Estimating the Kaspa Node Population via Capture–Recapture

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Status: Draft

1 Abstract

We present a practical methodology to estimate the total number of nodes participating in the Kaspa P2P network. Because many nodes are non-listening (NATed or firewalled) and because vantage-point sampling induces visibility bias, naïve counts of publicly reachable nodes are underestimates. We combine multiple independent samples of publicly listening peers and apply a classical capture–recapture estimator (Chapman variant of Lincoln–Petersen), then correct for visibility with reasonable assumptions about (i) the fraction of all nodes that are listening and (ii) the coverage of a sampling pass. On the study date, the two-pass listener estimate was $\hat{N}_L = 347$ with **95% CI [333, 361]**. Using baseline assumptions $f_L = 0.35$ and $q = 0.90$, we estimate the **total network size** at $\hat{N}_{\text{total}} \approx 1{,}101$ nodes, with a sensitivity range of roughly **0.8k–1.5k** across plausible parameter settings.

2 Introduction

Counting nodes in an open P2P system is hard: many nodes do not accept inbound connections, churn is continuous, and any single vantage point sees only a slice of the graph. Public dashboards that report "node counts" typically reflect reachable listeners, which are a subset of the full population. Our goal is to provide a reproducible, bias-aware method to estimate total nodes from readily obtainable public signals.

Contributions 1. A lightweight pipeline to gather independent samples of listening peers without privileged access.
2. A capture–recapture estimation procedure with uncertainty quantification.
3. A visibility-bias correction to infer total nodes from listener estimates.
4. A fully reproducible appendix with scripts/commands.

3 Threats to Validity & Visibility Slice

Each sampling method observes a **visibility slice** of the network, biased toward publicly reachable listeners. We mitigate this by (a) using **independent passes** from distinct sources and (b) explicitly modeling the unobserved portion. Key limitations:

- **Listening bias:** Non-listening (NAT/firewalled) nodes are under-sampled.
- **Vantage bias:** Different vantage points see different subgraphs.
- **Temporal drift:** Peer sets change over time; passes must be time-boxed.

These are addressed in later sections via multi-pass sampling, Chapman estimation, and a visibility correction.

4 Data Collection

We used two independent sampling passes that return IP:port endpoints for **currently connected, listening** peers. Each pass is converted to a CSV with schema `node_id,pass_id,listening` (listening=1 for proven listeners).

4.1 Pass A – Local-node vantage (connected peers)

- Source: your own archive Kaspad via RPC/wRPC or a light crawler that successfully handshakes and records neighbors.
- Output: `connected_pass_pass1-<timestamp>.csv`.

4.2 Pass B – DNS-seeder vantage (random listeners)

- Source: repeated queries to Kaspa DNS seeders (A/AAAA), optionally verified by a short TCP probe on port 16111.
- Output: `connected_pass_dns-<timestamp>.csv`.

Optional Passes: Public Node Network (PNN) resolver sampling; additional local nodes; later-day repeats to increase independence and smooth churn.

5 Estimation Methodology

5.1 Notation

- S_1: unique listeners observed in pass 1
- S_2: unique listeners observed in pass 2
- M: overlap = listeners observed in both passes
- $\hat{N}_L$: estimated size of the listening population
- $f_L \in (0, 1]$: fraction of **all** nodes that are listening
- $q \in (0, 1]$: pass coverage of the listening population (per pass)

5.2 Capture–Recapture (Chapman estimator)

For two passes, the Chapman estimator (variance per Seber) is:

$$\hat{N}_L = \frac{(S_1 + 1)(S_2 + 1)}{(M + 1)} - 1, \qquad \mathrm{Var}(\hat{N}_L) = \frac{(S_1 + 1)(S_2 + 1)(S_1 - M)(S_2 - M)}{(M + 1)^2(M + 2)}.$$

A 95% CI is $\hat{N}_L \pm 1.96\,\mathrm{SE}$, where $\mathrm{SE} = \sqrt{\mathrm{Var}}$.

5.3 Visibility Correction to Total Nodes

Listener estimates exclude non-listening nodes. If f_L is the fraction of nodes that are listening and q is the coverage of a pass over listeners, a single-pass count S relates to the total N_{total} as $S \approx f_L\, q\, N_{\text{total}}$. After estimating $\hat{N}_L$ with Chapman, we infer total nodes by:

$$\hat{N}_{\text{total}} \approx \frac{\hat{N}_L}{f_L\, q}.$$

We report a sensitivity grid over plausible (f_L, q) values.

6 Results

Sampling window: .
Passes used: Pass A (local node), Pass B (DNS seeder).

- **Chapman listener estimate:** $\hat{N}_L = 347$, **95% CI [333, 361]**.
- **Visibility-corrected total (baseline):** with $f_L = 0.35$, $q = 0.90 \rightarrow \hat{N}_{\text{total}} \approx 1{,}101$.

6.1 Sensitivity to f_L and q

Using $\hat{N}_L = 347$:

f_L	$q = 0.80$	$q = 0.90$	$q = 0.95$
0.30	1,445	1,285	1,217
0.35	1,239	**1,101**	1,043
0.40	1,084	964	913
0.45	964	856	811

Interpretation: under reasonable assumptions ($f_L \in [0.30, 0.45],\ q \in [0.80, 0.95]$), the total node count lies in the **0.8k–1.5k** range, centered near **1.1k** for the baseline.

6.2 (Optional) Empirical Coverage Check

Given $\hat{N}_L$, approximate pass coverages are $\hat{q}_1 \approx S_1/\hat{N}_L$, $\hat{q}_2 \approx S_2/\hat{N}_L$. Report and discuss if available.

7 Discussion

- **Independence:** Using different vantage points (local node vs DNS seeders) improves independence relative to two samples from the same node/IP.
- **Churn:** Time separation between passes reduces correlation; repeating the experiment across days tightens uncertainty.
- **Bias that remains:** Listener-only sampling still under-represents non-listening nodes; the visibility correction makes assumptions explicit.

8 Related Work (brief)

- Classical ecological capture–recapture: Lincoln–Petersen; Chapman correction; variance per Seber.
- Network measurement analogs: peer-to-peer crawl methods; DNS seeder methodologies in other crypto networks.

9 Reproducibility: Commands & Scripts

9.1 Convert local crawler output to CSV

```
# nodes.json → connected_pass_<id>.csv (listeners only)
jq -r --arg p "<PASS_ID>" '
  ["node_id","pass_id","listening"],
  (
    to_entries[]
    | select((.value.id != "") or (.value.error == ""))
    | [ .key,$p, "1" ]
  )
  | @csv
' nodes.json > connected_pass_<PASS_ID>.csv
```

9.2 DNS-Seeder pass to CSV

```
SEEDERS=(seeder1.kaspad.net)
PASS_ID="dns-$(date -u +%Y%m%dT%H%M%SZ)"
TMP=$(mktemp)
for s in "${SEEDERS[@]}"; do
  for i in $(seq 1 400); do
    dig +short A "$s"    >> "$TMP"
    dig +short AAAA "$s" >> "$TMP"
    sleep 0.2
  done
done
awk 'NF==1{ if ($1 ~ /:/) print "["$1"]:16111"; else print $1":16111" }' "$TMP" | sort -u > "$
# Optional TCP verify (polite):
probe(){ hp="$1"; ip="${hp%%:*}"; ip="${ip#[}"; ip="${ip%]}"; port="${hp##*:}";
         timeout 1 bash -c "</dev/tcp/$ip/$port" &>/dev/null && echo "$hp"; }
export -f probe
cat "$TMP.uniq" | xargs -n1 -P64 -I{} bash -lc 'probe "$@"' _ {} > "$TMP.open"
{
  echo 'node_id,pass_id,listening'
  awk -v p="$PASS_ID" '{print $0","p",1"}' "${TMP}.open"
} > connected_pass_${PASS_ID}.csv
```

9.3 Compute S_1, S_2, M and Chapman + CI

```
# Normalize helper: strip header/quotes and any 'ipv6:' prefixes
normalize(){ sed '1d;s/"//g' | sed 's/^ipv6:\[/[/' ; }
cut -d, -f1 connected_pass_pass1-*.csv | normalize | sort -u > /tmp/p1.ids
cut -d, -f1 connected_pass_pass2-*.csv | normalize | sort -u > /tmp/p2.ids
S1=$(wc -l < /tmp/p1.ids); S2=$(wc -l < /tmp/p2.ids)
M=$(comm -12 /tmp/p1.ids /tmp/p2.ids | wc -l)
awk -v S1="$S1" -v S2="$S2" -v M="$M" 'BEGIN{
  N=((S1+1.0)*(S2+1.0)/(M+1.0))-1.0;
  V=((S1+1.0)*(S2+1.0)*(S1-M)*(S2-M))/(((M+1.0)^2)*(M+2.0));
```

```
  SE=sqrt(V); lo=N-1.96*SE; hi=N+1.96*SE;
  printf "Listening (Chapman): %.0f  95%% CI [%.0f, %.0f]\n", N, (lo<0?0:lo), hi;
}'
```

9.4 Visibility-corrected total & sensitivity grid

```
N_L="<paste from Chapman>"
for fL in 0.30 0.35 0.40 0.45; do
  for q in 0.80 0.90 0.95; do
    awk -v NL="$N_L" -v f="$fL" -v q="$q" 'BEGIN{
      printf "N_total (f_L=%.2f, q=%.2f) approx %.0f\n", f, q, (f*q>0? NL/(f*q): 0)
    }'
  done
done
```

10 Ethical & Operational Considerations

- Respect community infrastructure: rate-limit DNS seeder queries and public node sampling.
- Do not publish raw IPs; aggregate results (counts and estimates) only.
- Avoid excessive active probing; use short timeouts and conservative concurrency.

11 Conclusion

A two-pass capture–recapture protocol, combined with an explicit visibility correction, yields a defensible estimate of Kaspa's total node population using only public information and your own node. On the study date, we estimated $\hat{N}_L = 347$ listeners (95% CI [333, 361]) and $\hat{N}_{\text{total}} \approx 1{,}101$ under baseline assumptions, with a plausible range of 0.8k–1.5k.

12 References (examples; expand as needed)

- Chapman, D. G. (1951). Some properties of the hypergeometric distribution with applications to zoological censuses. *Univ. of California Publications in Statistics.*
- Seber, G. A. F. (1982). *The Estimation of Animal Abundance and Related Parameters.* Macmillan.
- General background on DNS seeders and P2P measurement (add project-specific docs as appropriate).

13 Appendix A – File Manifest (example)

- `connected_pass_pass1-<ts>.csv` – local-node pass (listeners)
- `connected_pass_dns-<ts>.csv` – DNS-seeder pass (listeners)
- `addrbook_pass_<ts>.csv` – optional, discovered addresses (not used in Chapman)
- `analysis_notes.md` – scratch calculations / logs