VORAAQUE: RANGE QUERIES ON VORONOI OVERLAYS

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SEARCHING IN P2P NETWORKS

• Searching in large networks is a **basic functionality** offered by P2P systems
• Most P2P system exploit **Distributed Hash Tables**
  – load balancing guaranteed by hashing function
  – basic Searching function: `put`, `get`
  – no support for complex queries (multi attribute, range, k-neighbour, similarity queries)
• Several applications need **complex queries**
  – distributed directory service
  – geographic information system
• Alternatives to DHT are currently investigated
  – distributed tree-shaped data structures,
  – locality preserving hashing functions
  – Voronoi based overlays
VoRaQue: VORONOI RANGE QUERIES

- a P2P Voronoi overlay
- based on the VoRoNet approach [Beaumont et al. 2006], an object based P2P network
  - Voronoi tessellations + Kleinberg model
- extension introduced by VoRaQue
  - a routing strategy for range queries based on compass routing
  - compass routing in bounded regions
  - evaluation of the P2P network on the Grid 5000 platform
VORONET: AN OBJECT BASED OVERLAY

- **Voronet**: an object based P2P overlay
  - each peer publish an object
  - an object is
    - described by a set of $k$ attribute-value pairs
    - embedded in a $k$-dimensional space
  - the coordinates of the objects in the $k$-dimensional space are defined by the value of its attributes

- The Voronet overlay
  - include links between peers corresponding to objects 'close' in the virtual space
  - the virtual space is partitioned by a Voronoi tessellation
  - a content based topology, not based on Distributed Hash Tables
  - defines routing algorithm for exact query only
VORONOI TESSELLATIONS

- A set of points in $\mathbb{R}^2$
VORONOI TESSELLATIONS

- A set of points in \( \mathbb{R}^2 \)
- Consider object at point \( M \)
VORONOI TESSELLATIONS

- A set of points in $\mathbb{R}^2$
- Consider object at point $M$
- Region of points closer to $M$ than to $A$
VORONOI TESSELLATIONS

- A set of points in $\mathbb{R}^2$
- Consider object at point $M$
- Region of points closer to $M$ than to $A$
- Region of points closer to $M$ than to $A/B$
VORONOI TESSELLATIONS

- A set of points in $\mathbb{R}^2$
- Consider object at point $M$
- Voronoi Cell of $M$: region of points closer to $M$ than to any other object
VORONOI TESSELLATIONS

• A set of points in $\mathbb{R}^2$

• Consider object at point $M$

• Region of points closer to $M$ than to any other object

Voronoi Cell of $M$

• do the same for all objects
**VORONOI TESSELLATIONS**

- A set of points in $\mathbb{R}^2$
- Consider object at point $M$
- Region of points closer to $M$ than to any other object **Voronoi Cell of $M$**
- do the same for all objects
- **Voronoi neighbours**: belongs to a pair region sharing a border

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VoRaQue: Range Queries on Voronoi Overlays

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**VORONOI TESSELLATIONS**

- A set of points in $\mathbb{R}^2$
- Consider object at point $M$
- Region of points closer to $M$ than to any other object *Voronoi Cell of $M$*
- do the same for all objects
- *Voronoi neighbours*: share a border
- *Delaunay triangulation*: Graph connecting *Voronoi neighbours*
VoRaQue: Range Queries on Voronoi Overlays

KLEINBERG SMALL WORLD MODEL

- Kleinberg Model applied to Voronoi
  - add a set of long range links
  - long range links: connect objects at distance $L$ with probability $1/L^2$
- Exact query: greedy routing $O(\ln^2 n)$
COMPASS ROUTING IN DELAUNAY OVERLAYS

- Definition of a spanning tree embedded in a Delaunay overlay exploits the topological properties of the Delaunay triangulation
- Bottom up construction of a spanning tree rooted at \( R \)
  - node \( A \) computes \( B \) as its parent in the spanning tree, if \( B \) is the neighbour of \( A \) with the smallest angle to \( R \)

- To define a multicast routing algorithm the construction of the spanning tree should start from the root (topdown construction)
COMPASS ROUTING IN DELAUNAY OVERLAYS

Compass Routing:
• starting from the root, each node $n$ detects its children in the spanning tree
• $m$ is a child of $n$ in the spanning tree iff $n$ is on the path from $m$ to the root
• requires the knowledge of the neighbours of $m$ (neighbour of the neighbour)
Range query in VoRaQue. A range query $Q$ defines a region $R(Q)$ in a 2d-attribute space and can be submitted by any node of the network.
To find all the nodes matching the range query

1. exploit greedy routing (through Voronoi and long range links) to forward Q to any node $T$ belonging to $R(Q)$

2. starting from $T$ exploit compass routing to propagate Q to any other node $\in R(Q)$

Compass routing in a bounded region $R(Q))$ requires a refinement of the basic algorithm.
RANGE QUERIES IN VORAAQUE

- given a query Q
  - a node \( n \in R(Q) \) is an exact match of the query
  - a node \( n \) such that \( Voro(n) \cap R(Q) \neq \emptyset \) and \( n \notin R(Q) \) is a border match of the query (\( Voro(n) = \) Voronoi region of \( n \))

- to compute a spanning tree covering all the exact matches of the query, compass routing has to consider both exact and border matches of the query
  - some paths of the spanning tree may zigzag around the borders of \( R(Q) \)
  - the number of the zigzag paths may be minimized by choosing as the root of the spanning tree a node located around the center of \( R(Q) \)

- Formal proof in the paper
VoRaQue: THE PROTOCOL

• Defines a set of conditions to detect if the node is an exact match or a border match for the query:
  – sort the conditions with respect to their computational complexity

• A node asks its neighbours for their neighbours to apply compass routing

• A set of queries may be processed concurrently by any node

• Neighbour request messages are tagged by unique identifiers to match neighbour request with corresponding reply

• Query Matches are added incrementally to the query
VoRaQUE: THE PROTOCOL

• Incremental Search:
  – the maximum depth of the spanning tree may be bounded by pairing a Time To Live (TTL) with each query
  – the user may interactively increase the value of the TTL if further matches are needed
  – search is not repeated from scratch, but from the leaves of the previously computed tree

• Caching Strategies:
  – to reduce the number of messages required to implement compass routing, information related to the overlay topology is stored in the cache
  – cache refresh rate depends upon the churn rate of the network
TRAFFIC EVALUATION

- experimental environment: Grid 5000
  - 9 sites, heterogeneous clusters
  - 300 nodes
  - Evaluation of the average number of messages sent by each node for different size of the overlay
**LATENCY EVALUATION**

- evaluation of the time needed to resolve a range query for different sizes of the region defined by the query
- overlay network size = 300 nodes

**Fig. 5.** Latency without caching

**Fig. 6.** Latency with caching
HOP NUMBER EVALUATION

Compare the number of exact matches of a range query at each hop from the root when c the root of the spanning tree is located

• in the middle of the region

• at the border of the region
CONCLUSIONS

• VoRaQue: a distributed support for exact and range queries

• Experimental results show the effectiveness of our approach

• Future work:
  – investigate the behaviour of the network in presence of an high level of churn / of dynamic attributes
  – extension to higher order spaces