Master's Thesis Presentation :

Forwarding Capacity of an Infinite Homogeneous Wireless Network

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Outline

- Introduction
- Problem statement
  - Problem decomposition
- Network model
  - Performance measures
  - Network as a graph
- Max-flow min-cut theorem
- Moving window algorithm
- Results
- Conclusions

Introduction

- Large network scenario
  - Average distance between a source and a destination is much larger than the distance between adjacent nodes
  - Paths consist of many hops and the intermediate nodes act as relays
- Geographic routing
  - Based on location information
  - Nodes forward traffic towards the destination
  - Routing around concave nodes
    - Concave nodes do not have neighbors in the direction of the destination

Problem statement

- Problem decomposition
  - Macroscopic level corresponds to the distance between the source and destination nodes
  - Microscopic level corresponds to the distance between neighboring nodes
- Macroscopic level routing
  - Network nodes form a homogeneous, continuous medium
  - Routes are smooth geometric curves
- Microscopic level forwarding
  - Only the direction in which the packet is traversing is significant
  - There exists a maximum flow a given MAC protocol can sustain
  - The capacity can be shared between directions with time sharing
- Task: Find an upper bound for the maximal forwarding capacity

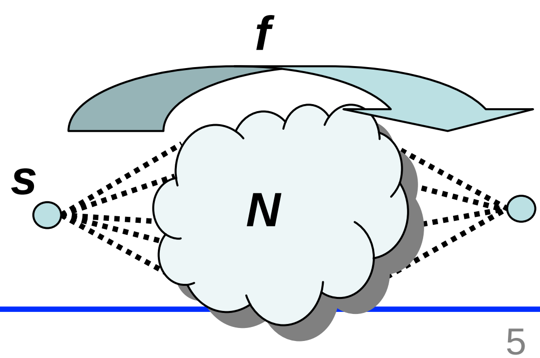
Routing:
• Define the geometric properties of the routes

Direction of packet flow

Forwarding:
• Maximize the packet flow in the given direction

Network model

- Nodes are distributed according to a homogeneous Poisson point process in two dimensions
  - Intensity λ
- Boolean interference model with a common, fixed transmission range R
  - Node can only receive a packet if it hears exactly one transmission
  - No separate interference range
  - Mean number of neighbors: $N_R = \lambda \pi R^2$
- Only relay traffic in single direction
  - Paths are long – mostly relay traffic anyway
  - Different directions by time sharing
- Slotted time



Performance measures

- Single node's point of view
  - Mean progress of a packet, D [m]
  - $D = P$(node transmits) · P(no collision | node transmits)
    · E[progress of a packet | successful transmission]
  - Dimensionless measure: $u = \sqrt{\lambda} \cdot D$
- Network level measure
  - Mean density of progress, I [1/(m · s)]
  - Total progress of packets per area per time
    - Also the number of packets crossing a line of unit length perpendicular to the direction of the packet flow in unit time

$$I = \frac{\lambda \cdot dA \cdot D}{dA \cdot \Delta t} = \frac{\sqrt{\lambda}}{\Delta t} \cdot u$$

Network as a graph

- Network is modeled as a flow network $N = (G,c,s,t)$
  - Nodes and links: $G = (V,E)$, link capacities: c, a source and a sink: s,t
- Schedule $\alpha = \{t_1, \ldots, t_n\}$ assigns each transmission mode L_i with the proportion of time t_i it is used
  - Transmission mode is an independent set of links
  - Capacity of link e is the time share the link is active

$$c(e) = \sum_{i=1}^{n} t_i 1_{\{e \in L_i\}}$$

- Flow f is a mapping $f : E \to \mathbb{R}^+$
  - $0 \leq f(e) \leq c(e)$ for all $e \in E$
  - Flows are preserved at every node (except at the source and the sink)
  - Value of a flow $w(f)$ is the net flow leaving the source (or entering the sink)
- Cut $q = (S,T)$ of N is a partition $V = S + T$ ($V = S \cup T$, $S \cap T = \emptyset$)
  - Capacity of a cut is a sum of the capacities of crossing links

Max-flow min-cut theorem

- (Ford and Fulkerson 1956) The maximal value of a flow on a flow network *N* equals the minimal capacity of a cut in *N*.
- In a wireless case, we have to find the optimal transmission radius and schedule as well

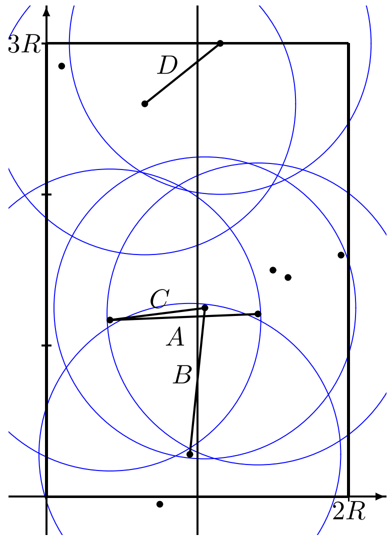
$$\max_{R} \max_{\alpha} \min_{q \in Q} c(q, \alpha; R)$$

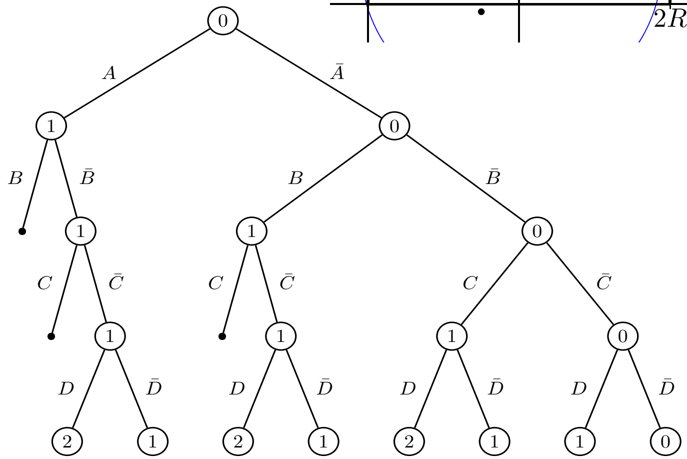
- We get an upper bound for the capacity by examining a smaller set of cuts

$$w(f_R^*) = \max_{\alpha} \min_{q \in Q} c(q, \alpha) \leq \max_{\alpha} \min_{q \in Q' \subset Q} c(q, \alpha)$$

Moving window algorithm

- Let *Q'* consist of one arbitrary cut corresponding to a straight line perpendicular to the direction of the packet flow
  - Maximizing with respect to *α* finds the size of the maximum independent set
- Window separating the links above and below is moved along the line
  - Maximum is found recursively by solving the maximum so far given a combination of active links in the window
  - Leaves of a binary tree represent the possible link combinations and the value assigned to each leaf corresponds to the optimum value



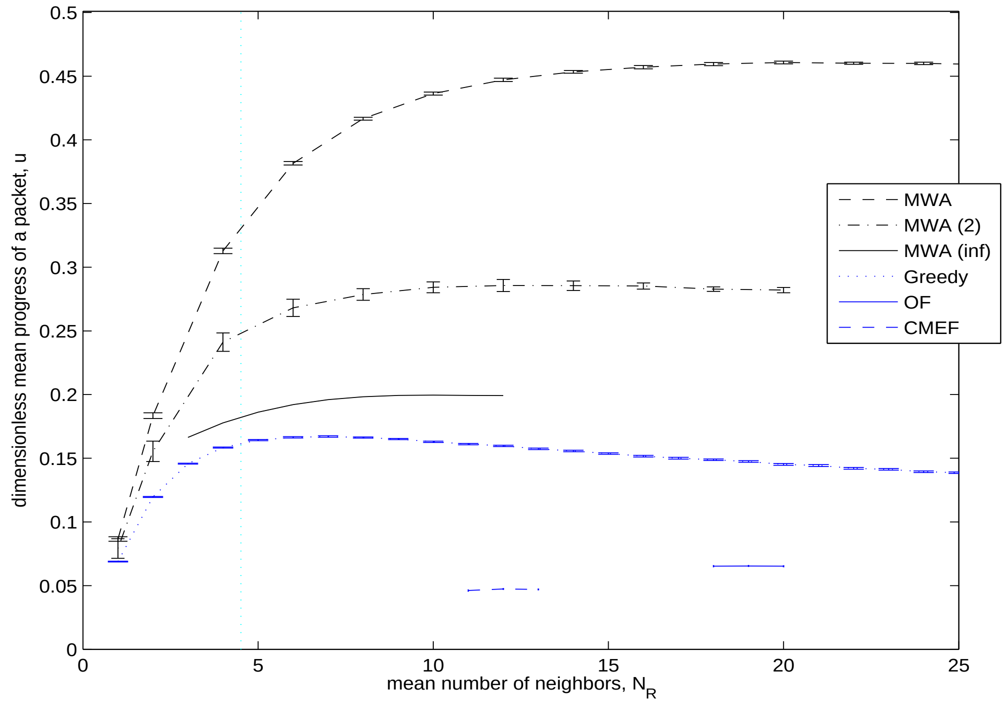


MWA – remarks

- Length of the simulation is not limited
  - The result converges unbiasedly towards the true value
- Capacity of one cut can only be achieved very locally
  - There is no horizontal interference
- We get a tighter upper bound by increasing the number of cuts in *Q’*
- Two cuts:
  - We want to find the distance with maximum interference
- Infinite number of cuts:
  - Number of crossed cuts is proportional to the progress of the link
  - Opposite sides of the window are connected together to form a tube
  - The result is still an upper bound, since the corresponding flow network is not connected
  - Gives the maximum capacity in one time slot

Results

- The results for one, two, and infinite number of cuts
- Greedy methods approximates the case with infinite number of cuts
- OF and CMEF are feasible forwarding methods
  - Actual methods give a lower bound for the maximum capacity
  - Opportunistic forwarding (OF) represents what can be achieved through local coordination



Conclusions

- Large, dense ad hoc network
  - Problem decomposition: Macroscopic (end-to-end) vs. microscopic (adjacent nodes)
  - Poisson Boolean model
  - Maximal forwarding capacity characteristic to the medium
- Augmented Max-flow min-cut theorem
  - Upper bound by examining a limited set of cuts
- The tightest upper bound is still three times the highest achieved dimensionless mean progress