Channel Dynamics Matter: Forwarding Node Set Selection in Cognitive Radio Networks

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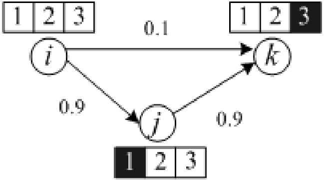
Motivation

- Routing in Cognitive Radio Networks (CRNs): Primary Users + Secondary Users
- Reliability becomes the main concern.
- Opportunistic routing is a promising solution.
  - Nodes do not stick to a particular route.



Problem

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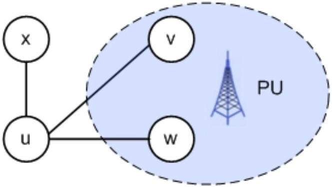
- The answer is negative.
- One problem is the forwarding node set selection.
  - PUs have to be taken into consideration.

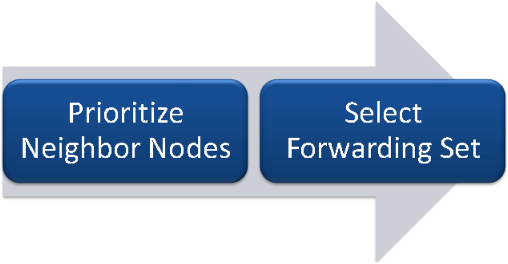


Problem

- Activities of primary users in CRNs are unknown and unpredictable.
- An optimal solution is unrealistic in such a dynamic environment.
- *Challenge*: How to select the forwarding node set in CRNs?

Overview

- To select forwarding sets for each sender, the neighbor nodes need to be prioritized first.
- After defining the weights for each neighbor, the basic algorithm, the greedy algorithm with one backtrack scheme, and the maximum weighted independent set algorithm are proposed.



Forwarding Node Prioritization

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    - Interference from primary users;
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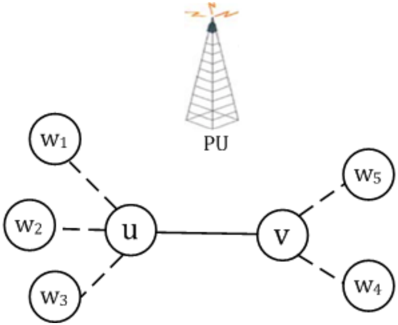


Forwarding Node Prioritization

- We use a conflict probability of adjacent links to a link uv to help define the weight of a forwarding node:

$$C_{uv}(m) = \sum_{w \in N_v} \frac{1}{|M_{uw}|} E_{uw}(m) + \sum_{w \in N_u} \frac{1}{|M_{vw}|} E_{vw}(m),$$

where N_v is the set of neighbor nodes for v; M_{uv} denotes the channels available on link uv, and $M_{uv} = M_u \bigcap M_v$; $E_{uw}(m)$ is a step function with a value of 1 when a channel $m \in m_{uw}$ and is 0 otherwise.

Forwarding Node Prioritization

- Based on the definition of $C_{uv}(m)$, we now define the *receiving ability* of node v from its sender u:

$$R_{uv} = \sum_{m \in M_{uv}} \frac{1}{C_{uv}(m)}.$$

- Obviously, node v, with more channels that are less likely to be used by adjacent links, has a better value of R_{uv}.

Forwarding Node Prioritization

- Finally, for $\forall v \in N_u$, the weight of v to be selected as a FN of u is:

$$W_{uv} = R_{uv}(\sum_{w \in N_v} |M_{vw} - M_{uv}|).$$

- $|M_{vw} - M_{uv}|$ is the number of elements left in M_{vw} after removing the elements in M_{uv} from M_{vw}.
- Nodes that have more non-conflict channels and more links to forward the packets will have a larger weight.

Basic Greedy Algorithm

- Candidates: The forwarding nodes are selected from the downstream neighbors, in terms of ETX (estimated transmission count) metrics.
- The ETX of a single link is:

$$\frac{1}{(1-p_r)\times 1-p_f}$$

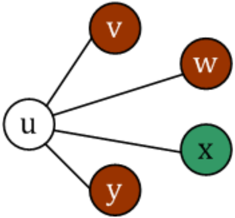
p_r and p_f: the loss probabilities of the link in the forward and reverse directions.

Basic Greedy Algorithm

- Intuitively, the easiest way to select a forwarding set is to apply the greedy algorithm.
- To calculate the forwarding node (FN) set F_u of u:
  - Select the node with the largest weight from the remaining candidates.
- Advantages: *Simple, less complicated, and relatively reliable.*

Greedy Algorithm With One Backtrack

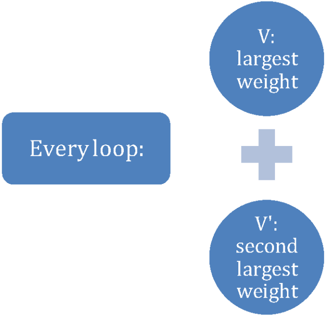
- The basic greedy algorithm is very straightforward and easy to implement.
- However, it is likely that the size of the FN set selected by the greedy algorithm is too small.



- We provide one backtrack scheme for the greedy algorithm.

Greedy Algorithm With One Backtrack

- During every loop in which one node is selected into the FN set by the greedy algorithm, we keep a backtrack node for it.



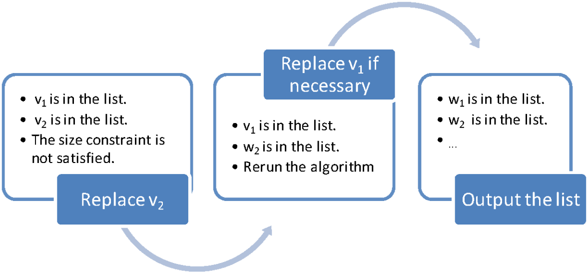
- When necessary, the backtrack scheme will go back one step, replace one element, and rerun the greedy algorithm from that point.

Greedy Algorithm With One Backtrack

- The greedy algorithm for selecting F_u for node u with backtrack list L_B maintained is:
  - Every time a node is selected with the maximum weight, maintain a backup node with the second maximum weight;
  - The backup node is later used for backtrack.
- Overlap is *possible* between the two lists, F_u and L_B.

Greedy Algorithm With One Backtrack

- When the F_u cannot meet the requirement, e.g, the size requirement τ, the backtrack algorithm is used.
  - Starting from the end of the FN list, replace with the corresponding backup node;
  - Repeat the greedy algorithm until the size constraint is satisfied.



Greedy Algorithm With One Backtrack

Some highlights are:

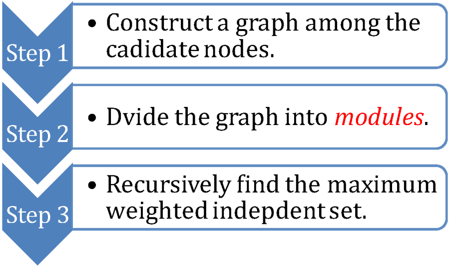
- We use the size requirement, which can be extended for other requirements.
- We only maintain one backtrack list here. Of course, more backtrack lists can be maintained, if one cannot find the appropriate FN set.
- The complexity of this backtrack scheme is low, since only one node is maintained for each node in the FN set.

Maximum Weighted Independent Set Algorithm

- The previous two algorithms cannot ensure that the selected FN set is the one with the maximum weight.
- Next part $\rightarrow$ the algorithm that gives the optimal result as of the overall weight.

Maximum Weighted Independent Set Algorithm

The process of the Maximum Weighted Independent Set Algorithm is:



Maximum Weighted Independent Set Algorithm

First, here are two definitions:

Definition

Given node u, its neighbor set N_u, and the distance threshold σ, we define a graph $G_u(\sigma)$, where

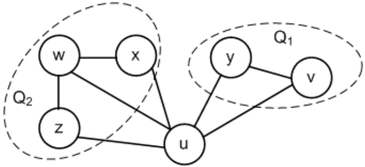
1. v is a vertex in $G_u(\sigma)$, iff $v \in N_u$, v is smaller of ETX to the destination than u and satisfies ETX constraint;
2. an edge exists between two vertices, v and w, in $G_u(\sigma)$ iff $d_{vw} > \sigma$,

Definition

Given a $G_u(\sigma)$, suppose U is a subset of the vertex in $G_u(\sigma)$. For a node v, which is a vertex of $G_u(\sigma)$ and $x \notin U$, x "distinguishes" U if x has both a neighbor and a non-neighbor in U. U is a *module* if it is indistinguishable for the vertices outside U.

Maximum Weighted Independent Set Algorithm

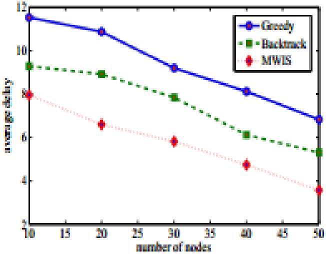
- An example for modules in a graph:

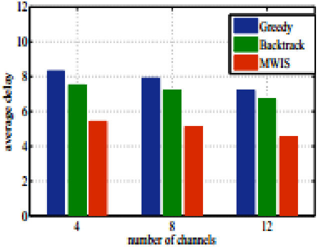


- The node x distinguishes the node set $\{z, w\}$, since x has both a neighbor and a non-neighbor in $\{z, w\}$. x cannot distinguish the node set $\{y, v\}$ since neither y nor v is x's neighbor.
- *Two modules*: $Q_1 = \{y, v\}$ and $Q_2 = \{z, w, x\}$.

Performance Evaluation

- We compare the three algorithms by varying different network parameters:





Conclusion

- We consider the FN set selection problem in CRNs under the opportunistic routing.
- Three algorithms are proposed: the basic algorithm, the greedy algorithm with one backtrack scheme, and the maximum weighted independent set algorithm.
- The simulation results show desirable performance of our algorithms.

Thank you!