CISS (Cooperative Information Sharing System): An Efficient Object Clustering Framework for DHT-based Peer-to-Peer Applications

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Motivation – New applications

**MMOG (Massively Multiplayer Online Game)**

- <update message >
- Location: 60, 30

**Multi-dimensional Range Queries**

- Product=Electronics.Computer.HP.*

**P2P Catalog System**
Problem – Many DHT lookups

Periodic location updates – semantically related objects

Unrelated Keys

Multi-dimensional Range query

MMOG

P2P Catalog System

Solution Approach – Object clustering

Periodic location updates – semantically related objects

Locality Preserving Load Balancing

Routing Protocol

LT: Local Preserving Function
Related Work

- Most recent DHT extensions [A.Gupta, ‘03], [A.Kothari, ‘03]
  - Simple one-dimensional range queries
  - Not compatible with existing DHT implementations
- CLASH [A.Misra, ‘04] and PHT [S. Ratnasamy, ‘03]
  - Extensible hashing
  - Adaptive object clustering, range queries
  - No multi-dimensional range query support
- Squid [C.Schmidt, ‘03]
  - Multi-dimensional range queries over DHTs
  - Limited scalability due to query congestion

System Architecture

- Three-tier P2P system
  - CISS: Internet-scale data management system interacting with P2P applications
  - DHT: basic lookup layer
Locality Preserving Function (LPF) (1/2)

- Construct \( N \)-bit keys from objects while preserving locality

- 1st step – encoding each attribute to an \( M = \frac{N}{D} \)-bit key
  - Numerical: rescaling by multiplying a coefficient
    \[
    \{x=60 \land y=70\} \left(\times \frac{2^N}{\text{MaxAttributeValue}}\right) \rightarrow \{x=1010 \land y=1011\}
    \]
  - String: hash-concatenation encoding scheme
    - Hashing the value of each level in the hierarchy into \( M/d \) bit values
    - Concatenating the values into an \( M \)-bit key

- 2nd step – Mapping multiple keys to an one-dimensional \( N \)-bit key
  - Hilbert Space Filling Curve (SFC)
Routing Protocols (1/2)

- Minimize the number of costly DHT lookups

- *Caching-based update routing protocol*
  - Key range cache of the most-recently-searched rendezvous node

Routing Protocols (2/2)

- *Forwarding-based query routing protocol*
  - Forwarding a query to a succeeding peer node
  - Utilizing the object clustering property of CISS
Locality Preserving Load Balancing (1/2)

- Preserve locality after load balancing
  - *cf.* virtual server approach
- Two load balancing schemes
  - Local-handover, global-handover
- **Local-handover**
  - An Overloaded node hands over a part of its own key range to one of its neighbor nodes
  - Cascading load propagation can occur

![Diagram](image)

Locality Preserving Load Balancing (2/2)

- **Global-handover**
  - An Overloaded node hands over a part of its key range to a victim node
    - Victim node
      - the most lightly loaded node among the randomly probed nodes
  - Cascading load propagation doesn’t occur

<table>
<thead>
<tr>
<th></th>
<th>Local-handover</th>
<th>Global-handover</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DHT routing table updates</strong></td>
<td>$O(\log S)$ messages</td>
<td>$O(\log S)$ messages</td>
</tr>
<tr>
<td><strong>Object Transferring</strong></td>
<td>From the overloaded node to the neighbor node</td>
<td>From the overloaded node to the neighbor node From the victim node to the successor Of victim node</td>
</tr>
<tr>
<td><strong>Victim Probing</strong></td>
<td>None</td>
<td>$n$ DHT lookups</td>
</tr>
</tbody>
</table>

**Load Balancing Cost**
Experiments (1/2)

- Data Update Performance
  - Setting
    - Topology – 1000, 10000, 100000 nodes
    - Map – \([0, 2^{12}] \times [0, 2^{12}]\)
    - Mobility model – ns-2 random waypoint model
  - Result
    - Low mobility – High hit ratio
      - The range of client movement is much smaller than the range managed by the responsible server
    - Small number of nodes – High hit ratio
      - The range managed by each node is large

![Hit Ratio of the key range cache](image)

Experiments (2/2)

- Multi-dimensional range query performance
  - Setting
    - P2P catalog system
    - 2 attributes: each attribute–4 levels
  - Result
    - The total # of messages for query processing is significantly reduced.
    - When the query range become large – # of DHT lookups significantly reduced
    - Most of queries don’t require query forwarding.
Conclusion & Future work

- Conclusion
  - CISS is a framework that supports an efficient object clustering for DHT-based P2P applications, especially data-intensive and multi-dimensional range query-intensive applications.
  - LPF is used instead of a hash function.
  - Routing protocols effectively reduce costly DHT lookups.

- Future work
  - Technical details for locality preserving load balancing
    - Overload detection
    - Load estimation
    - Victim selection