DHT Routing Table Health

Our DHT is in good shape!

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Protocol Labs**

**IPFS Camp
28th October 2022**

IPFS Camp

Protocol Labs

What is a Distributed Hash Table?

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- Computer Overlay Network
- Distributed key-value store
- Keyspace is flat: content can be found at the location of its hash
- State is `Log(n)`
- Lookup is `Log(n)`

Kademlia DHT in IPFS

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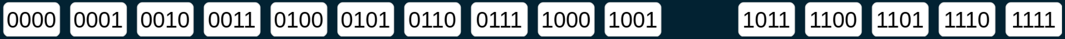
- Keyspace is 256-bits
- Each peer has a `PeerID` in the keyspace
- Locality between peers is based on XOR distance
- The DHT doesn’t store the content but **pointers** to the content: **Provider Records**
- Each peer keeps track of other peers in `k-buckets`, and sorts their `PeerIDs` by XOR distance / Common Prefix Length

Joining the DHT



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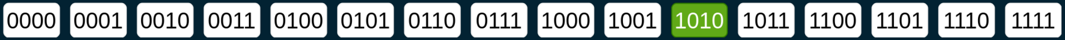
Joining the DHT



0000 0001 0010 0011 0100 0101 0110 0111 1000 1001 **1010** 1011 1100 1101 1110 1111

Joining the DHT

0000 0001 0010 0011 0100 0101 0110 0111 1000 1001 1010 1011 1100 1101 1110 1111

Joining the DHT: self lookup

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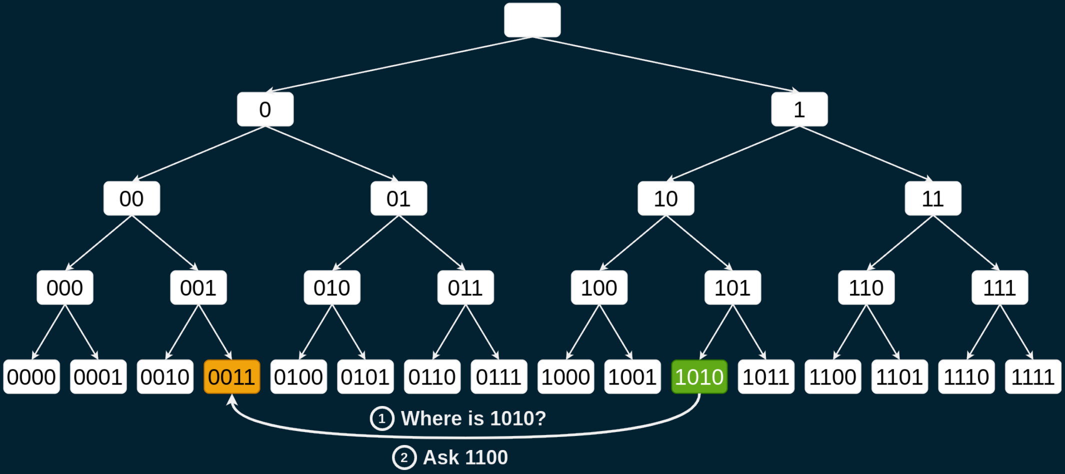

Joining the DHT: self lookup

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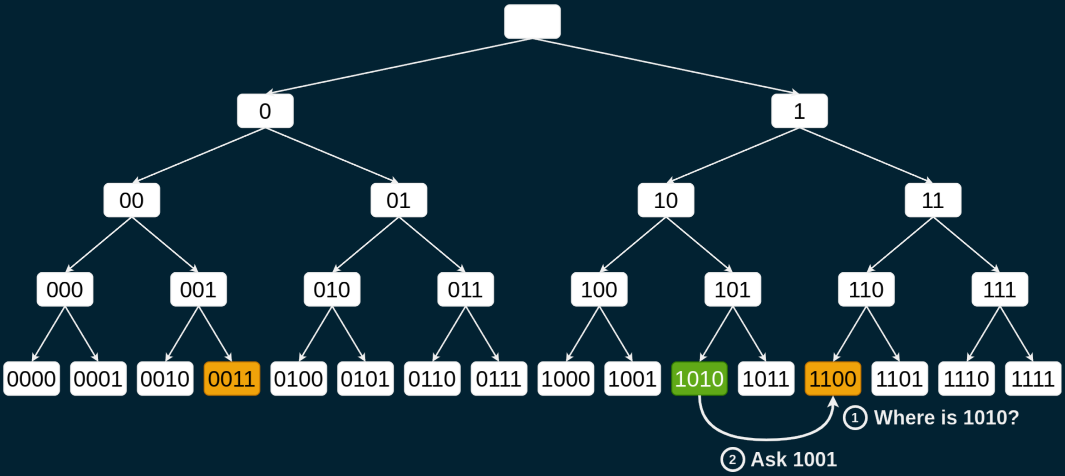

Joining the DHT: self lookup

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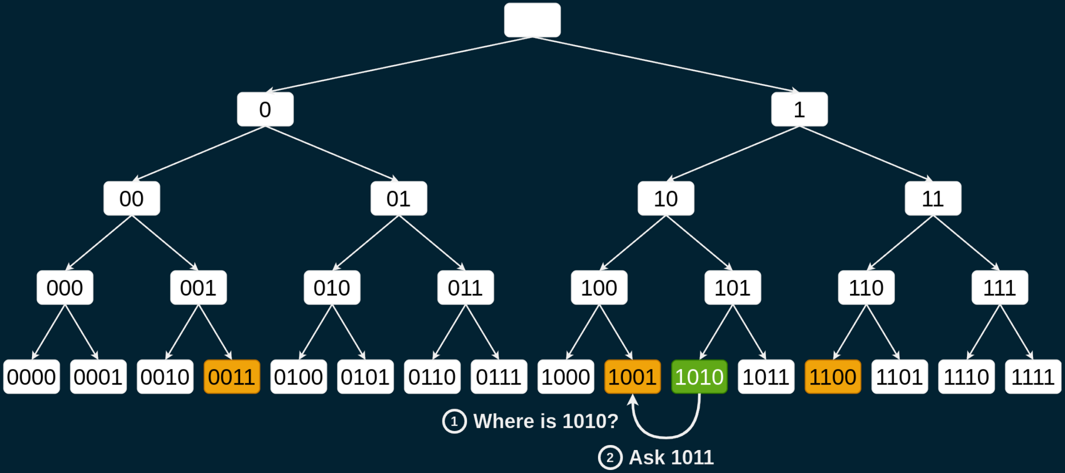

Joining the DHT: self lookup

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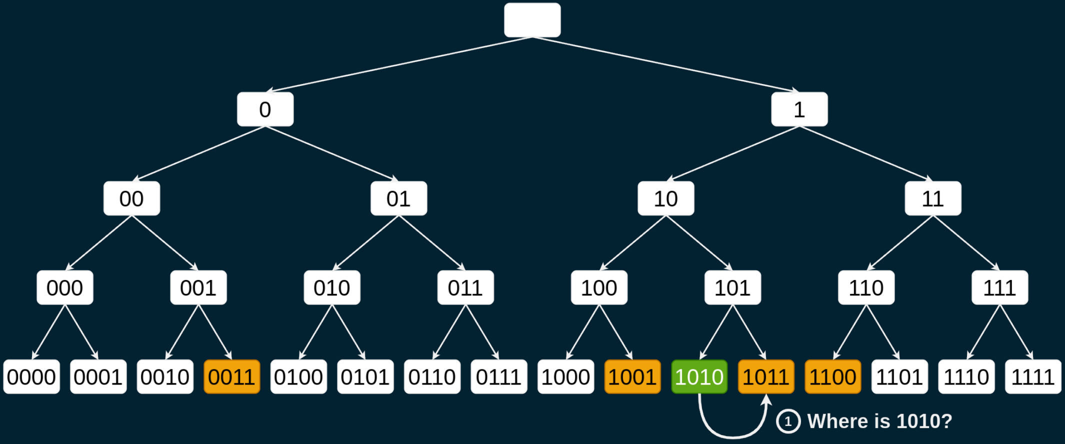

① Where is 1010?

② I don't know anyone closer

Kademlia details

- Each node periodically looks up for its own `PeerID`
- Multiple requests happen concurrently for the same key
- Upon request a peer returns the 20 closest peers it knows to the requested key
- When a Provider Records is published to the DHT it is stored on the 20 closest peers to its key
- Buckets are capped at 20 peers

- **These constants don’t need to be the same value!**

Kademlia keyspace

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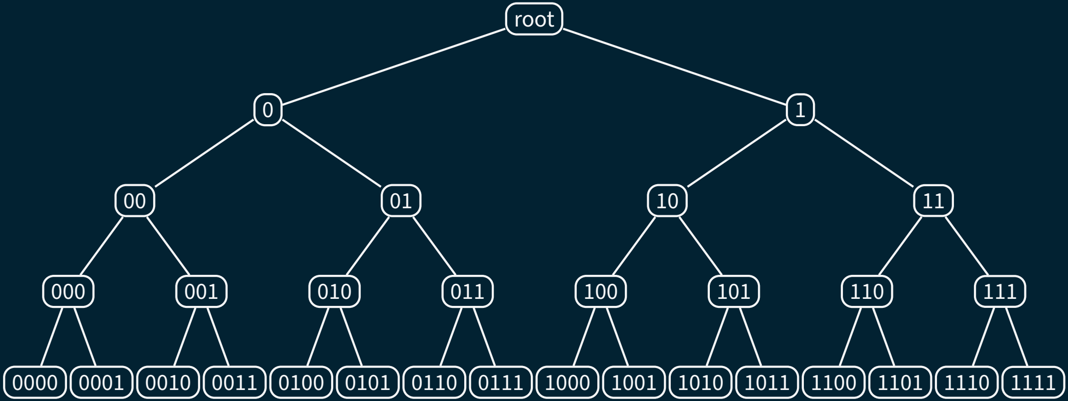

Kademlia keyspace

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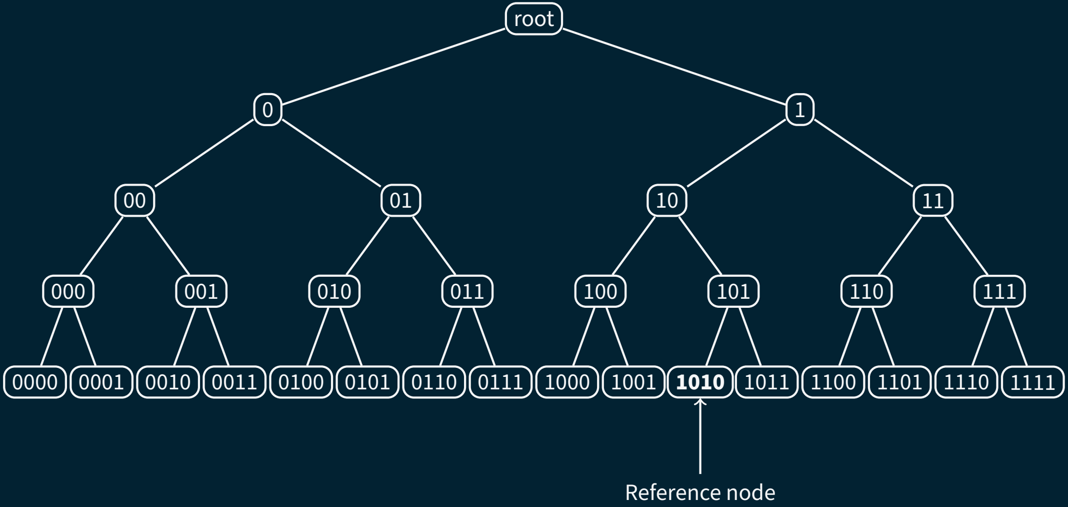
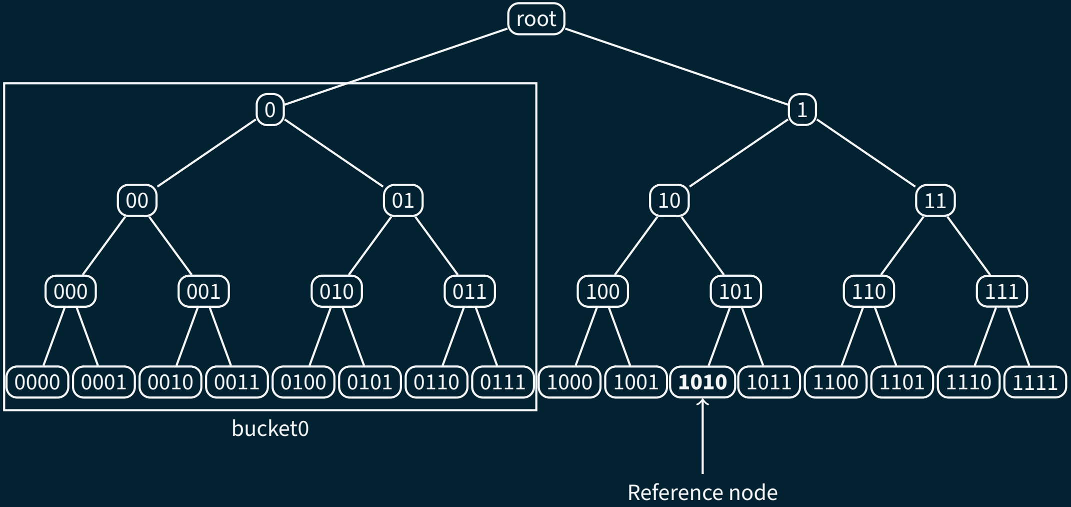


Kademlia keyspace



Kademlia keyspace

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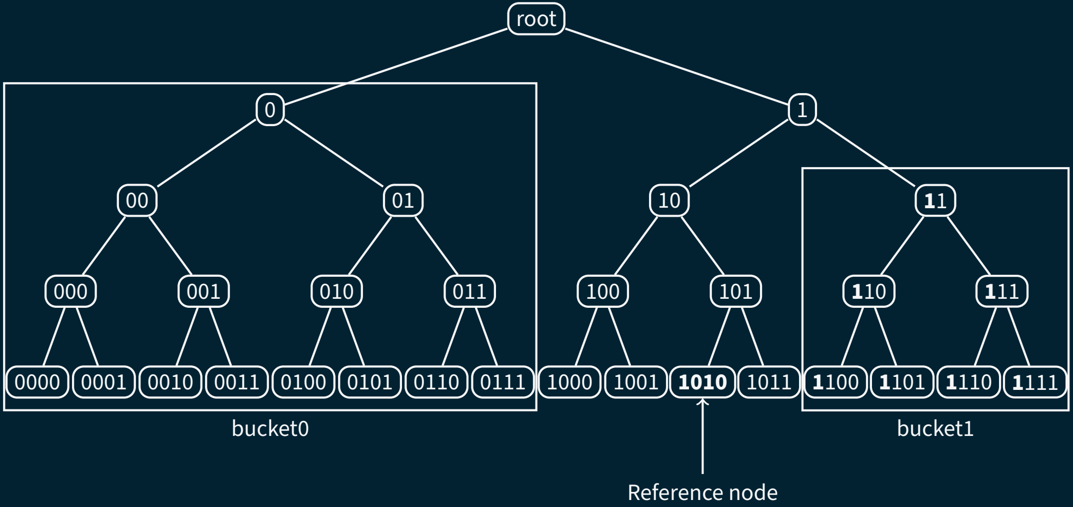

Kademlia keyspace

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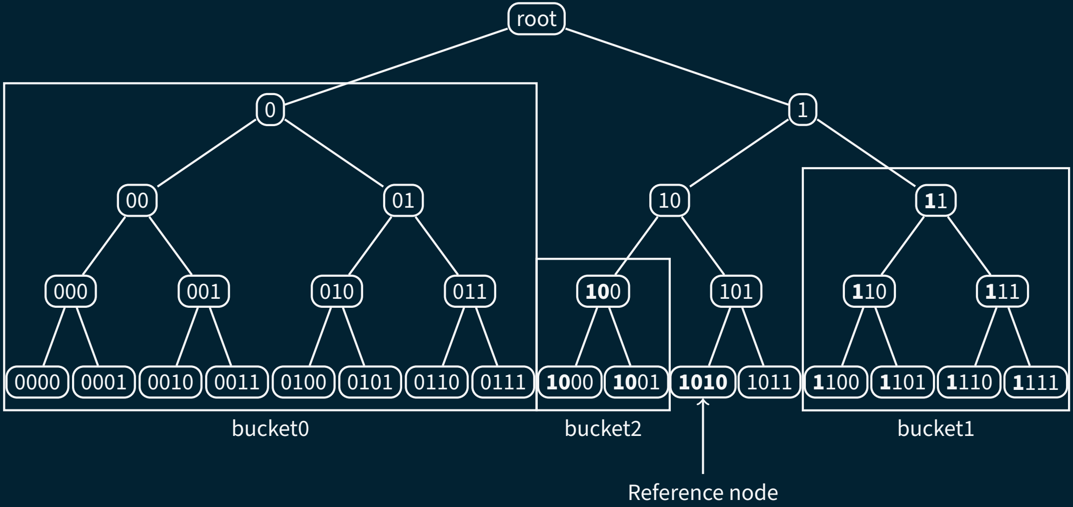

Kademlia keyspace

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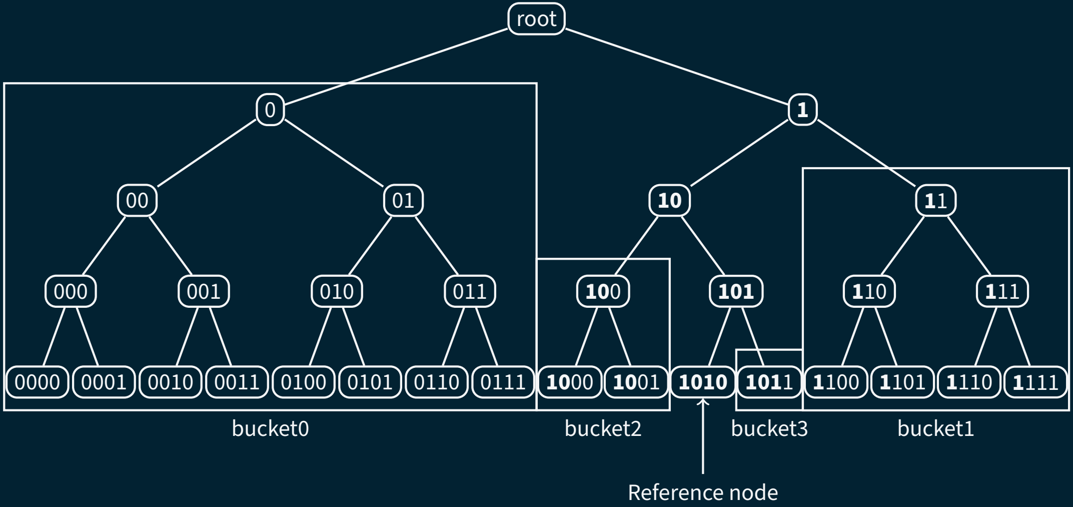

Example: Routing Table of peer 01101000

Bucket 0

1. 11010111
2. 10001011
3. 10101110
4. 11110101
5. 10000010
6. 11010100
7. 11000100
8. …

Bucket 1

1. **0**0110101
2. **0**0001000
3. **0**0111011
4. **0**0101101
5. **0**0110100

Bucket 2

1. **01**011101
2. **01**001111
3. **01**010110

Bucket 3

1. **011**11011
2. **011**10001

Bucket 4

1. **0110**0011

`k-bucket` replacement policy

- `Kademlia`: only when a bucket is full and there is a new candidate, least-recently seen and unreachable node gets evicted, but live nodes are never evicted
- `kubo` implementation: periodically ping the nodes in the routing table, and evict the unresponsive ones

Measurements data

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- The Nebula Crawler crawls the IPFS network and provides all peers in the network along with their routing table for a point in time
- Data taken from 28 crawls over 1 week (4 crawls per day) starting on 2022-04-19

Methodology

- The Nebula Crawler provides a global snapshot of the network
- We can reconstruct the `k-buckets` of all peers by computing the XOR distance between a `PeerID` and the `PeerID`s of all peers in its routing table
- From the global snapshot we can find the closest peers to every other peer and verify if any peer is missing from a `k-bucket`

Unreachable peers in the Routing Table

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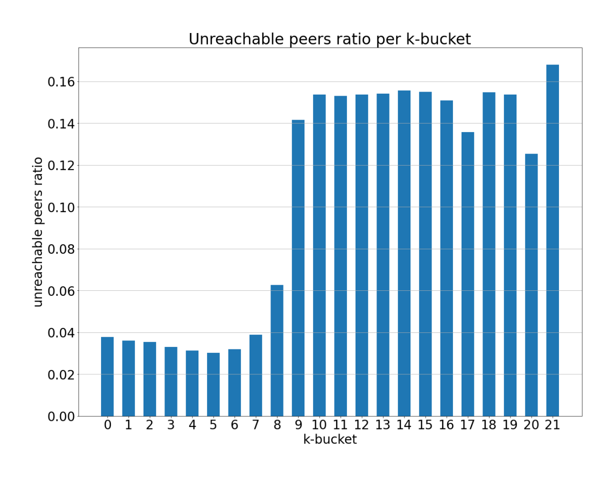
Unreachable peers may still be referenced in other peers routing tables (stale entries)

- Average for buckets 0 to 8: 3.8% ~ 0.75 peers
- Average for buckets 9 to 21: 15%



Peers distribution in the k-buckets

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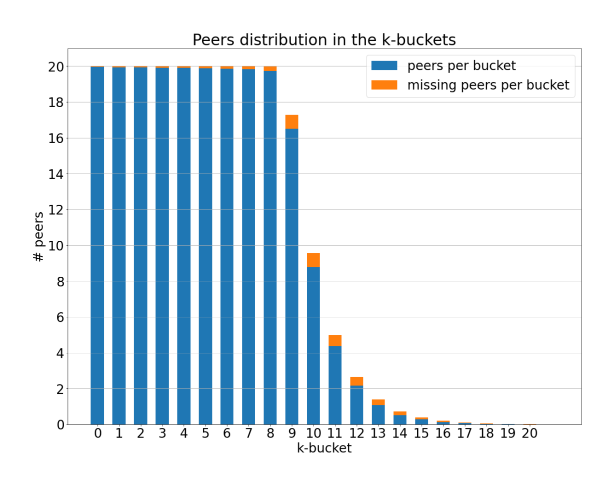
- Peers distribution in bucket follows an exponential growth, capped at 20
- Buckets 0–8 are missing on average 0.12 peers per bucket
- Buckets 9–14 are missing on average 0.53 peers per bucket



20 closest peers awareness

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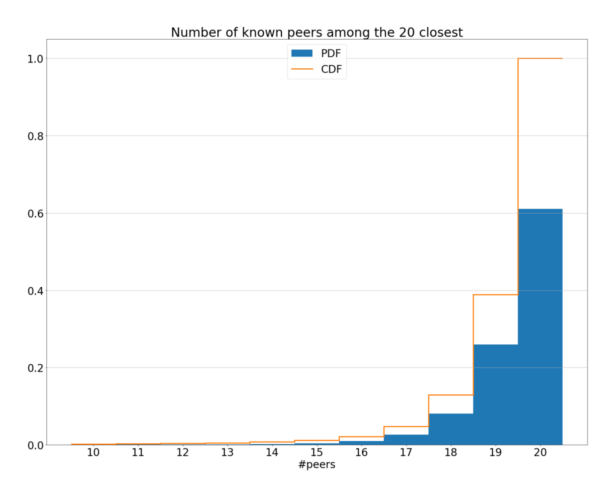
- Probability Density Function (PDF)
- Cumulative Distribution Function (CDF)

- 61.1% of the peers know all their 20 closest peers
- 95.2% of the peers know at least 18 of their 20 closest peers



Diversity in the k-buckets

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- Live peers never get replaced in the `k-buckets` by design
- Eventually, buckets with many candidates (e.g buckets `0-1`) will be filled almost exclusively with a small number of very stable peers
- Routing for content *far away* (in XOR distance) may become centralized on a small set of peers
- Bad for decentralization :(
- Bad for load balancing :(

Diversity measurements

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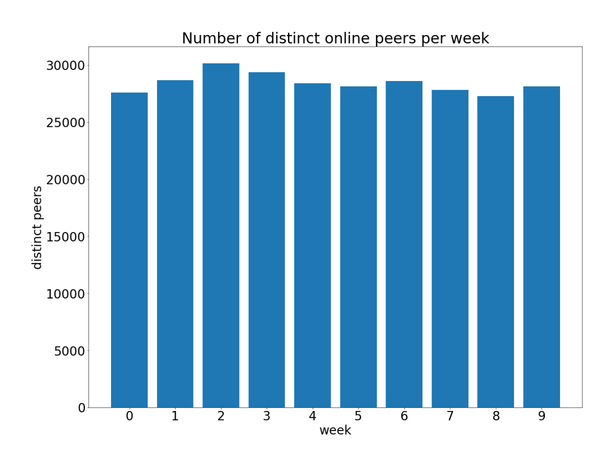
- Measurements for 10 consecutive weeks starting on 2022-02-16
- Each week’s measurements are based on data from 14 crawls (2x/day)
- Diversity in `k-buckets` is measured as the number of distinct `peer_ids` observed in each bucket for all peers



Diversity in each k-buckets

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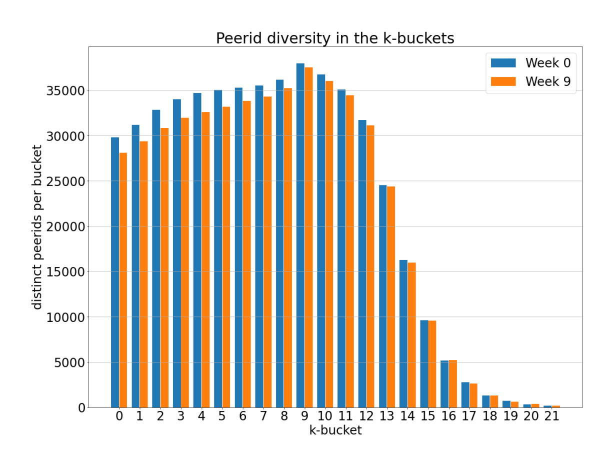
- Buckets 10+: non-full buckets → low diversity
- Bucket 9: bucket just full → highest diversity
- Buckets 0–1: many candidates, only the most stable don't get evicted → lower diversity
- We expect diversity in buckets 0–1 to decrease over time



Diversity evolution over time

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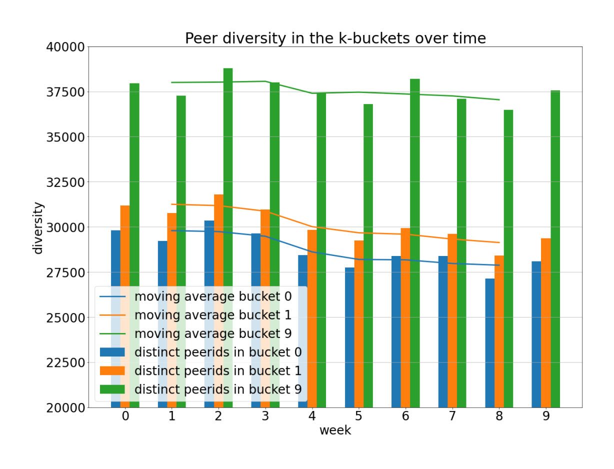
Moving average difference between week 1 and week 8:

Bucket 0: **-6.9%**

Bucket 1: **-7.3%**

Bucket 9: -2.6%



Persisting Routing Table States

- Routing table currently flushed upon node shutdown
- Routing table has to be repopulated on restart, using bootstrap peers

Persisting the state of the routing table would allow:

- Faster convergence
- Less dependence on bootstrap nodes

DHT connection graph

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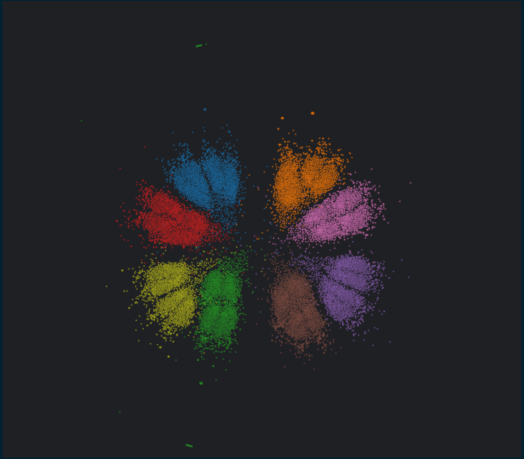

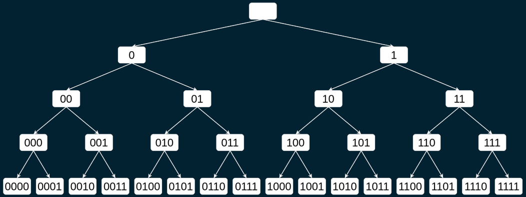

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Conclusion

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- Very low rate of stale entries in the routing table, given high churn
- Peers distributions in the `k-buckets` as expected
- The `k-buckets` are only missing a small number of peers
- `95.2`% of the nodes have at least 18 of their 20 closest peers in their Routing Table
- We observed diversity decreasing over time in low ID buckets, which might become a concern for decentralization

References

Complete report available

https://github.com/protocol/network-measurements

Digression: Bucket quotas

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Make the bucket replacement policy smarter

- Reduce number of hops
- Reduce hop latency
- More load balancing through diversity
- Make the DHT agile and upgradable
- Keep DHT stability

Current quotas

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- No more than 3 IP addresses from the same Autonomous System (AS) in the routing table
- No more than 2 IP addresses from the same AS in the same bucket

Quotas example

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Out of the 20 peers per bucket, if possible we want:

- The 5 nodes with the longest uptime
- 5 nodes whose RTT is below the 30th percentile of this bucket candidates' RTT
- 1 node in each of the 4 sub-buckets (4 in total)
- 4 peers whose DHT version is higher or equal to its own version
- 2 random peers

Nodes from the low RTT, DHT version and random peers get probabilistically pruned and replaced, e.g every 6 hours one node is pruned.

Note: peers can belong to multiple categories at once.

Side effects

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- Close buckets (high ID) will not change
- Far buckets (low ID) are expected to change
- Stable up-to-date central nodes will be easy to find
- Reaching unstable outdated nodes with high latency may require one extra hop
- Lookup latency (finding 1 of the 20 closest nodes to a key) is expected to significantly decrease
- Provide latency (finding the 20 closest nodes to a key) is expected to slightly decrease