An Efficient Interference Management Framework for Multi-hop Wireless Networks

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WCNC 2013 – ShangHai, China

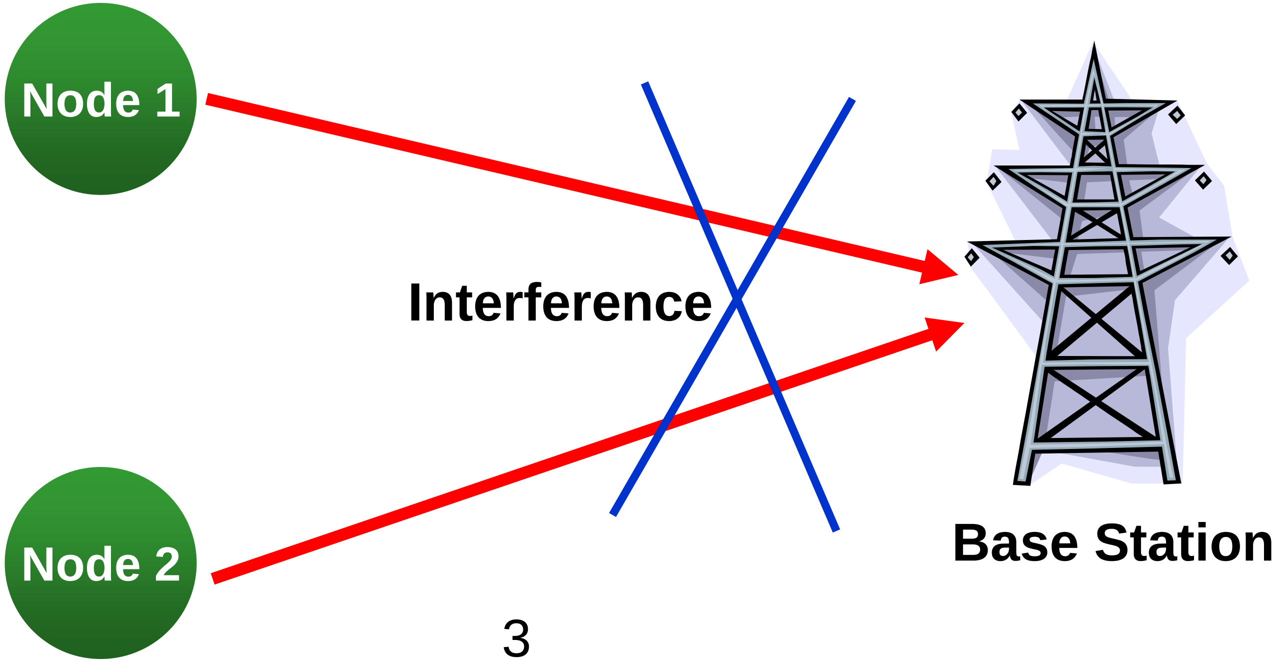
Outline

- Introduction
- **Traditional Multi-hop Wireless Networks**
- **Multi-hop Wireless Networks with SIC**
- **Simulation Results**

Problem and Background

- The BS can receive one packet from a wireless node at any time
  - The achievable data rate depends on SNR

- Collision happens when several nodes transmit at the same time



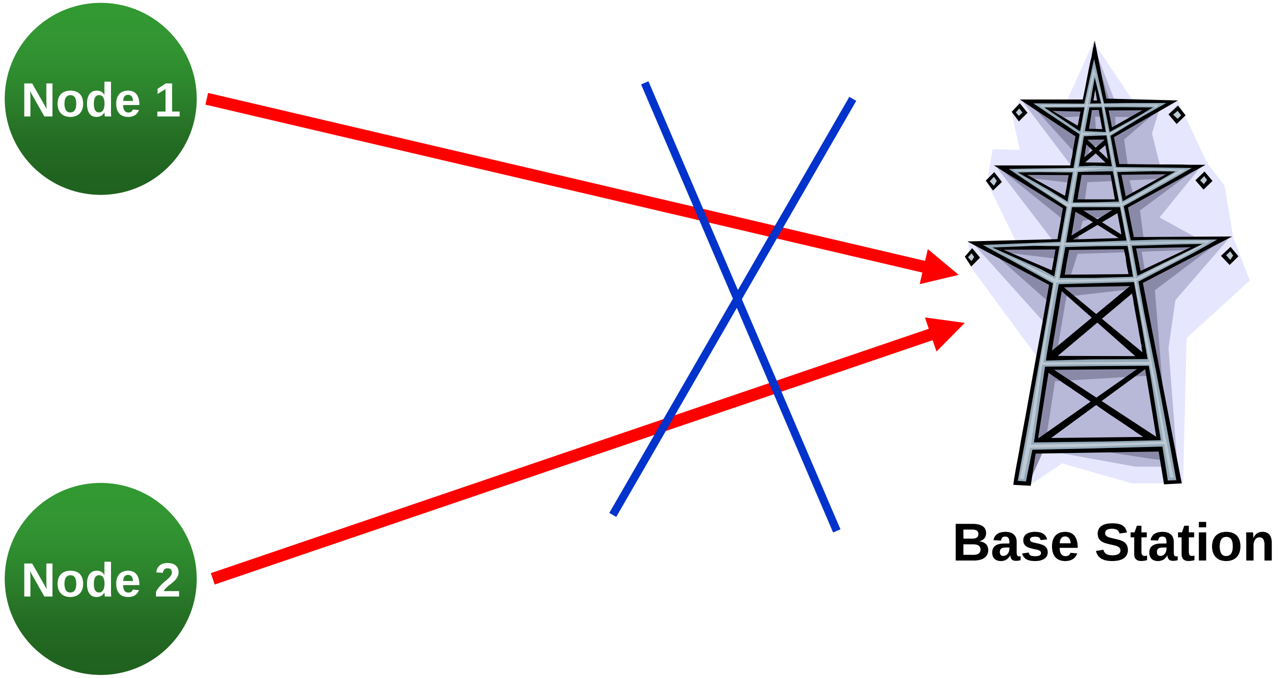
Node 1

Node 2

Interference

Base Station

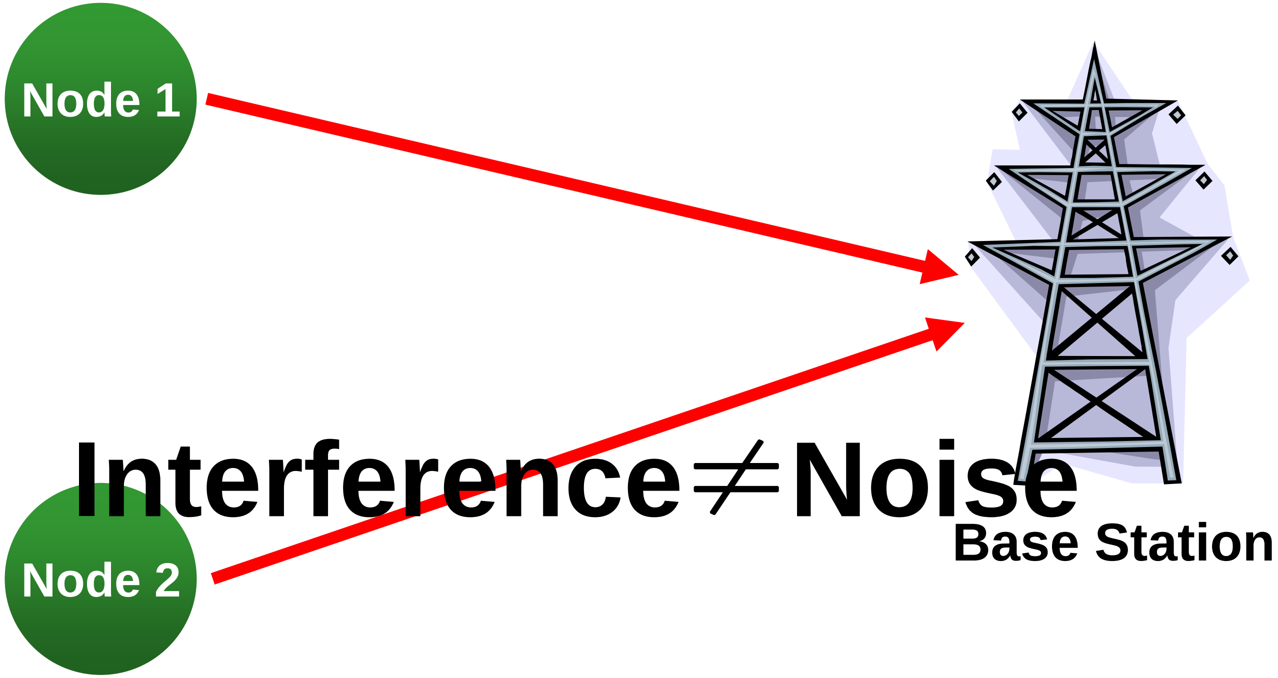
Traditional mechanisms



Interference Avoidance

TDMA CDMA FDMA CSMA

Interference Management



Interference≠Noise

Interference Cancellation
Interference Randomization
Interference Coordination

Interference Cancellation and SIC

Interference Cancellation

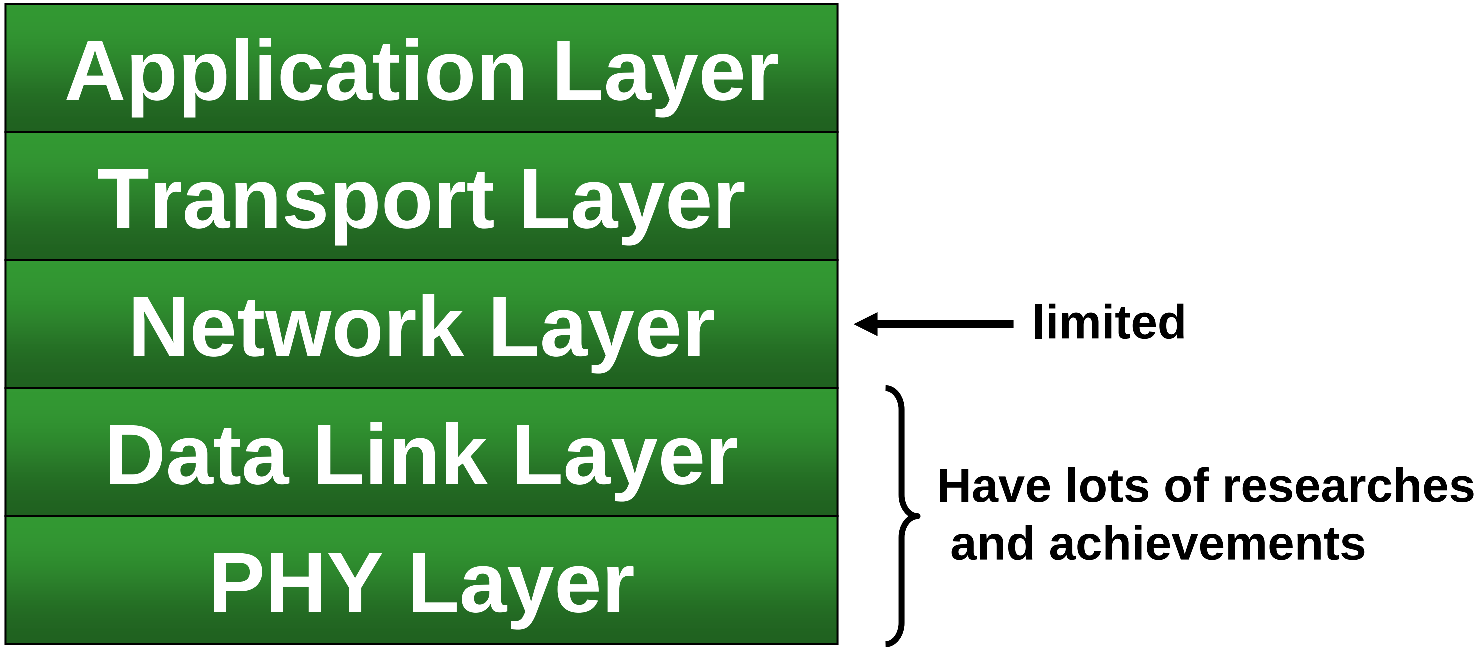
- Successive Interference Cancellation (SIC)
- Parallel Interference Cancellation (PIC)
- Iterative Interference Cancellation

SIC is based on the SINR

Suppose a node s_i is transmitting to a node s_j in the time slot *k*
And some other nodes s_l are transmitting at the same time

$$SINR_{ij}[k] = \frac{g_{ij}P}{\sum_{s_l \neq s_i}^{g_{lj} \leq g_{ij}} (g_{lj}P \sum_{g_m \in T_l} x_{lm}[k]) + N_0} \geq \beta$$

Research about SIC Now



Application Layer

Transport Layer

Network Layer

Data Link Layer

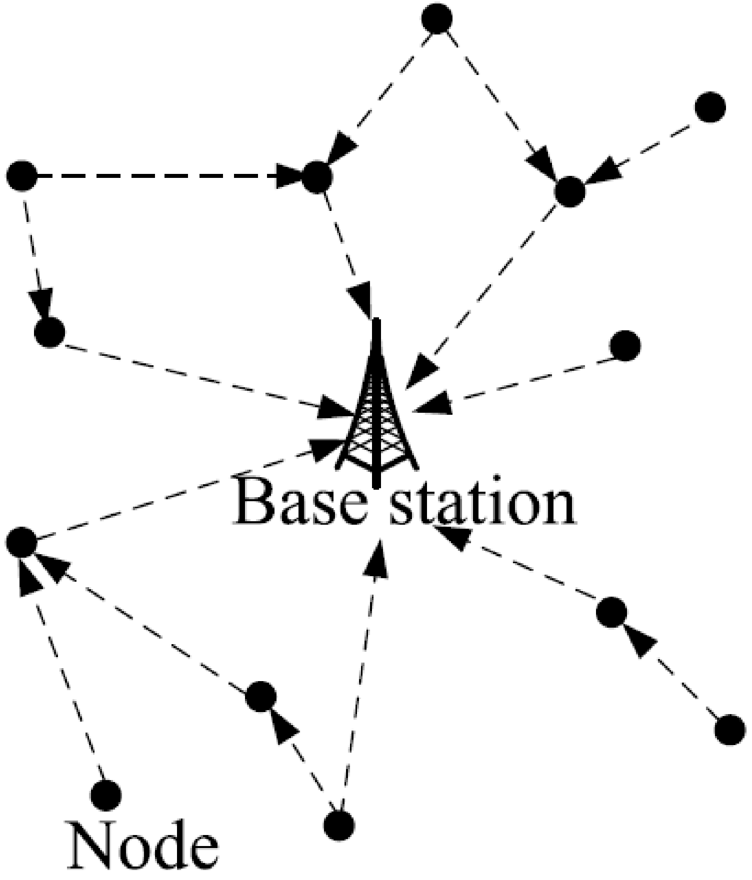
PHY Layer

limited

Have lots of researches and achievements

Our Work

- To build an efficient interference management framework for multi-hop wireless networks.



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PHY Layer and Link Layer Model

$$x_{ij}[k] = \begin{cases} 1 & s_i \text{ is transmitting to } s_j \text{ at the time slot } k \\ 0 & \text{otherwise} \end{cases}$$

$$\sum_{s_l \in T_i} x_{li}[k] + \sum_{s_j \in T_i} x_{ij}[k] \le 1 \quad (s_i \in N, 1 \le k \le h)$$

$$x_{ij}[k] + \frac{\sum_{s_l \in I_j}^{s_l \neq s_i} \sum_{s_m \in T_l} x_{lm}[k]}{|I_j| - 1} \le 1 \quad (s_i \in N, s_j \in T_i, 1 \le k \le h)$$

the set of all neighboring nodes in the interference range of node s_j

Network Layer Model

$r(s_i)$ minimum data rate requirement of a session from the node s_i to the bs

r_{ij} the average data rate from node s_i to node s_j

K the common scaling factor which we wish to optimize

$$\sum_{s_l \in T_i} r_{li} + K r(s_i) = \sum_{s_j \in T_i} r_{ij} \ (s_i \in N)$$

$$r_{ij} \leq \frac{1}{h} \sum_{k=1}^{h} (C \cdot x_{ij}[k]) \ \ (s_i \in N, s_j \in T_i)$$

C the data rate by a successful transmission

h the number of the time slots

Problem and Its Solution

$$
\begin{array}{ll}
\max & K \\
s.t. & \sum_{s_l \in T_i} x_{li}[k] + \sum_{s_j \in T_i} x_{ij}[k] \le 1 \ (s_i \in N, 1 \le k \le h) \\
 & x_{ij}[k] + \frac{\sum_{s_l \in I_j}^{s_l \neq s_i} \sum_{s_m \in T_l} x_{lm}[k]}{|I_j| - 1} \le 1 \ (s_i \in N, s_j \in T_i, 1 \le k \le h) \\
 & \sum_{s_l \in T_i} r_{li} + K r(s_i) = \sum_{s_j \in T_i} r_{ij} \ \ (s_i \in N) \\
 & r_{ij} \le \frac{1}{h} \sum_{k=1}^{h} (C \cdot x_{ij}[k]) \ (s_i \in N, s_j \in T_i)
\end{array}
$$

mixed integer linear programming problem

Without SIC

Problem and Its Solution

$$
\begin{array}{ll}
\max & K \\
s.t. & \left\{
\begin{array}{ll}
\gamma_i[k] = \sum\limits_{s_j \in T_i} x_{ij}[k] + x_{iB}[k] & (s_i \in N, 1 \le k \le h) \\
\sum\limits_{s_i \in T_j} x_{ij}[k] + \gamma_j[k] \le 1 & (s_j \in N, 1 \le k \le h) \\
x_{ij}[k] + \frac{\sum_{l \neq i}^{s_l \in I_j} \gamma_l[k]}{|I_j|-1} \le 1 & (s_i \in T_j, s_j \in N, 1 \le k \le h) \\
x_{iB}[k] + \frac{\sum_{l \neq i}^{s_l \in I_B} \gamma_l[k]}{|I_B|-1} \le 1 & (1 \le k \le h, s_i \in T_B) \\
\sum\limits_{\substack{s_j \in T_i \\ s_j \neq s}} r_{ij}(s_i) + r_{iB}(s_i) = K r(s_i) & (s_i \in N) \\
\sum\limits_{\substack{s_j \in T_i \\ s_j \neq s}} r_{ij}(s) + r_{iB}(s) = \sum\limits_{s_l \in T_i} r_{li}(s) & (s \in N, s_i \neq s) \\
\sum\limits_{s \in N} r_{ij}(s) \le \sum\limits_{k=1 \cdots h} \frac{x_{ij}[k] \cdot W log_2(1+\beta)}{h} & (s_j \in N, s_i \in T_j) \\
\sum\limits_{s \in N} r_{iB}(s) \le \sum\limits_{k=1 \cdots h} \frac{x_{iB}[k] \cdot W log_2(1+\beta)}{h} & (s_i \in T_B)
\end{array}
\right.
\end{array}
$$

With SIC

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Main Idea

$$\begin{array}{ll}
\max & K \\
s.t. & \sum_{s_l\in T_i} x_{li}[k] + \sum_{s_j\in T_i} x_{ij}[k] \le 1 \ (s_i \in N, 1 \le k \le h) \\
 & x_{ij}[k] + \frac{\sum_{s_l\in I_j}^{s_l\neq s_i} \sum_{s_m\in T_l} x_{lm}[k]}{|I_j|-1} \le 1 \ (s_i \in N, s_j \in T_i, 1 \le k \le h) \\
 & \sum_{s_l\in T_i} r_{li} + K r(s_i) = \sum_{s_j\in T_i} r_{ij} \ (s_i \in N) \\
 & r_{ij} \le \frac{1}{h} \sum_{k=1}^{h} (C \cdot x_{ij}[k]) \ (s_i \in N, s_j \in T_i)
\end{array}$$

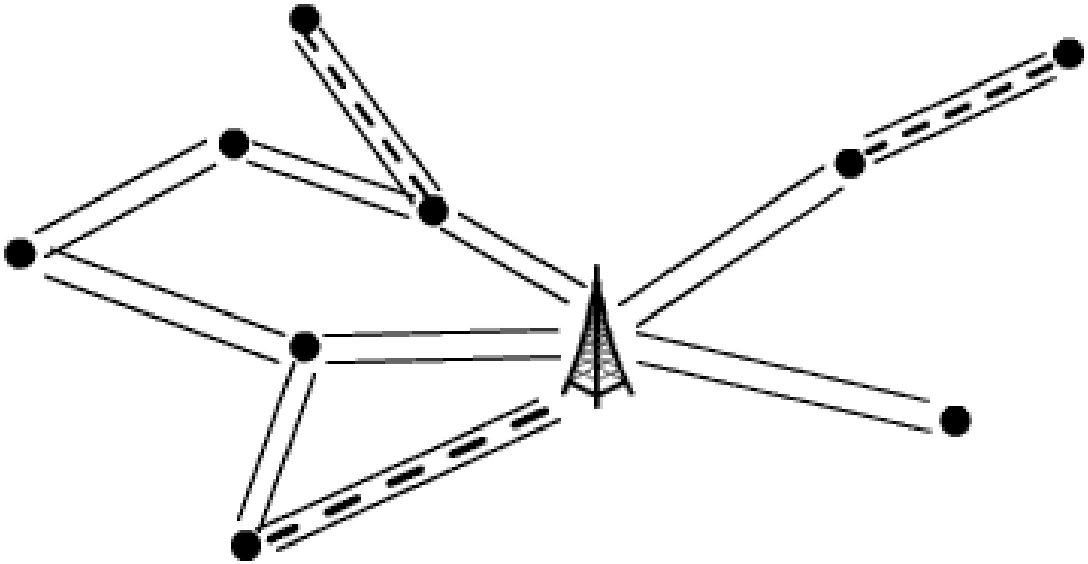
Find a way to determine these $x_{ij}[k]$ values

The original formulation will become a linear programming problem

First Step

Try to Build an initial path to the base station for each node

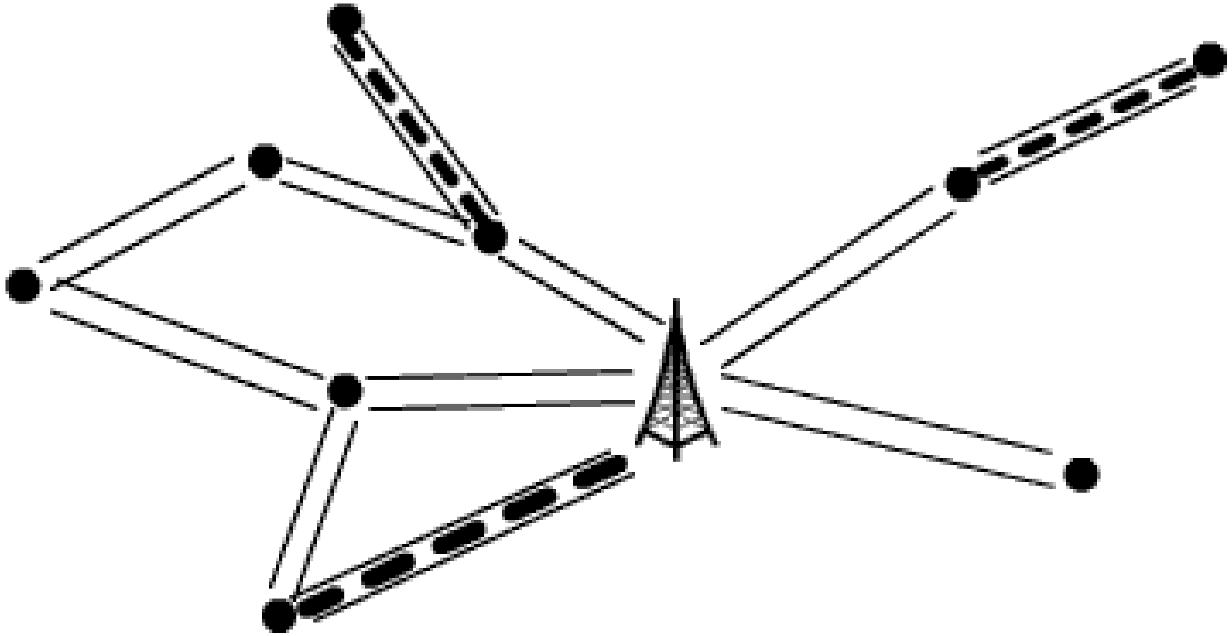
Initialize $K = 0$ and all $x_{ij}[k] = 0$.
For each node, establish an initial path to the base station and time slots assignment for each link on this path, such that the first equation holds and each link has an improved SINR no less than β .



Second Step

Try to find out some way to increase the value *K*

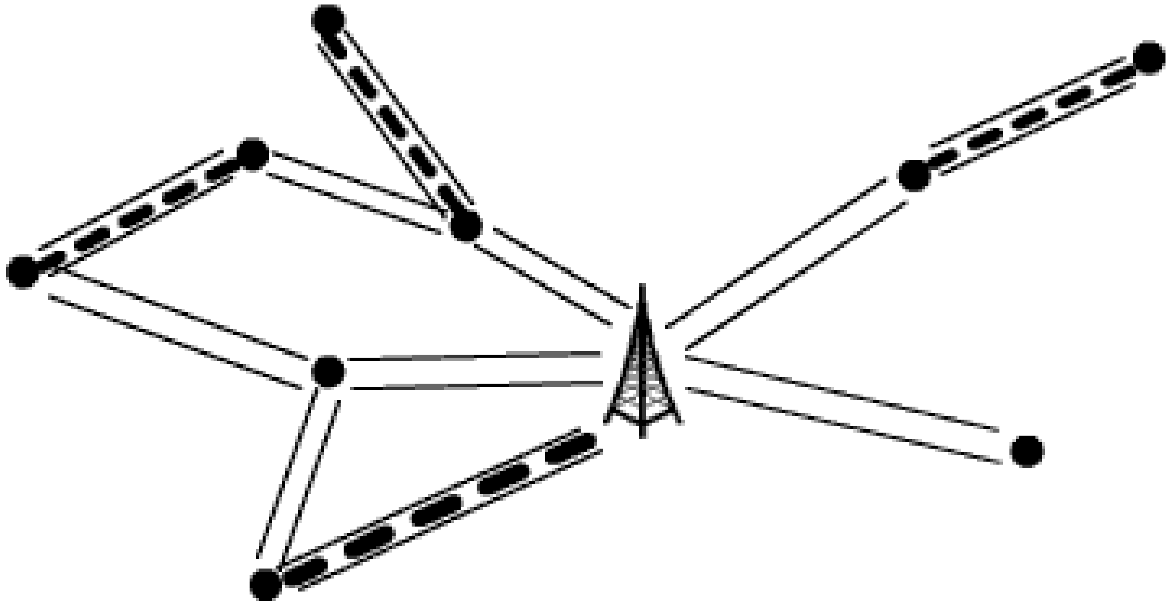
Calculate the maximum *K* and all r_{ij} values. Note that routing solution (r_{ij} values) may be updated and thus *K* may be increased.

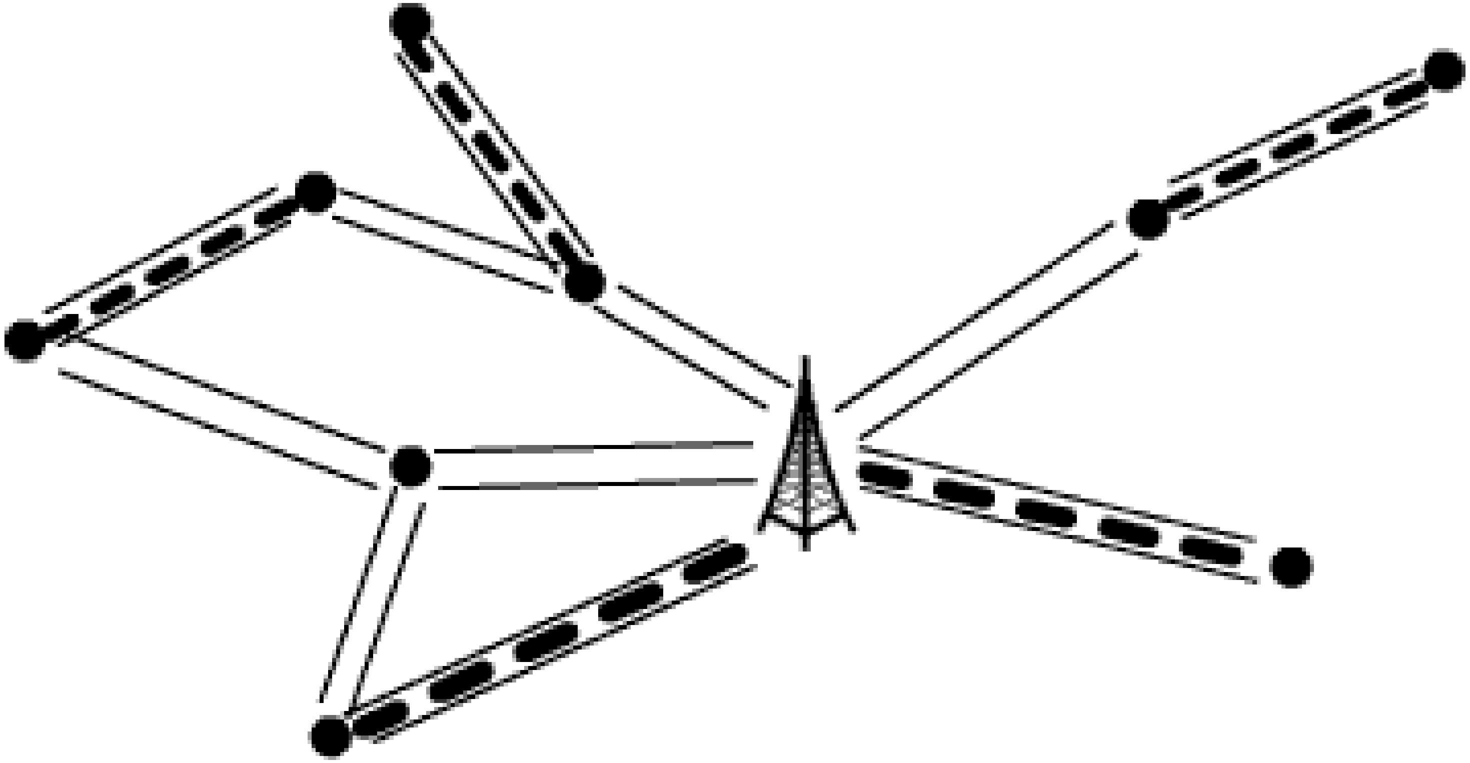


Third Step

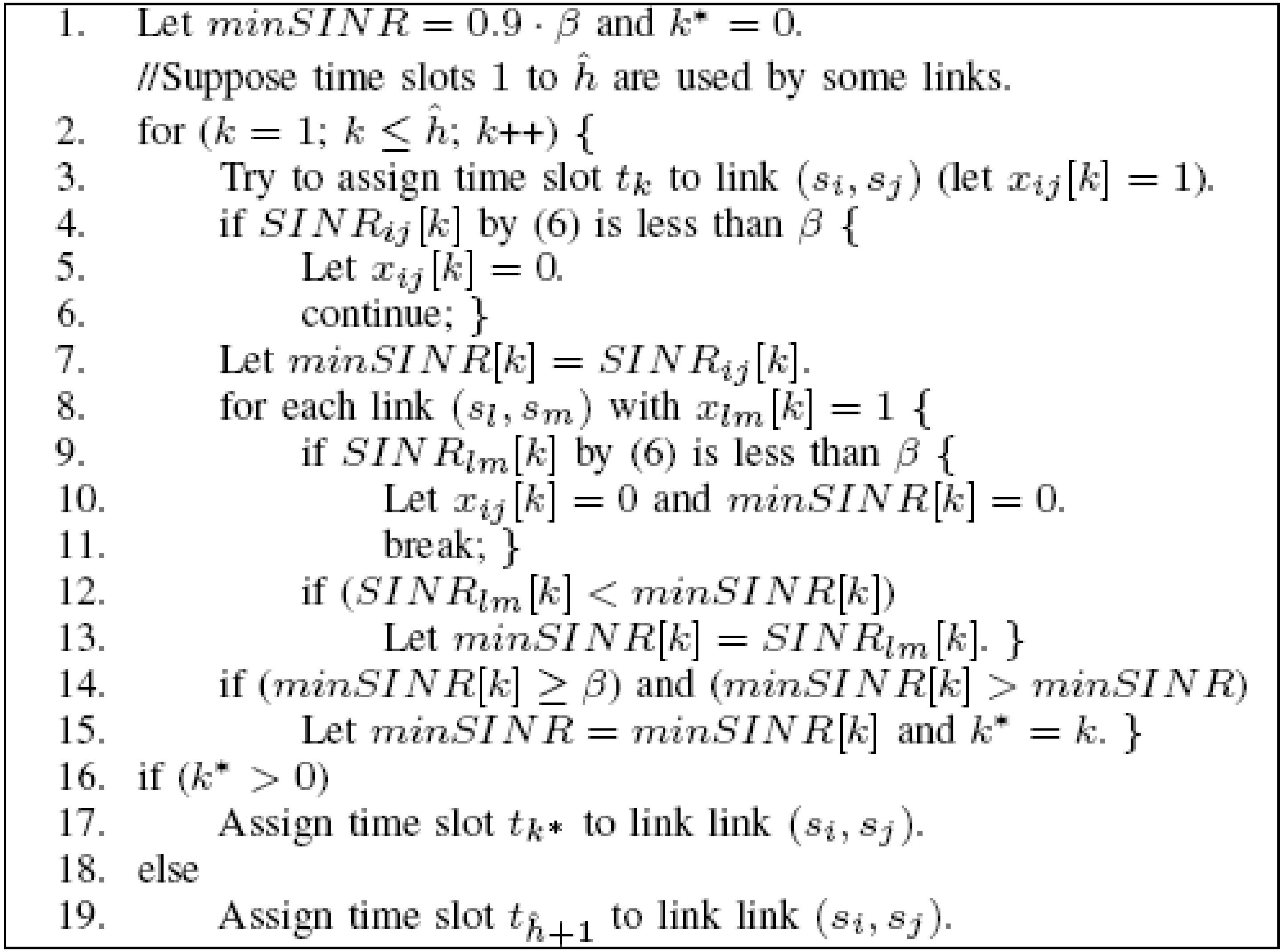
Iterate

If calculated *K* is equal to the previous *K*, then our algorithm terminates. Otherwise, try to improve the current scheduling solution ($x_{ij}[k]$ values) and go to the second step.



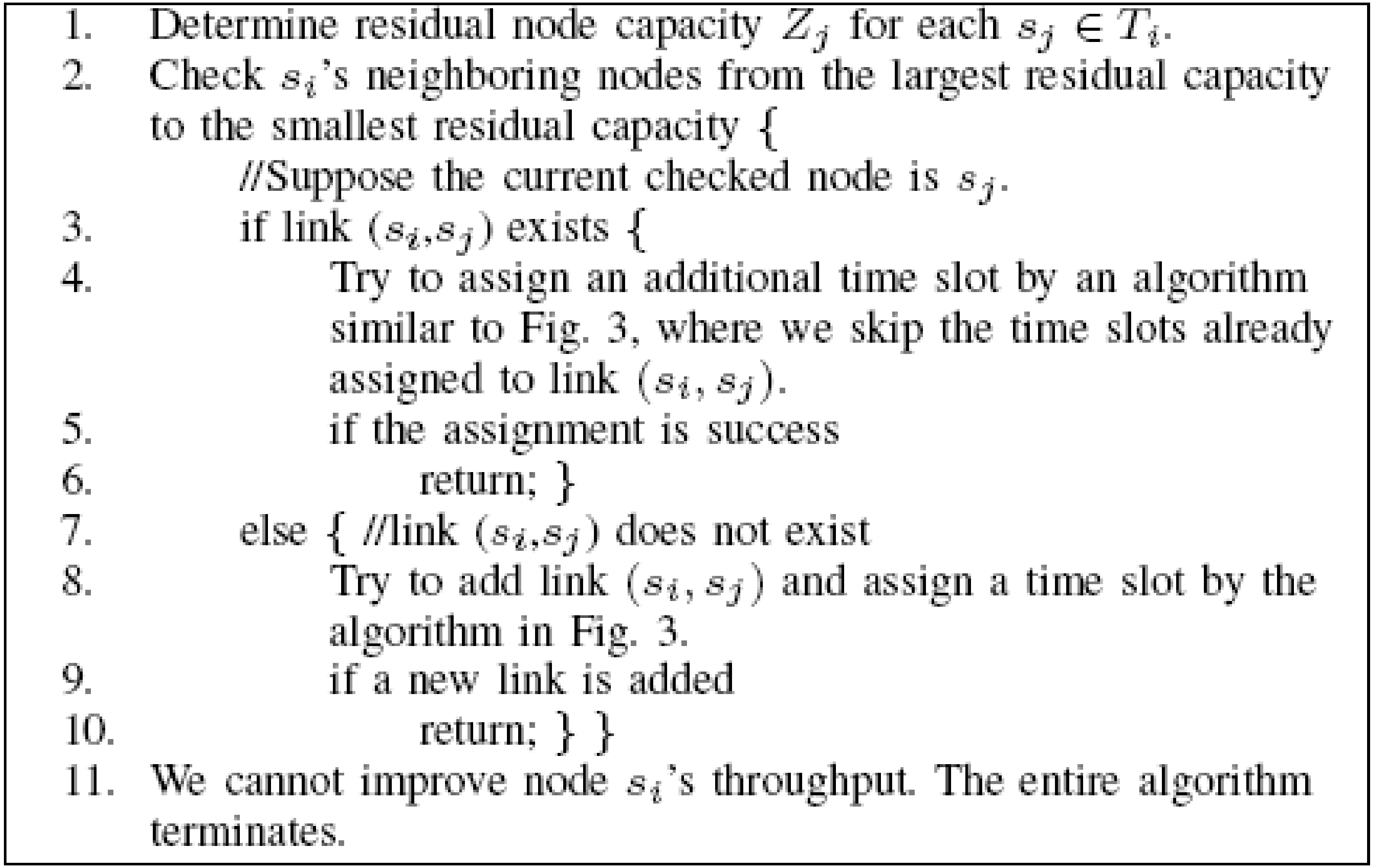


Establish Initial Paths



```
Let $minSINR = 0.9 \cdot \beta$ and $k^* = 0$.
//Suppose time slots 1 to $\hat{h}$ are used by some links.
for ($k = 1$; $k \leq \hat{h}$; $k$++) {
    Try to assign time slot $t_k$ to link $(s_i, s_j)$ (let $x_{ij}[k] = 1$).
    if $SINR_{ij}[k]$ by (6) is less than $\beta$ {
        Let $x_{ij}[k] = 0$.
        continue; }
    Let $minSINR[k] = SINR_{ij}[k]$.
    for each link $(s_l, s_m)$ with $x_{lm}[k] = 1$ {
        if $SINR_{lm}[k]$ by (6) is less than $\beta$ {
            Let $x_{ij}[k] = 0$ and $minSINR[k] = 0$.
            break; }
        if ($SINR_{lm}[k] < minSINR[k]$)
            Let $minSINR[k] = SINR_{lm}[k]$. }
    if ($minSINR[k] \geq \beta$) and ($minSINR[k] > minSINR$)
        Let $minSINR = minSINR[k]$ and $k^* = k$. }
if ($k^* > 0$)
    Assign time slot $t_{k*}$ to link link $(s_i, s_j)$.
else
    Assign time slot $t_{\hat{h}+1}$ to link link $(s_i, s_j)$.
```

Increase Bottleneck Node Throughput



```
1.  Determine residual node capacity $Z_j$ for each $s_j \in T_i$.
2.  Check $s_i$'s neighboring nodes from the largest residual capacity
    to the smallest residual capacity {
        //Suppose the current checked node is $s_j$.
3.      if link ($s_i$,$s_j$) exists {
4.          Try to assign an additional time slot by an algorithm
            similar to Fig. 3, where we skip the time slots already
            assigned to link ($s_i$, $s_j$).
5.          if the assignment is success
6.              return; }
7.      else { //link ($s_i$,$s_j$) does not exist
8.          Try to add link ($s_i$, $s_j$) and assign a time slot by the
            algorithm in Fig. 3.
9.          if a new link is added
10.             return; } }
11. We cannot improve node $s_i$'s throughput. The entire algorithm
    terminates.
```

Complexity

$$O(n^2) + O(n) + O(n^4 + hn^2) + O(n^6) = O(n^6 + hn^2)$$

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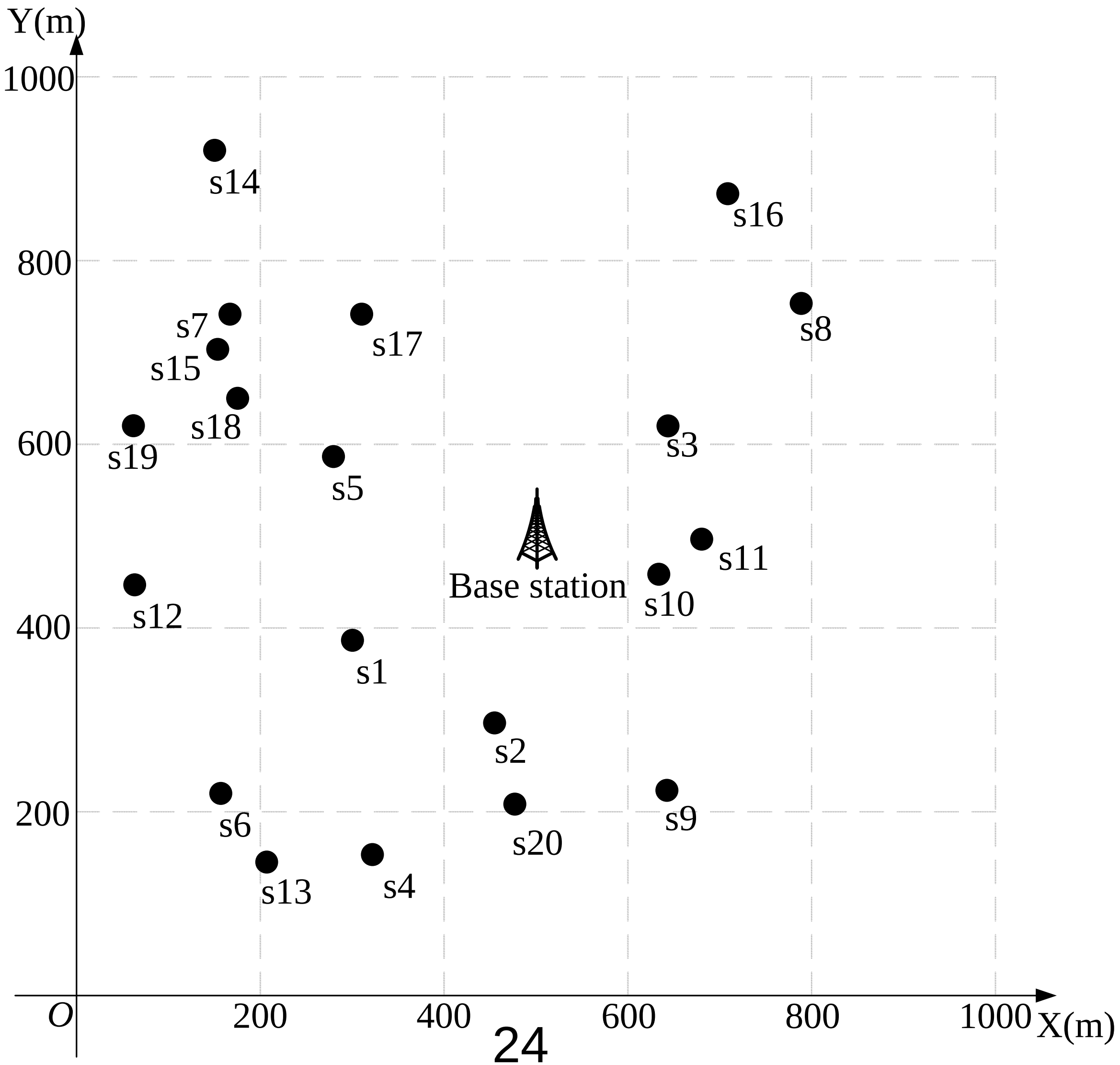
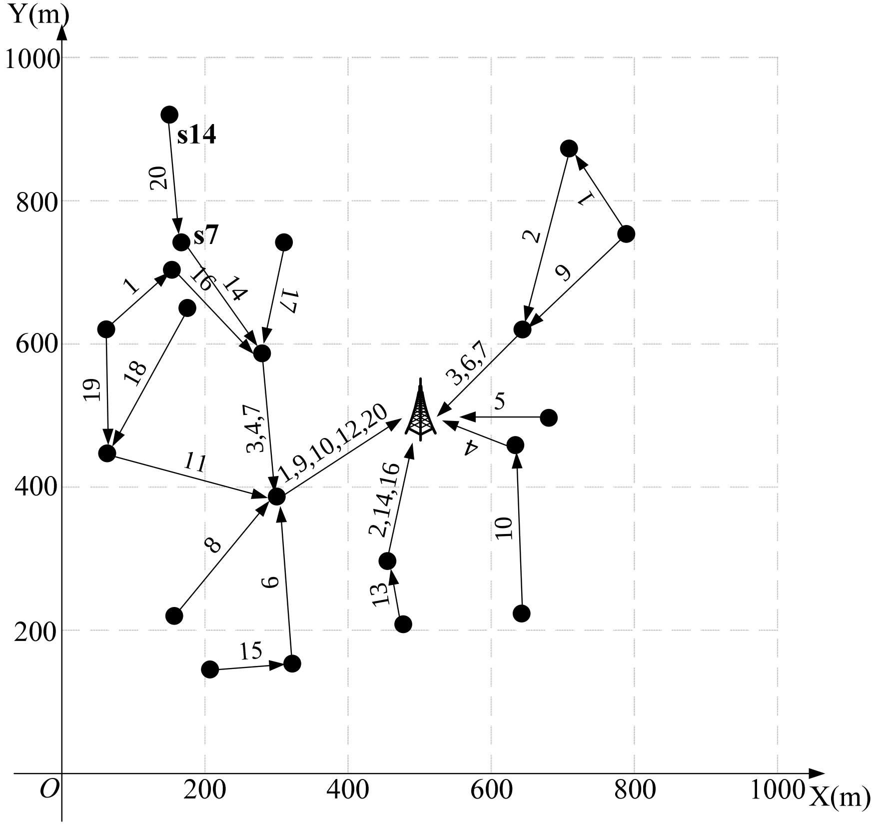
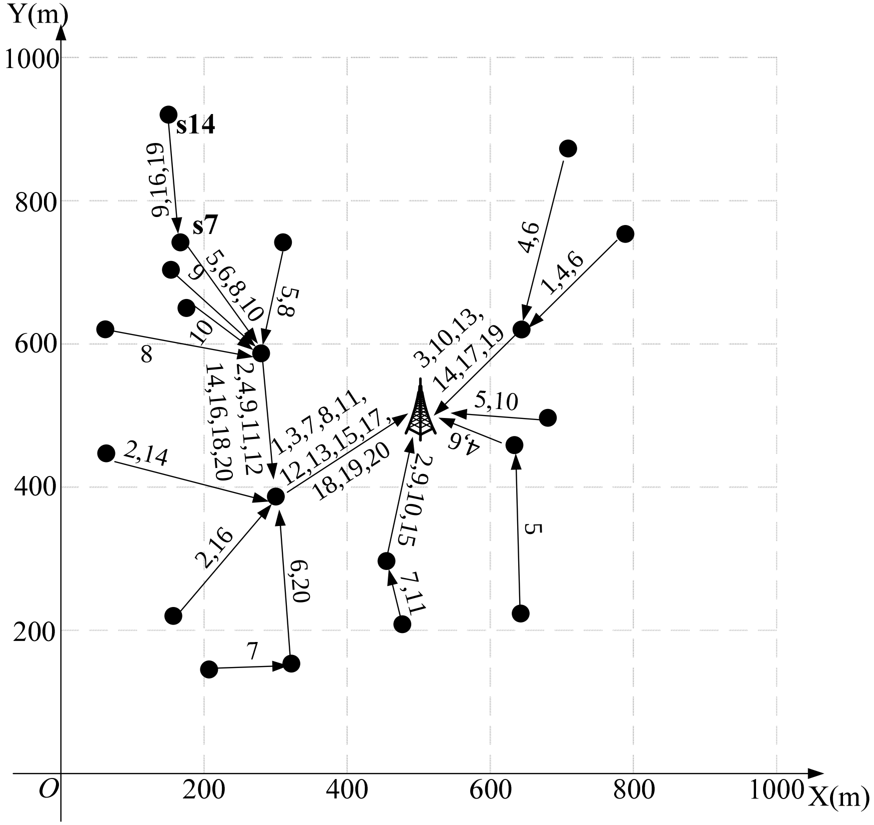
Simulation Results



Simulation Results



$$K = 15.6$$



$$K = 63.9$$

Simulation Results

n	Traditional K	SIC K	Improvement
10	37.8	156.7	314.55%
15	29.8	139.1	366.78%
20	23.2	100.0	331.03%
25	20.0	81.1	305.50%
30	16.7	70.8	323.95%
35	15.8	64.6	308.86%
40	14.9	59.2	297.32%
45	12.5	52.1	316.80%
50	11.7	48.3	312.82%

Summary

- Consider a throughput maximization problem with a cross-layer design (SIC at the PHY layer, time slot assignment at the link layer, and routing at the network layer).
- identify the challenge of this problem: MILP, NP-Hard.
- design an iterative framework to determine time slot assignment efficiently and solve the remaining problem by a linear programming.
- show the overall complexity of our algorithm is polynomial.
- Simulation results show that throughput of a multi-hop wireless network can be increased by about 300% by using SIC.

Thank You!