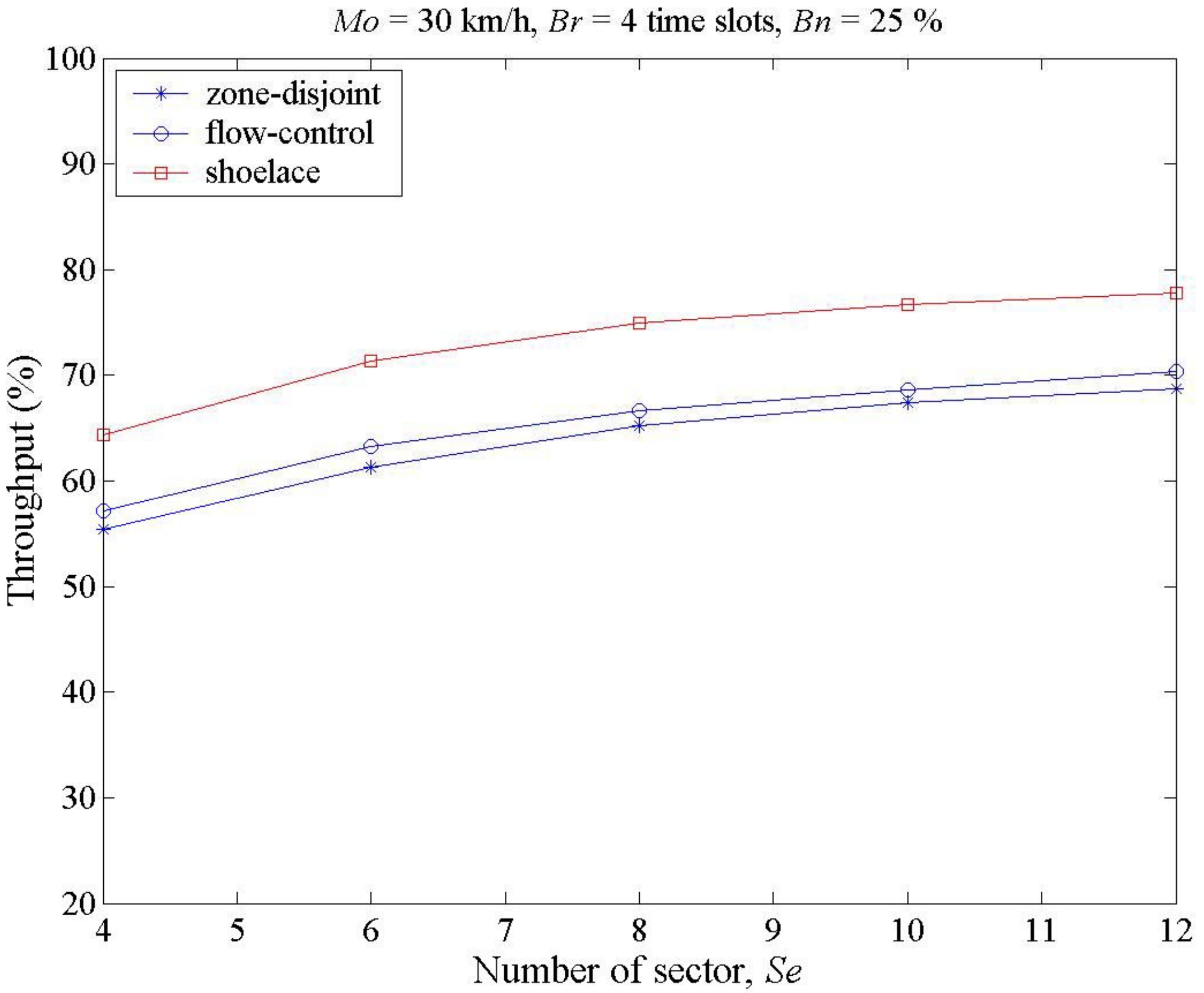
Throughput vs. average network bandwidth



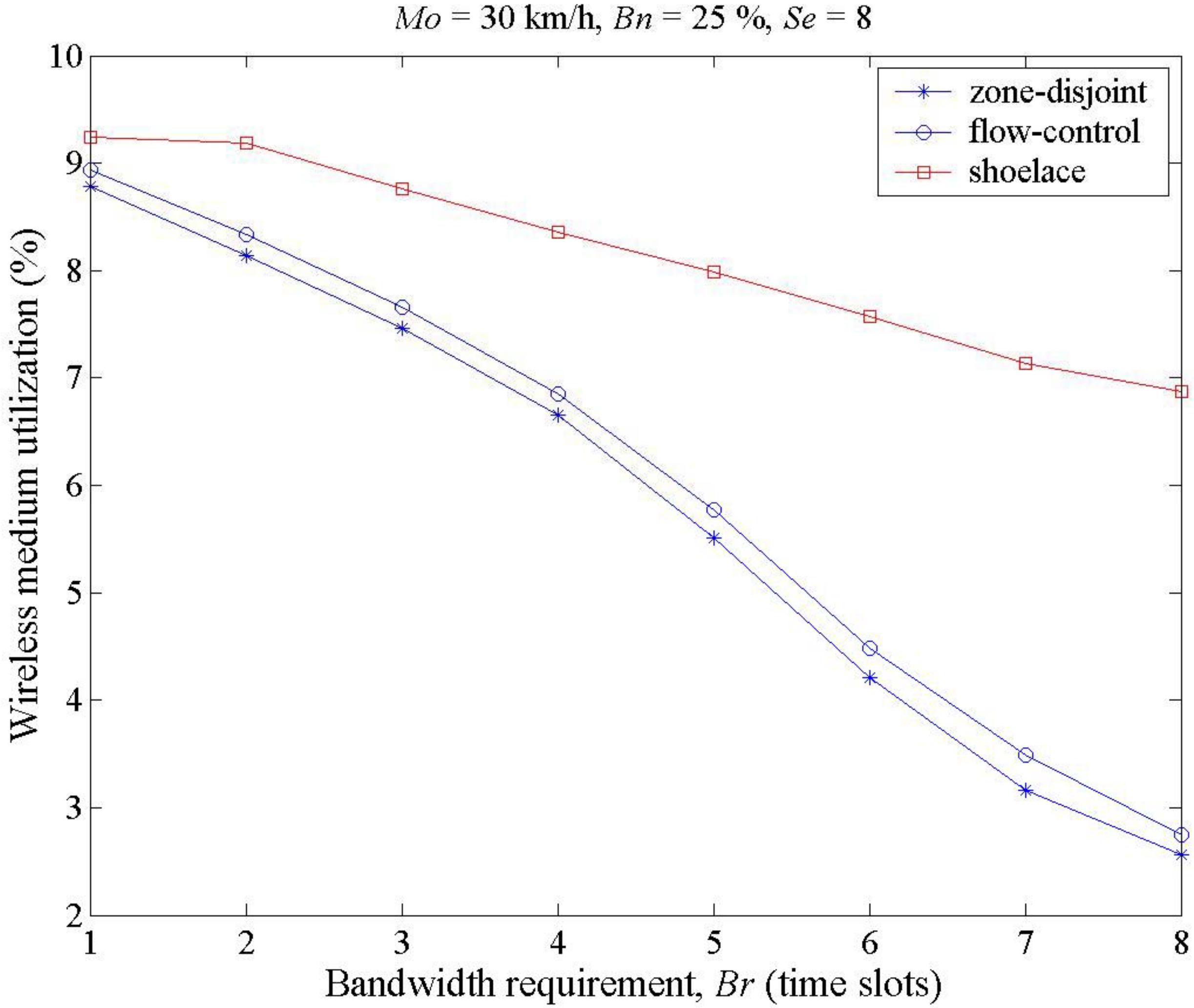
Throughput vs. mobility



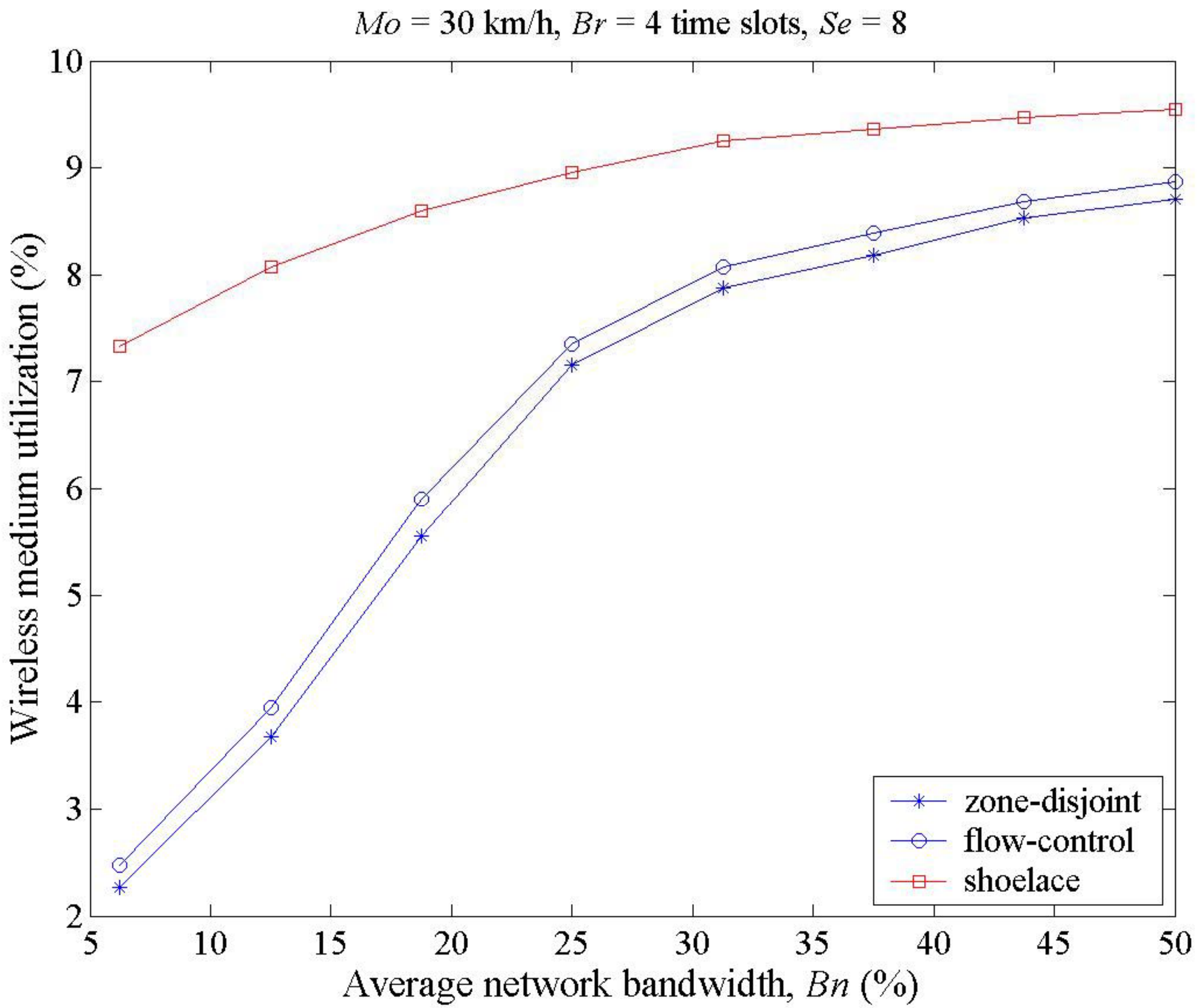
Throughput vs. number of sector



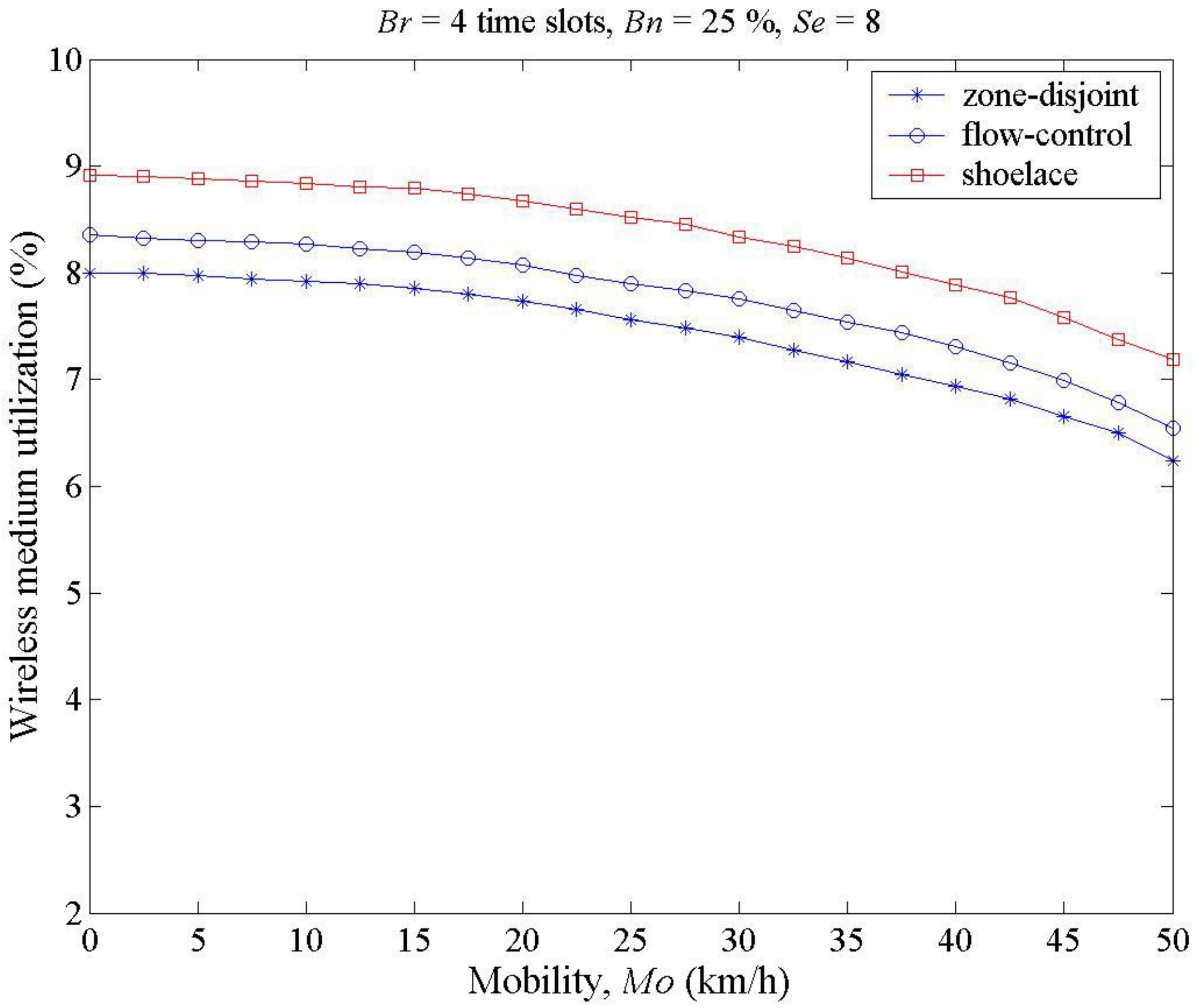
Wireless medium utilization vs. bandwidth requirement



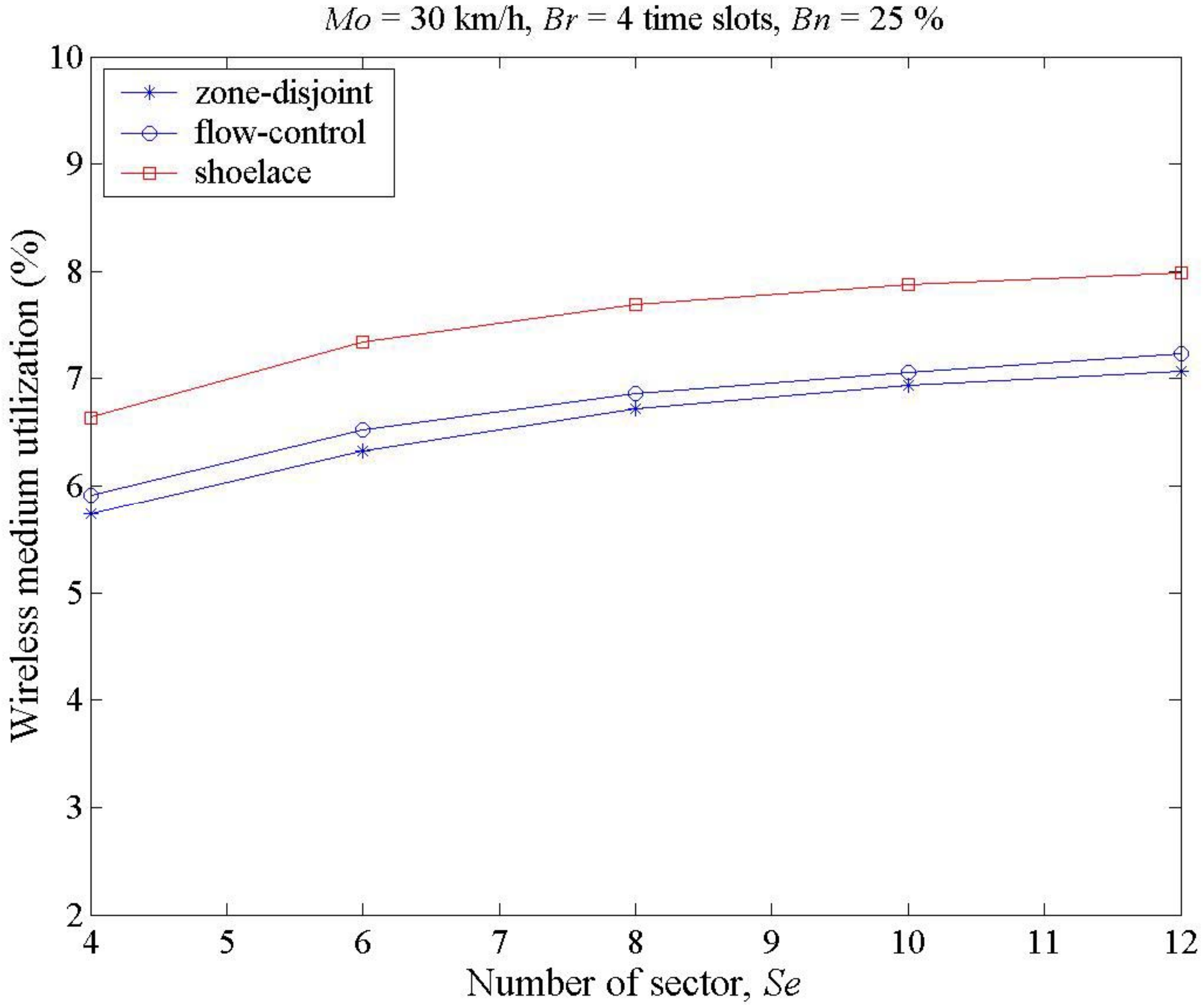
Wireless medium utilization vs. average network bandwidth



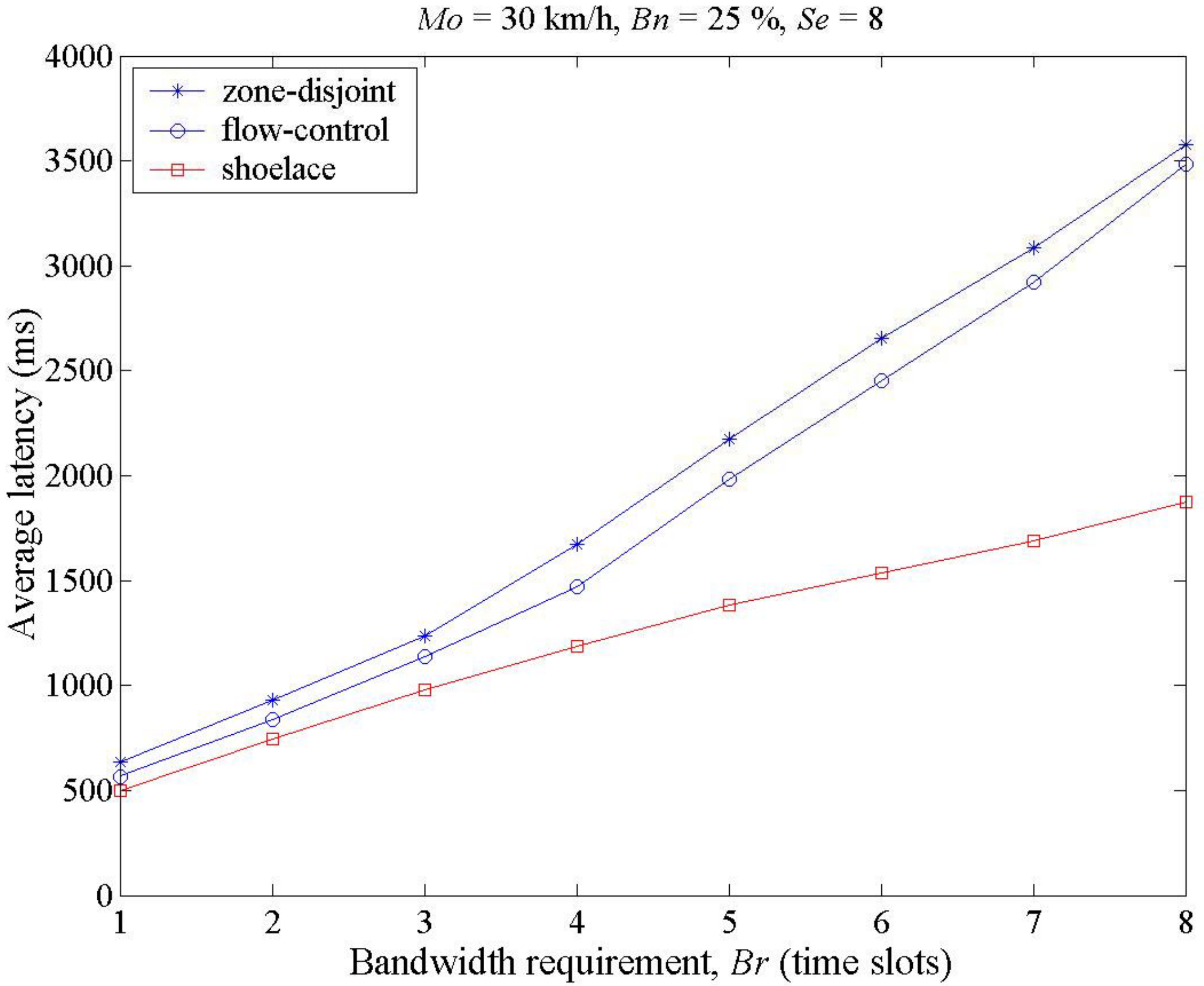
Wireless medium utilization vs. mobility



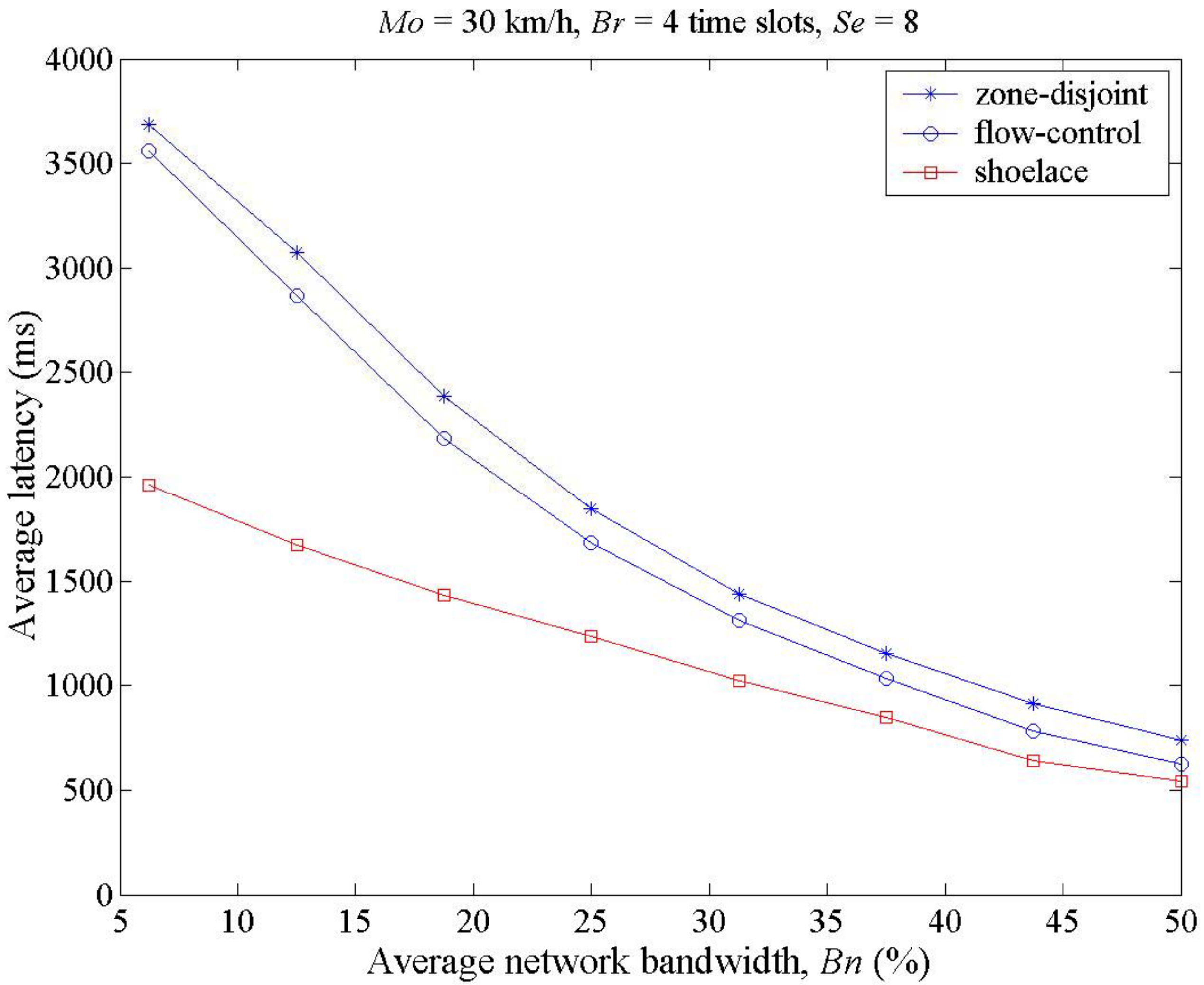
Wireless medium utilization vs. number of sector



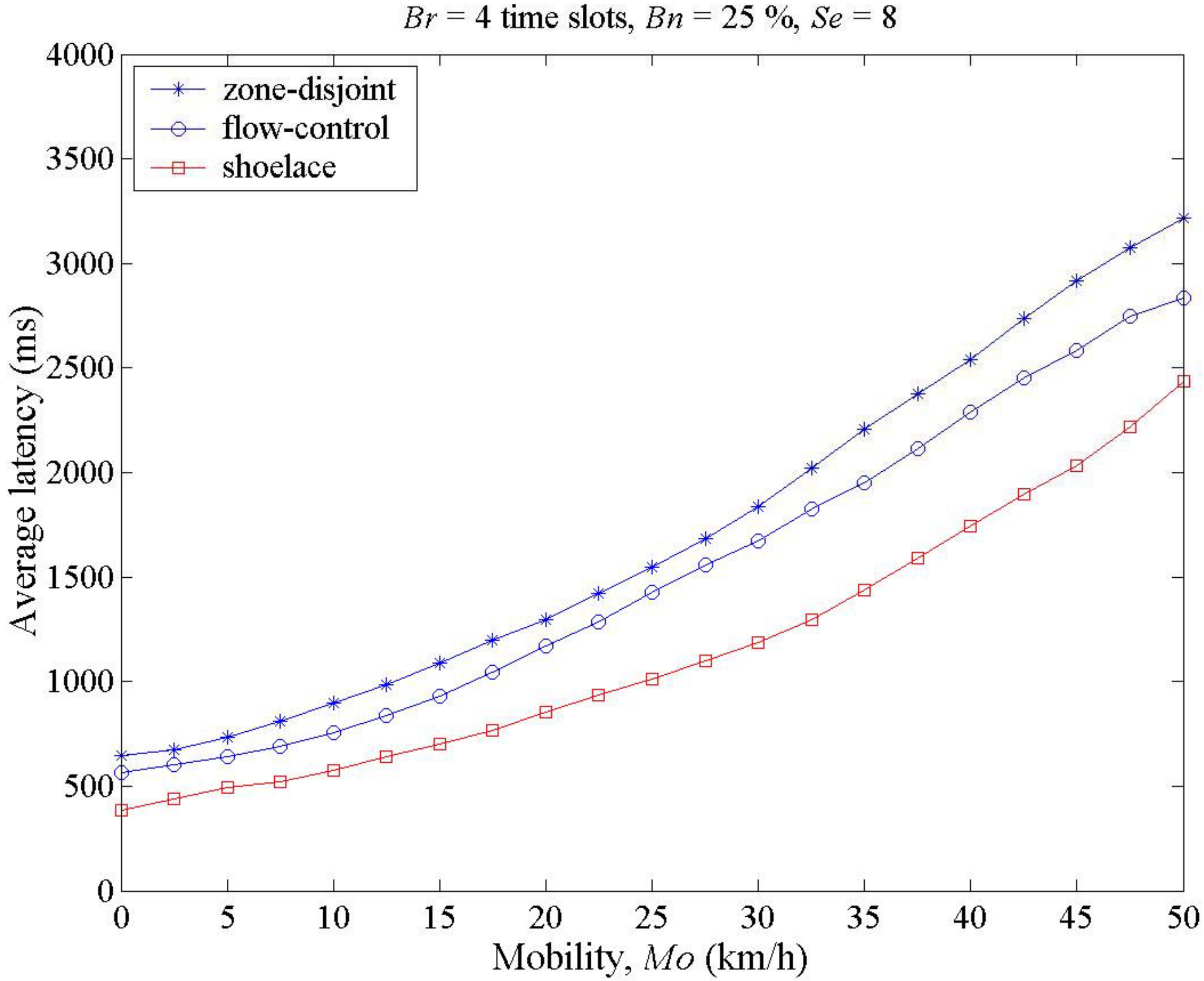
Average latency vs. bandwidth requirement



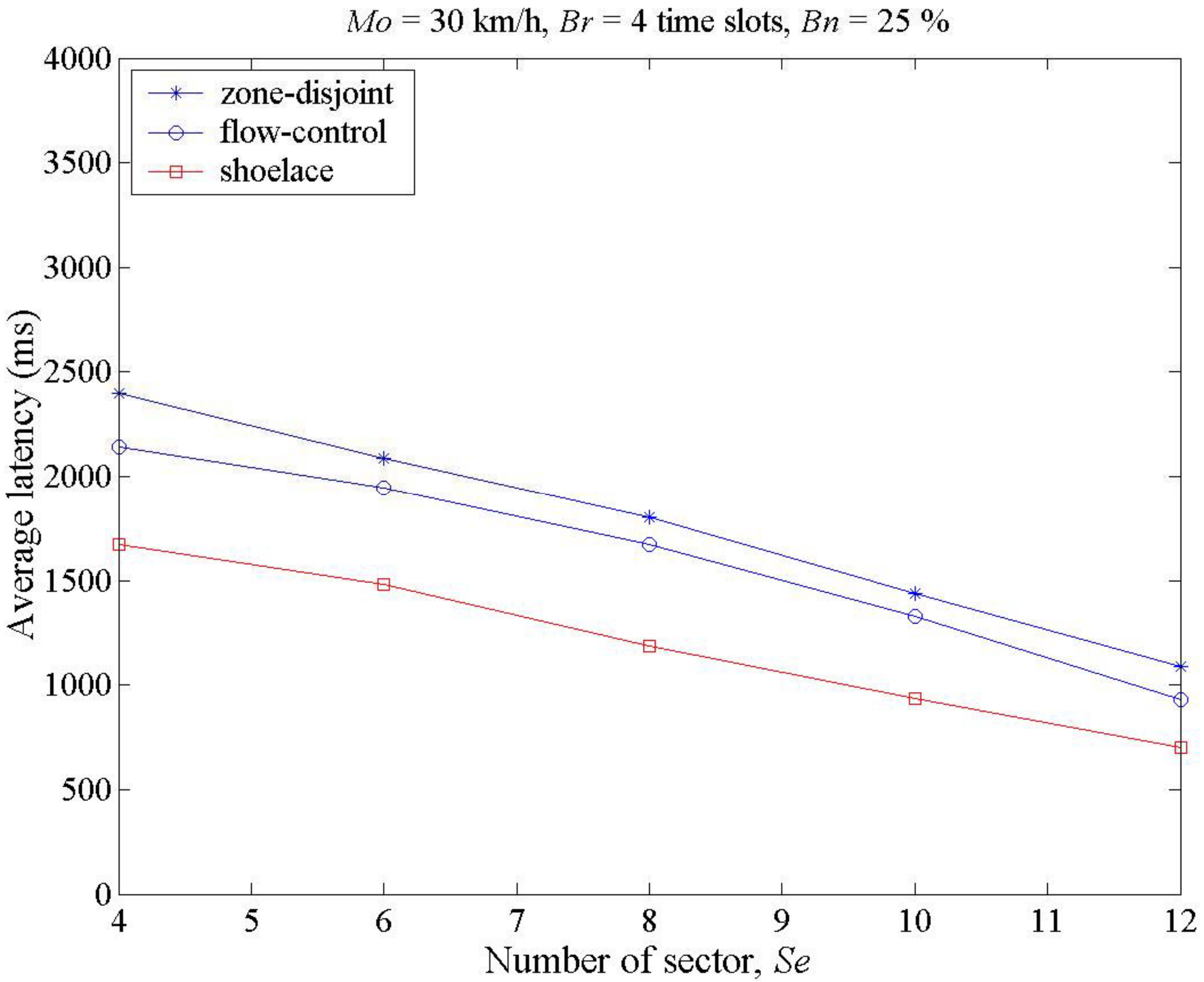
Average latency vs. average network bandwidth



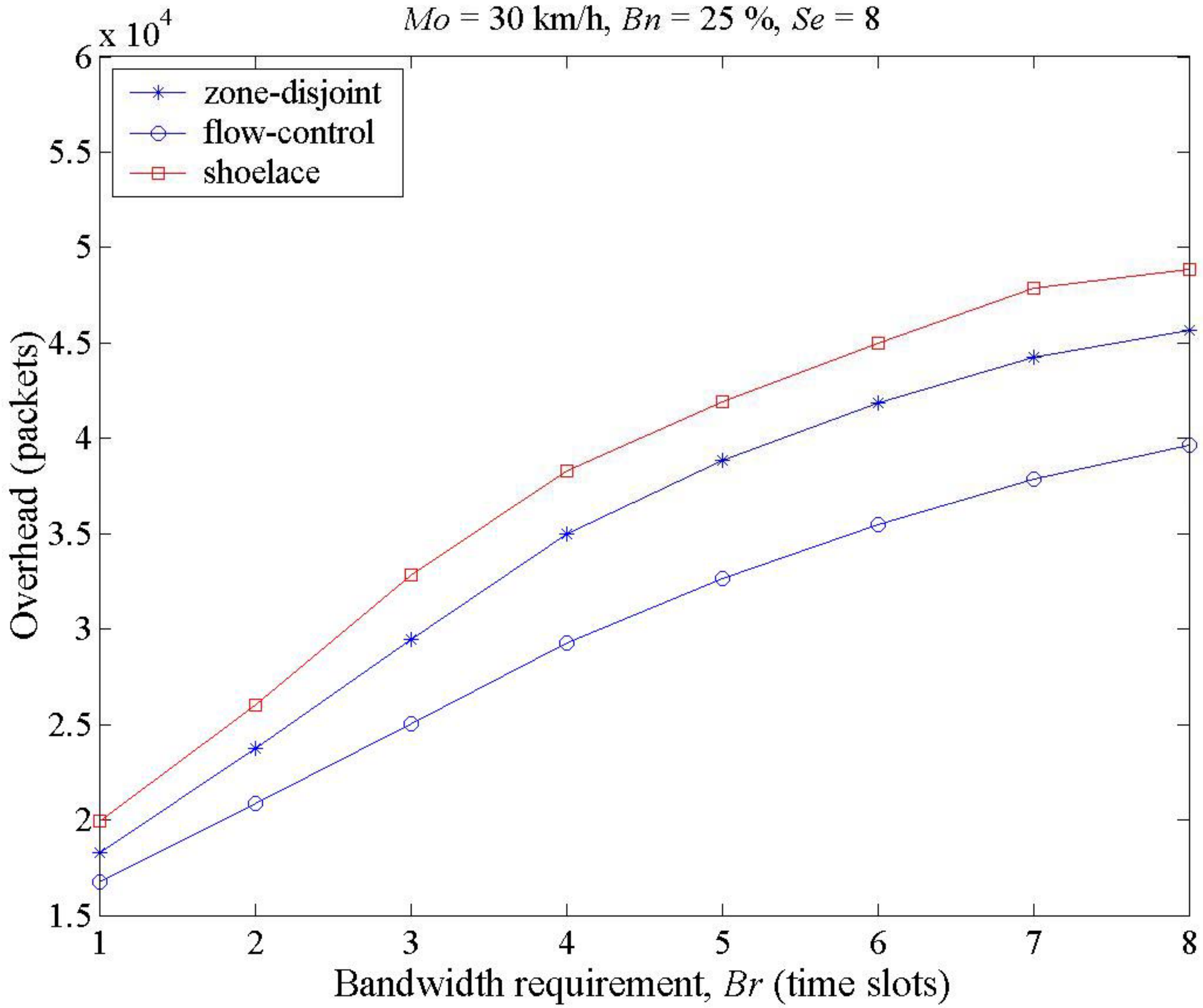
Average latency vs. mobility



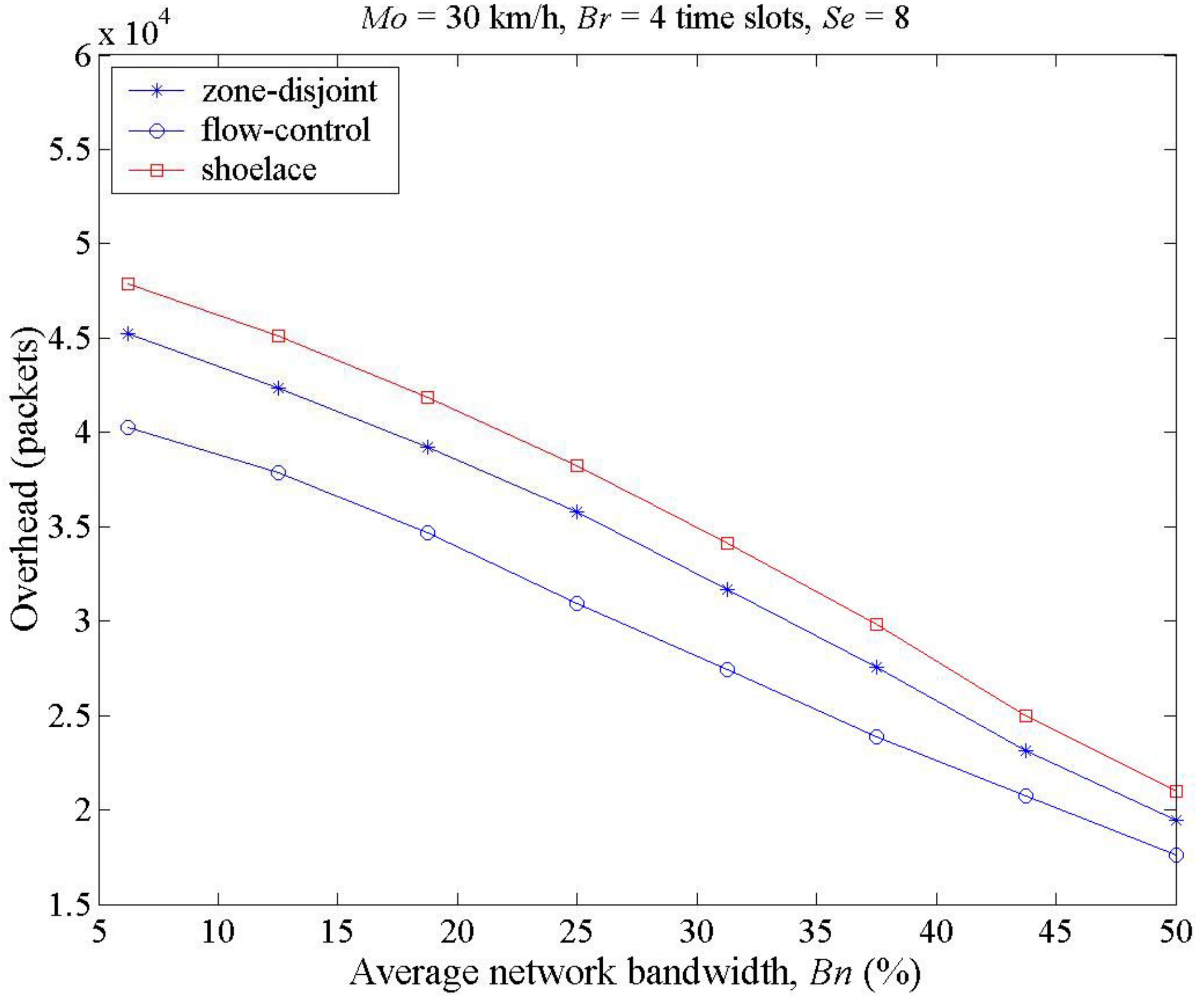
Average latency vs. number of sector



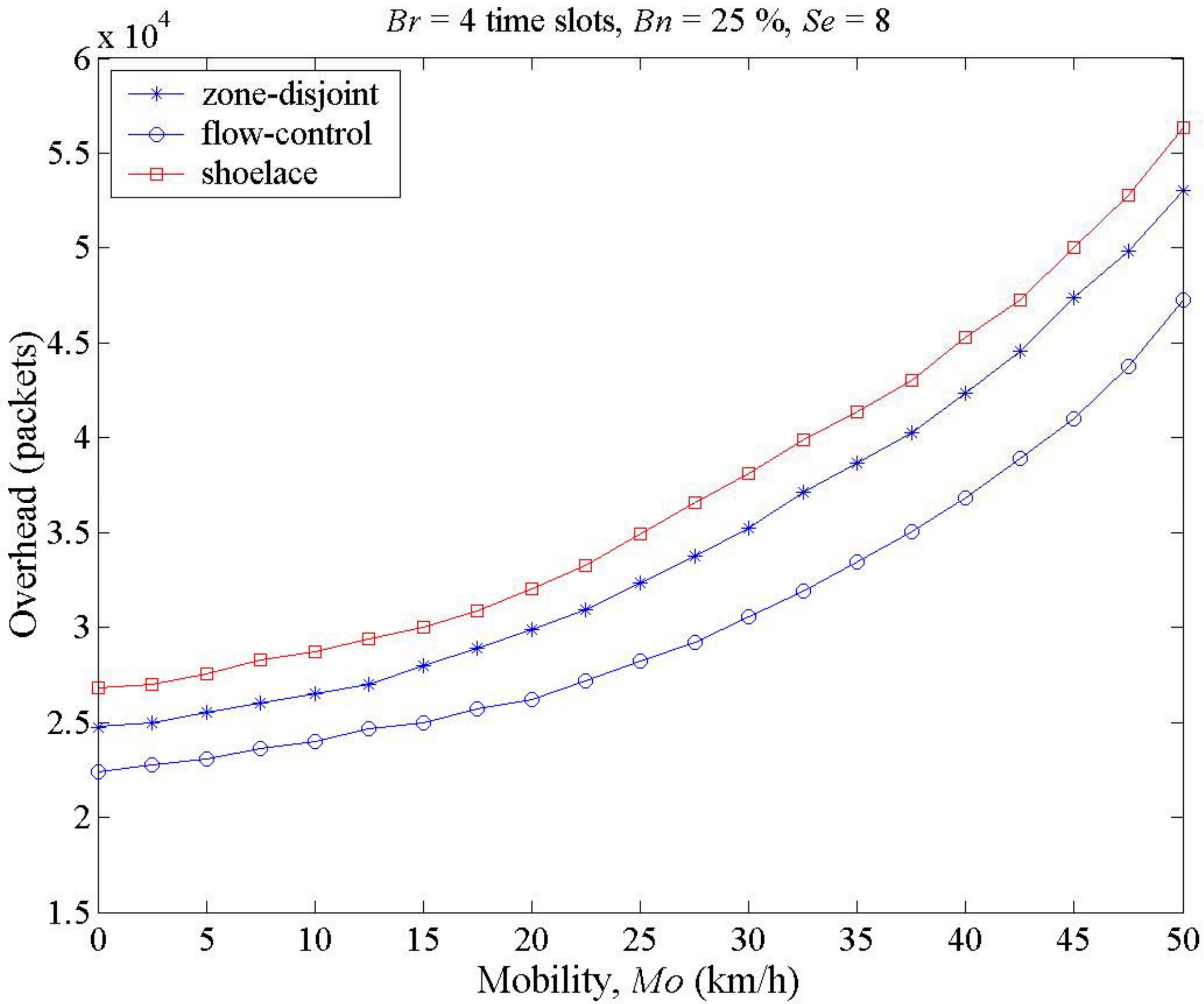
Overhead vs. bandwidth requirement



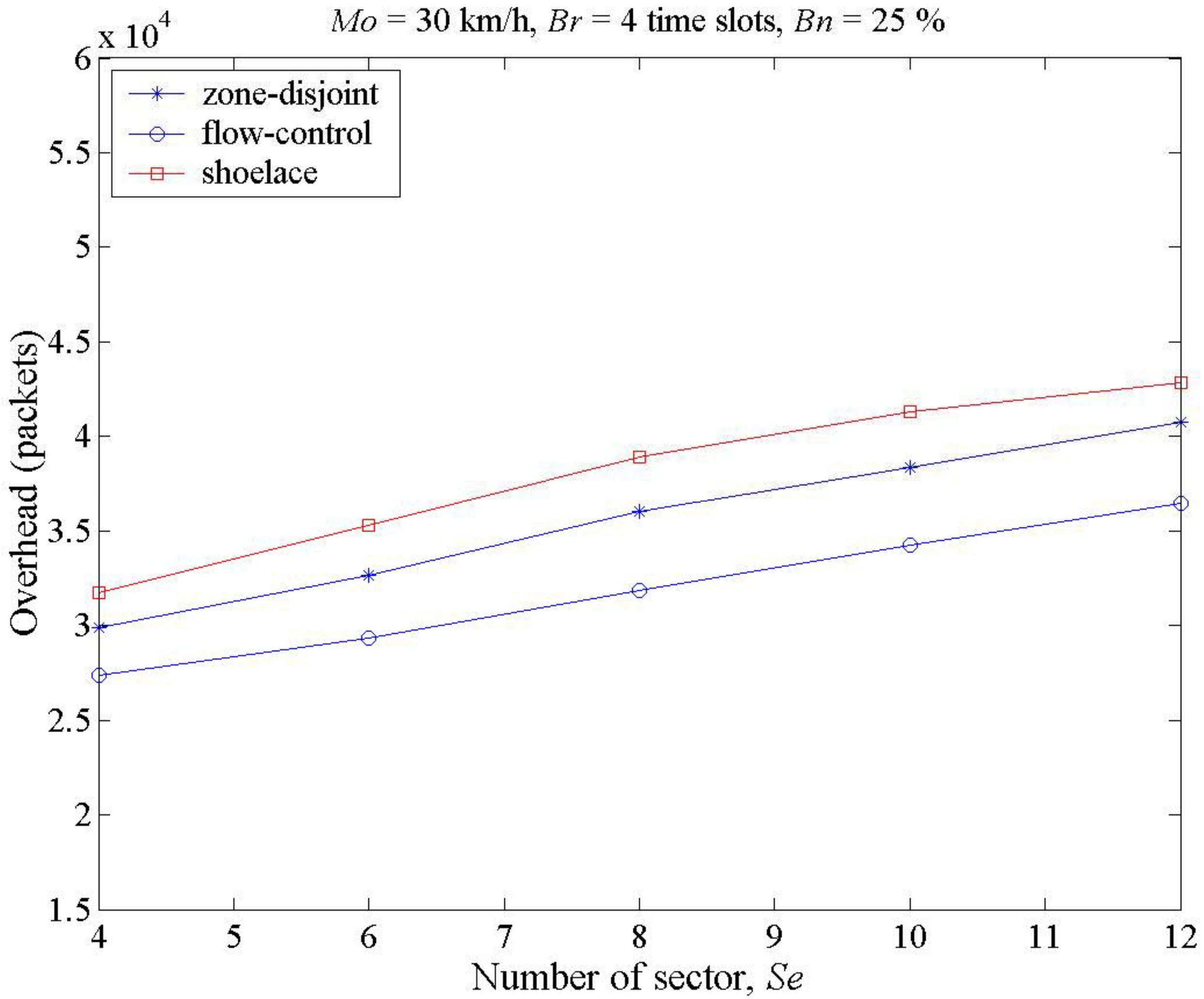
Overhead vs. average network bandwidth



Overhead vs. mobility



Overhead vs. number of sector



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Conclusion

- This paper proposes a new QoS routing protocol for mobile ad hoc network using directional antenna.
  - These cross links, called as shoelace, can simultaneously transmit data without any data interference.
  - The shoelace-based protocol is a multi-path routing.
- Our shoelace-based protocol offers a higher success rate to construct a QoS route in MANET using directional antenna.

Homework #14.

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