Broadcasting in an Unreliable SINR Model

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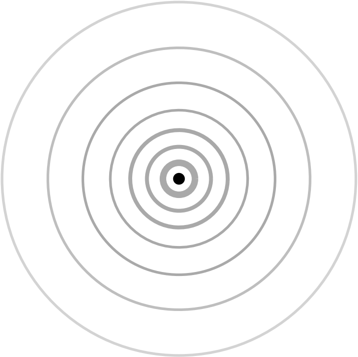
Signal Propagation in the SINR Model

Signal with transmission power P **fades with distance** from source.



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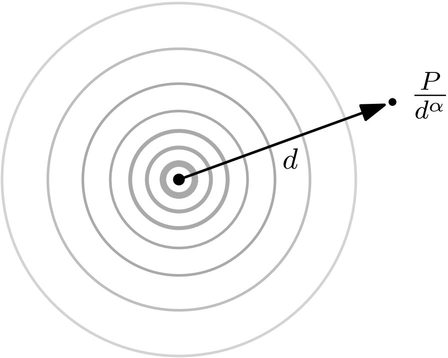

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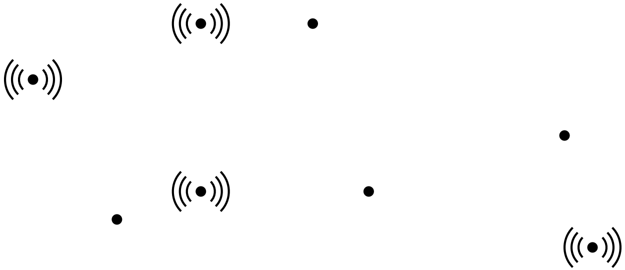
Nodes *either send or listen*. Set of *interfering nodes* I.



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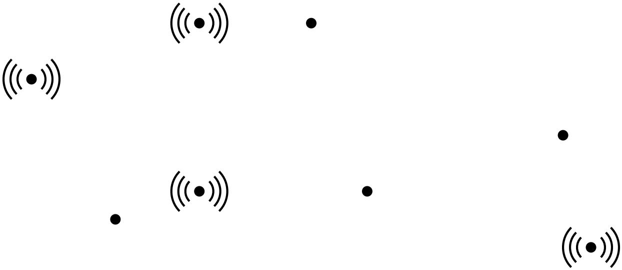

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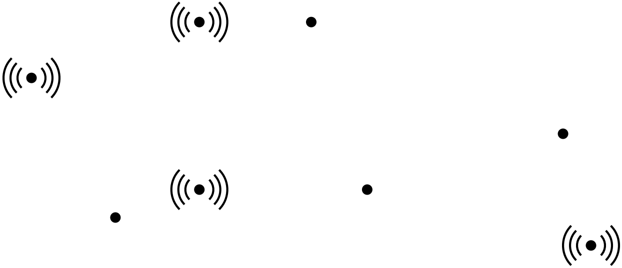

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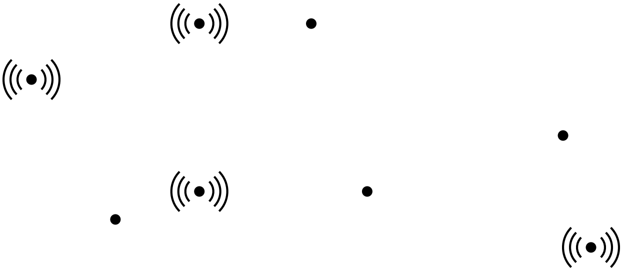

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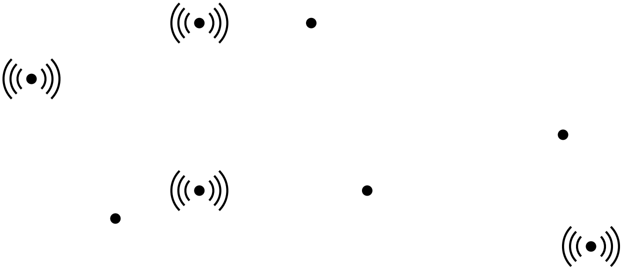

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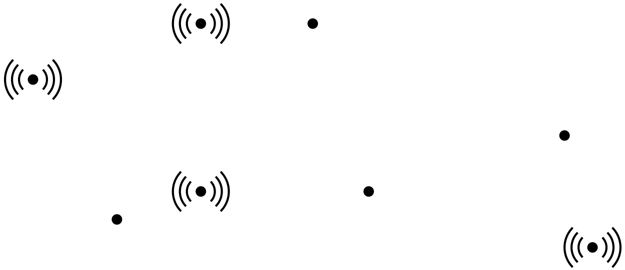

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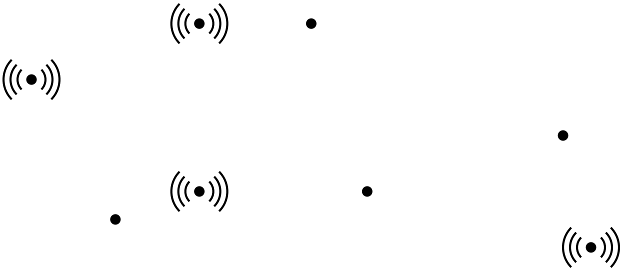

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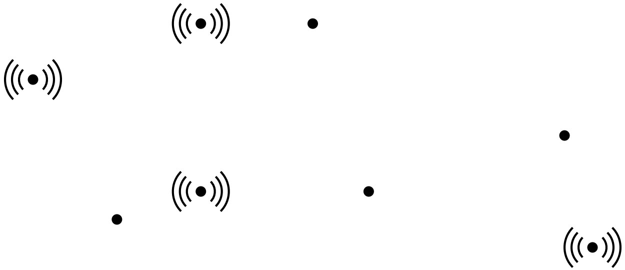

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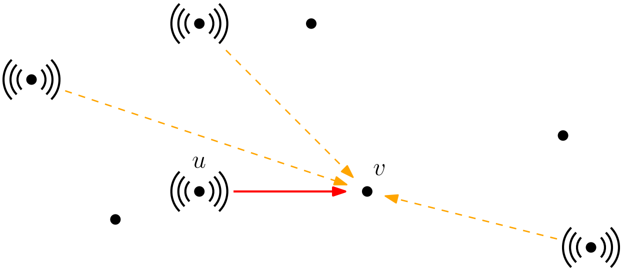

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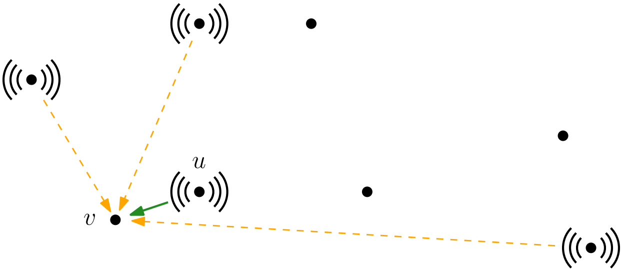


Transmission!

Modeling Choices

Minimal assumptions:

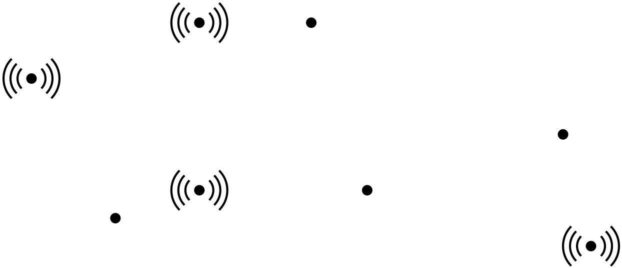
- No geometric information.
- No power control.
- No additional capabilities (e.g. carrier sensing).

Model Extension: Unreliable SINR Model

Silent node v receives transmission from sender u if and only if

$$\mathrm{SINR}(u,v,I) := \frac{P/d(u,v)^{\alpha}}{N + \sum_{w \in I} P/d(w,v)^{\alpha}} \geq \beta_v$$

Adversary chooses $\beta_v \in [\beta_{\min}, \beta_{\max}]$ for each transmission.



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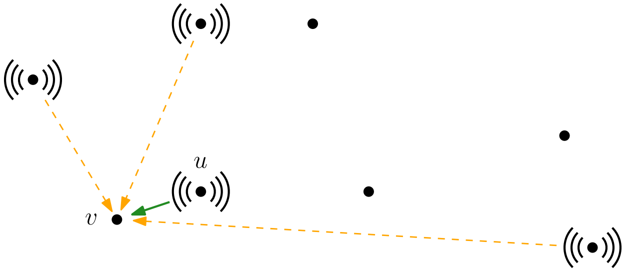

Safe Transmission!

Model Extension: Unreliable SINR Model

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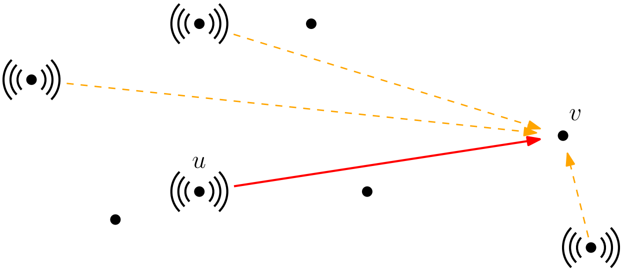

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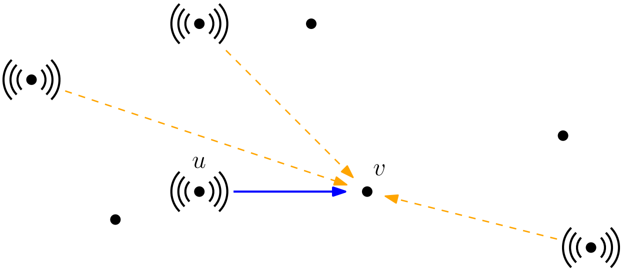

Adversary decides!

Adversary Motivation

In standard SINR models message reception is subject to a *deterministic* function.

- Real wireless transmission is *inherently unstable and unreliable*.
- Adversary adds a *dynamic* component.
- The proposed adversarial model captures a seemingly stronger adversary that manipulates *all* SINR-parameters (P, N, α, β).

The Broadcast Problem

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Communication graph

$G_C := (V, \{\{u,v\} \mid u,v \in V, u \neq v, d(u,v) \leq r_e\})$. Defined by the set of edges among nodes within *effective communication range* r_e of each other.

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Observation: *Global Broadcast* can be solved by solving *Neighborhood Dissemination* D times where D is the *diameter* of G_C.

Solution Requirements

We want a *robust* randomized algorithm to solve broadcast, that works

- ... *with high probability* (w.h.p.),
  that is with probability at least $1 - \frac{1}{n^c}$, for constant c and $n := |V|$.
- ... for *any strategy* of the adversary.

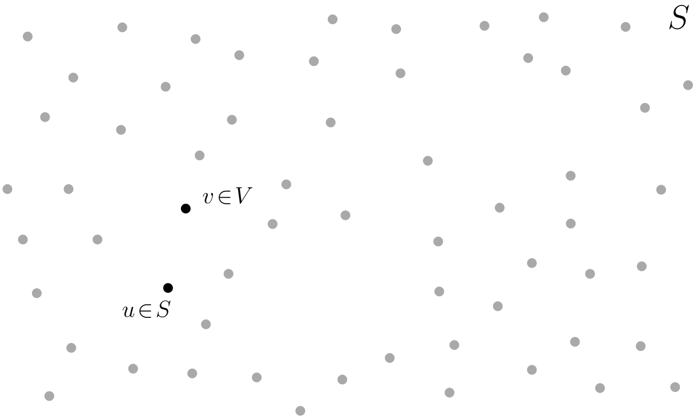
Previous Results and Our Result

Paper	Model	Broadcast
Daum et al., 2013	Reliable SINR	$\mathcal{O}\left(D \cdot \log n \cdot \log^{\star} n \cdot \operatorname{polylog} R\right)$
Jurdzinski et al., 2014	Reliable SINR	$\mathcal{O}(D \cdot \log^2 n)$
Halldórsson et al., 2015	Reliable SINR	$\mathcal{O}\left((D + \log n) \cdot \operatorname{polylog} R\right)$
This paper	Unreliable SINR	$\mathcal{O}\left(\frac{\beta_{\max}}{\beta_{\min}} \cdot D \cdot \log n \cdot \log^{\star} n \cdot \operatorname{polylog} R\right)$

R is the ***Ratio*** between the length of the *longest and shortest edge* in G_C.

Communication Among Relatively Close Nodes

Lemma [cf. Daum et al., 2013]: Nodes $S \subseteq V$ send with probability p. If nodes $u \in S, v \in V$ are closer than a constant multiple of $d^S_{\min}$ and are in safe transmission range r_s of each other then a safe transmission from u to v takes place with *constant* probability $\mu \in (0, p)$.



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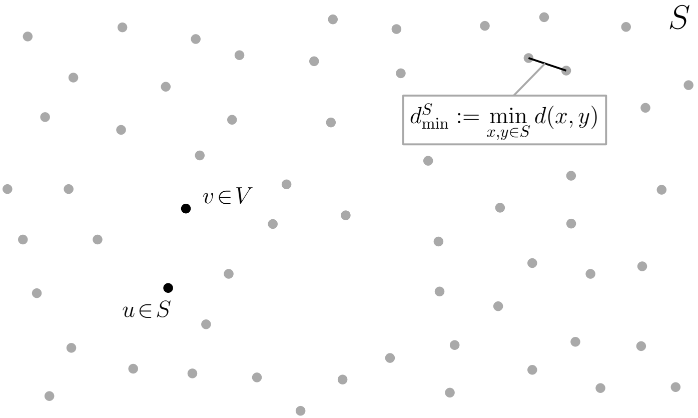

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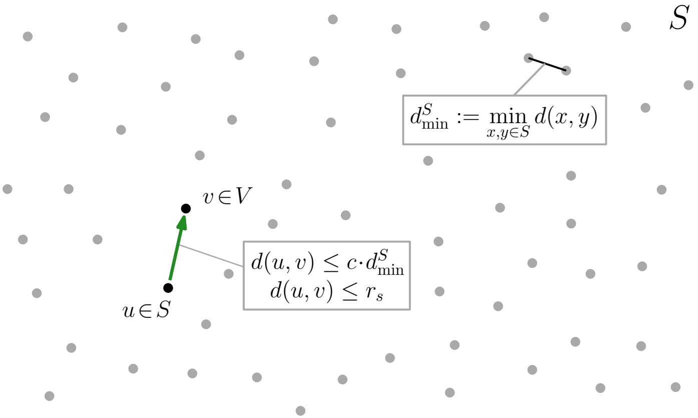

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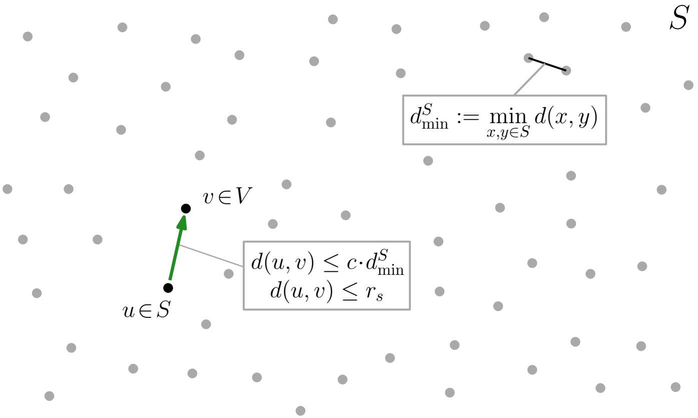

Neighborhood Dissemination Algorithm

Algorithm ROBUSTDISSEMINATION

For phase $\phi = 1$ to $\Theta(\log R)$ do:

1. S_ϕ sends with prob. $\frac{p}{Q}$ for $\mathcal{O}(Q \log n)$ rounds $(S_1 := S)$
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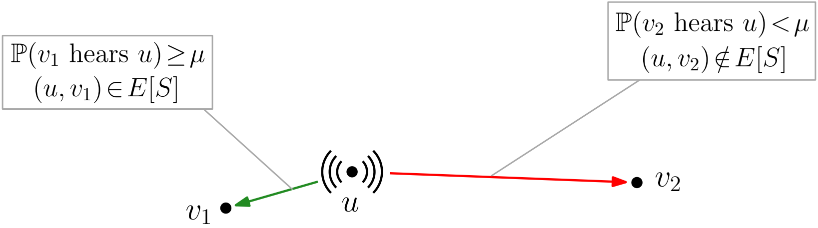
- **Lemma**: Neighbors of S_ψ receive $\mathcal{M}$.

SINR-Induced Graphs - Without Adversary

$S \subseteq V$: sending with probability p.

$H[S]$ has **nodes** S and **reliable edges** $E[S]$.

$E[S]$ contains (u, v) iff **v receives message from u with probability** $\geq \mu$.



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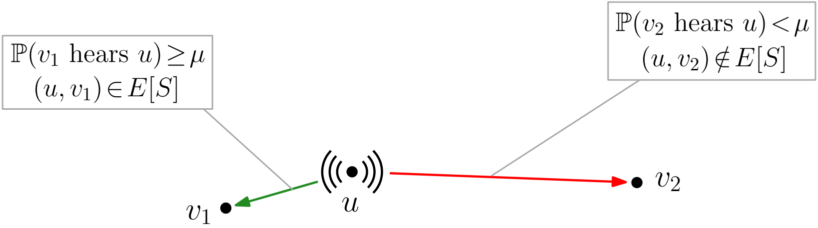

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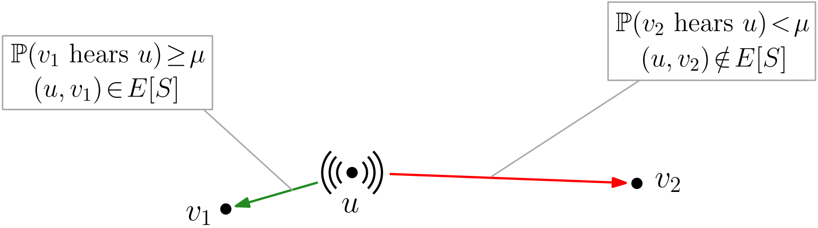

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Constant degree of $\Delta \leq 1/\mu$.

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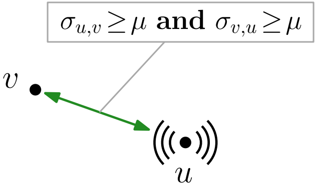

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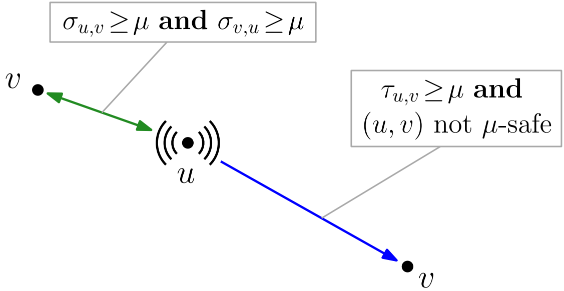
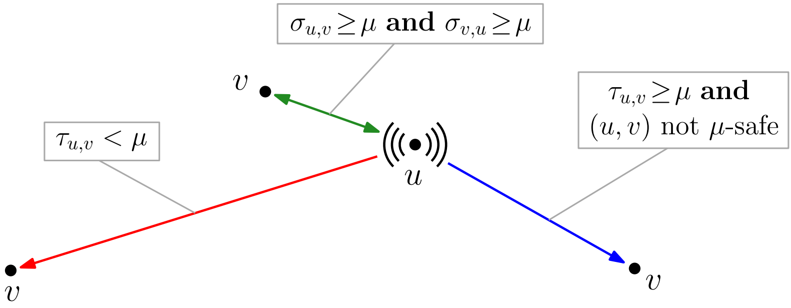
- $H[S]$ **contains all** μ-safe edges
- $H[S]$ **may contain** μ-unsafe edges (adversary decides)



SINR-Induced Graphs - With Adversary

$\sigma_{u,v} := \mathbb{P}\big(SINR(u,v,I) \geq \beta_{\max}\big) \quad \tau_{u,v} := \mathbb{P}\big(SINR(u,v,I) \geq \beta_{\min}\big).$

- $H[S]$ **contains all** μ-safe edges
- $H[S]$ **may contain** μ-unsafe edges (adversary decides)
- $H[S]$ **does not contain any** other edges



SINR-Induced Graphs - Computation

- $H[S]$ **cannot be pre-computed** due to the adversary.
- Instead provide **sub-procedure** TRANSMIT that nodes in S execute.
- For pair $u, v \in S$ participating in TRANSMIT:
  - If $\{u, v\}$ is μ-safe: Message transmitted.
  - If (u, v) is μ-unsafe: Adversary decides.
  - Otherwise: Message not transmitted.
- $\Rightarrow$ **Edges along which transmission takes place induce** $H[S]$.
- TRANSMIT **probes edges** by sending with prob. p for $\mathcal{O}(\log n)$ rounds.
- TRANSMIT **allows transmission** if sufficiently many probes were successful.

Dominating Independent Set

Dominating Independent Set (DIS) [Censor-Hillel et al., 2014]

Let $G = (V, E, E')$ be a graph with disjoint edge sets E and E'. A *DIS* $D \subseteq V$ of G is *independent* w.r.t. E and *dominating* w.r.t. $E \cup E'$.

Independent Set: Let $G = (V, E)$ be a graph. $Ind \subseteq V$ of G is *independent* if for all $u, v \in Ind$ there is **no** edge $\{u, v\} \in E$.

Dominating Set: Let $G = (V, E')$ be a graph. $Dom \subseteq V$ of G is *dominating* if for all $v \in V \setminus Dom$ there is a node $u \in Dom$ and an edge $(u, v) \in E'$.

Dominating Independent Set of $H[S]$

Edges $E[S]$ of $H[S]$ can be partitioned into

- $E_{\text{safe}}[S]$: μ-safe edges
- $E_{\text{unsafe}}[S]$: μ-unsafe edges .

Algorithms ComputeDIS($S, E_{\text{safe}}[S], E_{\text{unsafe}}[S]$)

---

1. Combine algorithm by [Linial, 1992] with Transmit:
   Obtain $\mathcal{O}(1)$-coloring w.r.t. $E_{\text{safe}}[S]$ in $\mathcal{O}(\log n \log^\star n)$ rounds.
2. For each color do
   3. Active nodes of current color join DIS ...
   4. ... and deactivate their neighbors via Transmit in $\mathcal{O}(\log n)$.

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Neighbors w.r.t. $E_{\text{safe}}[S]$ are differently colored $\Rightarrow$ **Independence w.r.t. $E_{\text{safe}}[S]$**.

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Neighbors w.r.t. $E_{\text{safe}}[S]$ are differently colored $\Rightarrow$ **Independence w.r.t. $E_{\text{safe}}[S]$**.

Node deactivated via Transmit $\Rightarrow$ **Node dominated w.r.t. $E_{\text{safe}}[S] \cup E_{\text{unsafe}}[S]$**.

Summary

Algorithm ROBUSTDISSEMINATION

For phase $\phi = 1$ to $\Theta(\log R)$ do:

1. S_ϕ sends with prob. $\frac{p}{Q}$ for $\mathcal{O}(Q \log n)$ rounds $\quad \mathcal{O}\left(\log n \cdot \text{polylog}(R) \cdot \frac{\beta_{\max}}{\beta_{\min}}\right)$
2. Determine DIS $S_{\phi+1}$ of $H[S_\phi]$ $\quad \mathcal{O}\left(\text{polylog}\, n\right)$

Property 1: There exists Q such that nodes in $N(S)$ that did not receive $\mathcal{M}$ yet, still have a neighbor in S_ϕ. $\quad Q \in \mathcal{O}\left(\text{polylog}\, R \cdot \frac{\beta_{\max}}{\beta_{\min}}\right)$

Property 2: In final phase ψ remaining active nodes S_ψ are 'sparse'
$\Rightarrow$ all neighbors of S_ψ receive $\mathcal{M}$ (Lemma).

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For phase $\phi = 1$ to $\Theta(\log R)$ do:

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2. Determine DIS $S_{\phi+1}$ of $H[S_\phi]$ — $\mathcal{O}\left(\text{polylog}\, n\right)$

Property 1: There exists Q such that nodes in $N(S)$ that did not receive $\mathcal{M}$ yet, still have a neighbor in S_ϕ. $Q \in \mathcal{O}\left(\text{polylog}\, R \cdot \frac{\beta_{\max}}{\beta_{\min}}\right)$

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Summary

Algorithm RobustDissemination

For phase $\phi = 1$ to $\Theta(\log R)$ do:

1. S_ϕ sends with prob. $\frac{p}{Q}$ for $\mathcal{O}(Q \log n)$ rounds $\quad \mathcal{O}\left(\log n \cdot \text{polylog}(R) \cdot \frac{\beta_{\max}}{\beta_{\min}}\right)$
2. Determine DIS $S_{\phi+1}$ of $H[S_\phi]$ $\quad \mathcal{O}\left(\text{polylog}\, n\right)$

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$\Rightarrow \mathcal{O}\left(\text{polylog}(n+R) \cdot \frac{\beta_{\max}}{\beta_{\min}}\right)$ rounds to solve neighborhood dissemination.

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$\Rightarrow \mathcal{O}\left(\text{polylog}(n+R) \cdot \frac{\beta_{\max}}{\beta_{\min}}\right)$ rounds to solve neighborhood dissemination.
$\Rightarrow \mathcal{O}\left(D \cdot \text{polylog}(n+R) \cdot \frac{\beta_{\max}}{\beta_{\min}}\right)$ rounds to solve broadcast in the **Unreliable Model**.

Thank you.

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