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Principles of Distributed Computing
Exercise 5: Sample Solution

1 Greedy Dominating Set

Our worst-case graph $G_x = (V_x, E_x)$ for $x \in \mathbb{N}$ is defined as follows. The node set V_x consists of a node r, x nodes $u_1, \ldots, u_x$, $2^{x+1} - 2$ nodes $v_{k\ell}$ for all $k \in \{1, \ldots, x\}$ and $\ell \in \{1, \ldots, 2^k\}$, and the two nodes w_1 and w_2. There are edges between r and the nodes u_i for all $i \in \{1, \ldots, x\}$. Each node u_i is further connected to all nodes $v_{k\ell}$ for which $i = k$. Moreover, w_1 is connected to all nodes $v_{k\ell}$ for which $\ell \leq 2^{k-1}$, and w_2 is connected to all nodes $v_{k\ell}$ for which $\ell > 2^{k-1}$. As an example, the graph G_3 is given in Figure 1.

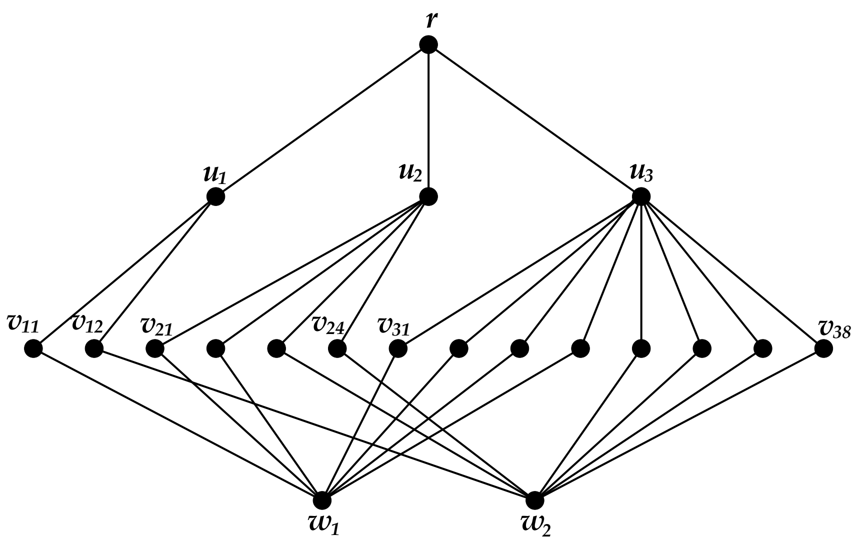

Figure 1: The graph G_3.

Note that the number of nodes of G_3 is $3 + x + (2^{x+1} - 2) = 2^{x+1} + x + 1 \leq 2^{x+2}$. The degree $\delta(r)$ of r is exactly x. We further have that $\delta(u_i) = 2^i + 1$, $\delta(v_{k\ell}) = 2$, and $\delta(w_1) = \delta(w_2) = 2^x - 1$.

In the first round, only u_x is chosen, because it has the largest degree. Let $\delta^{(i)}(v)$ denote the number of *white* (i.e., uncovered) nodes in round 2. After the first round, we have that $\delta^{(2)}(u_i) = 2^i$ for all $i \in \{1, \ldots, x-1\}$ and $\delta^{(2)}(w_1) = \delta^{(2)}(w_2) = 2^{x-1} - 1$. This means that only node u_{x-1} is chosen in round 2. Inductively, we get that only node u_{x-i+1} is chosen in round i, as $\delta^{(i)}(u_{x-i+1}) = 2^{x-i+1} > \delta^{(x-i+1)}(w_1) = \delta^{(x-i+1)}(w_2) = 2^{x-i+1} - 1$ for all $i \in \{2, \ldots, x-1\}$. In round x, we have that $\delta^{(x)}(u_1) = \delta^{(x)}(v_{11}) = \delta^{(x)}(v_{12}) = 2$, thus identifiers have to be used to decide which nodes join the DS. In the worst case, three nodes, e.g., w_1, w_2, and u_1, are chosen to complete the DS.

Overall, $x + 2$ nodes are chosen. The optimal DS consists only of the nodes r, w_1, and w_2, hence the approximation ratio is

$$\frac{x+2}{3} \geq \frac{\log n}{3} \in \Omega(\log n).$$

2 Fast Dominating Set

We describe the messages a node v executing Algorithm 21 sends and receives. Note that the local computation necessary to compute the messages is omitted.

Algorithm 1 Fast Distributed Dominating Set Algorithm (at node v):

send ID to neighbors; receive IDs from neighbors
no communication
no communication
send $\tilde{w}(v)$ to neighbors; receive $\tilde{w}(u)$ from neighbors; forward $\tilde{w}(u)$ to neighbors; receive $\tilde{w}(u)$ from 2-hop neighbors
no communication
send $v.active$ to neighbors; receive $u.active$ from neighbors
send $s(v)$ to neighbors; receive $s(u)$ from neighbors
no communication
no communication
no communication
no communication
send $v.candidate$ to neighbors; receive $u.candidate$ from neighbors
send $c(v)$ to neighbors; receive $c(u)$ from neighbors
no communication
no communication;
send $v.joined$ to neighbors; receive $u.joined$ from neighbors; send $v.white$ to neighbors; receive $u.white$ from neighbors
no communication;

Eight communication rounds are necessary for each phase.

3 Dominating Set on Regular Graphs

a) The number of steps each node has to execute is constant, thus the time complexity of this algorithm is $O(1)$.

b) A node can join the DS either in Step 1 or in Step 5. The probability that a node joins the DS in Step 1 is $\frac{\ln(\delta+1)}{\delta+1}$. The probability that a node joins the DS in Step 5 equals the probability that it neither joined the DS in step 1, nor has any neighbors that joined the DS in Step 1. This probability is $(1 - \frac{\ln(\delta+1)}{\delta+1})^{\delta+1} \leq \frac{1}{\delta+1}$. The expected size of the DS is hence

$$n \cdot (Pr[node\ joins\ in\ Step\ 1] + Pr[node\ joins\ in\ Step\ 5]) \leq \frac{n(\ln(\delta+1)+1)}{\delta+1}.$$

c) In an optimal dominating set DS* there is at least one node per $\delta + 1$ nodes, since no node can dominate more than $\delta + 1$ nodes, i.e., $|\mathrm{DS}^*| \geq \lceil \frac{n}{\delta+1} \rceil$. Consequently, the expected approximation ratio of this algorithm is

$$\mathbb{E}\left[\frac{|DS|}{|DS^*|}\right] \leq \frac{n(\ln(\delta+1)+1)/(\delta+1)}{n/(\delta+1)} = \ln(\delta+1) + 1.$$