Enforcing Routing Consistency in Structured Peer-to-Peer Overlays: Should We and Could We?

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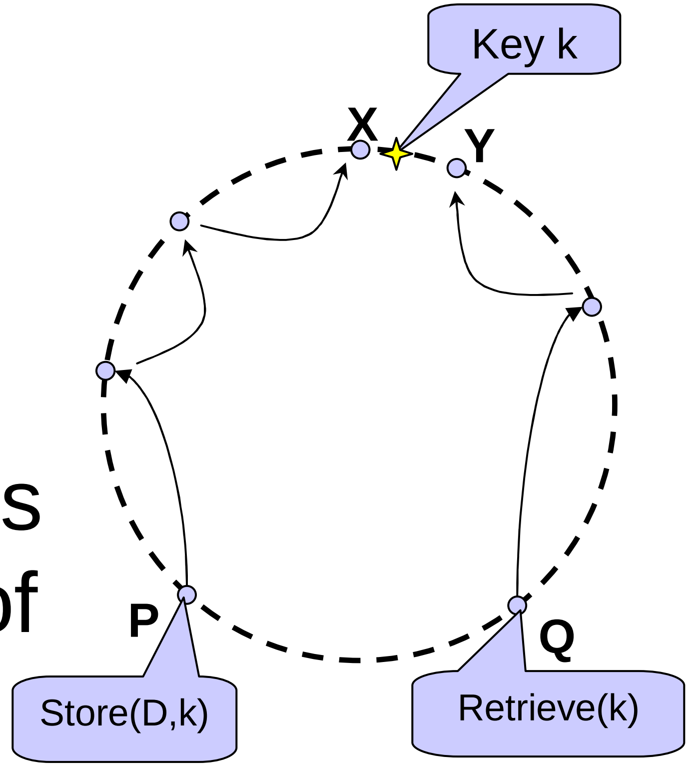
Routing Consistency

- Key-based routing (KBR)
  - Large key space
  - Routing to a destination close to a given *key*
- KBR consistency: routings always reach the owner of the key.

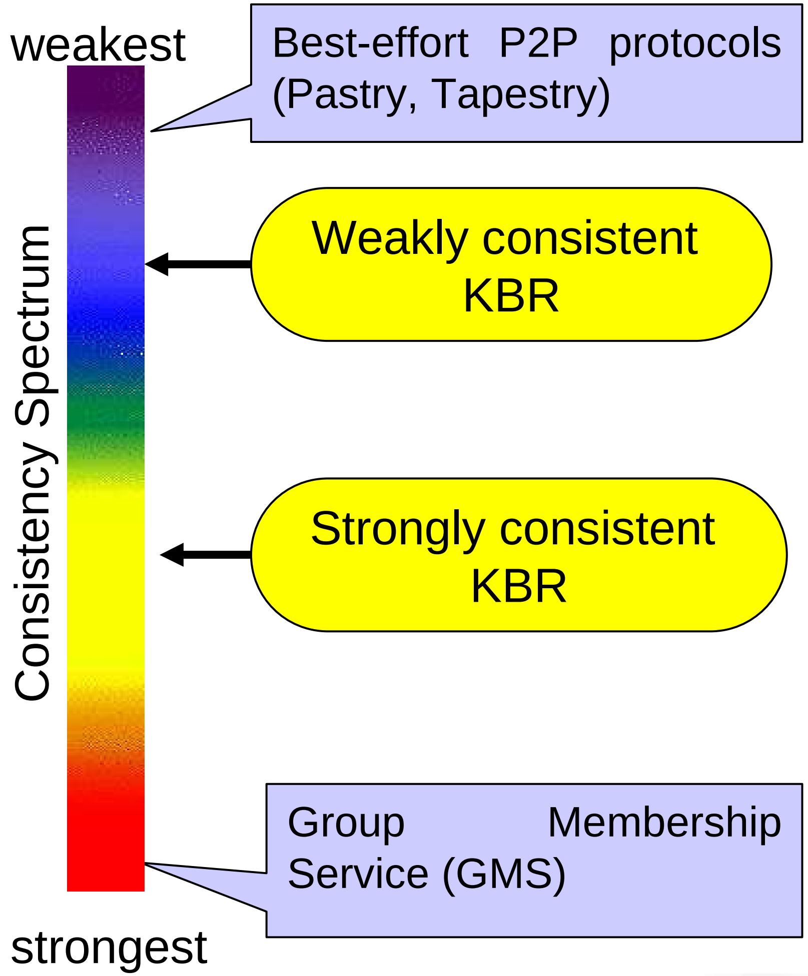


Why Routing Consistency?

- Important to applications (p2p storage, pub/sub, etc). Without consistency:
  - Incorrect/failed results
  - Performance cost: extra retries, extra maintenance
  - Application complexity
  - ⇒ limit applicability of structured p2p overlay
- Prior researches focus on performance and scalability

How to Enforce Routing Consistency?

- Formal specification
- Algorithm for strong consistency
  - Provably correct
  - Use group membership service (GMS)



Rest of the Talk

- Introduction
- System model
- Group membership service
- Routing consistency specification
- Algorithm for strong consistency
- Proposals for scalability and adaptivity
- Ongoing and future work

System Model

- Nodes $\Sigma = \{x_1, x_2, x_3, \ldots\}$
- Time $\mathcal{T} = \{0, 1, 2, \ldots\}$
- Nodes may join, leave/crash.
- Membership pattern $\Pi = \mathcal{T} \rightarrow 2^{\Sigma}$
  - $\Pi(t)$: finite, set of live nodes at time *t*.
  - $sset(\Pi)$: the set of eventual live nodes, if Π is eventually stable.
- Asynchronous message passing
  - No creation, no duplication, reliable.

Group Membership Service (GMS)

- Membership view $v = (set, ver)$

  $$v.set \subset \Sigma,\ v.ver \text{ is a nonnegative integer}$$

- Query interface action: $\mathsf{getCV}()$
  - Return a view *v* or a $\perp$
- Internal update actions: join() and remove()
- getCV(), join() and remove() are totally ordered

GMS Properties

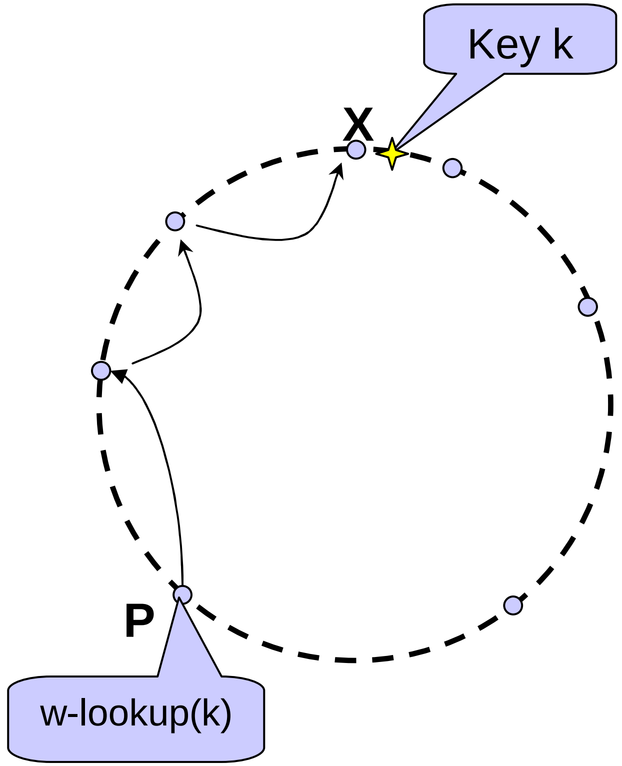
---- those related to KBR

- *Causality Consistency*: If node x_1 and x_2 each invokes a getCV(), and the return of getCV() on x_1 causally precedes the invocation of getCV() on x_2, and the return values are two views v_1 and v_2, respectively, then $v_1.ver \leq v_2.ver$.
- *Agreement*: For any two views v and w returned by getCV()'s, if $v.ver = w.ver$, then $v.set = w.set$.
- *Eventual Convergence*: If membership pattern Π is eventually stable, then there is a view v such that $v.set = sset(\Pi)$ and for any node $x \in sset(\Pi)$, there is a time t_1 such that if x invokes getCV() after time t_1, the return value is v.

- Can be implemented using consensus and eventually perfect failure detector

Weakly Consistent KBR (W-KBR)

- Node id: x.id $\in \mathcal{K}$
- Lookup primitive:
  - w-lookup$(k), k \in \mathcal{K}$
  - returns *x*, including *x.id* and *x.address*, or return $\perp$



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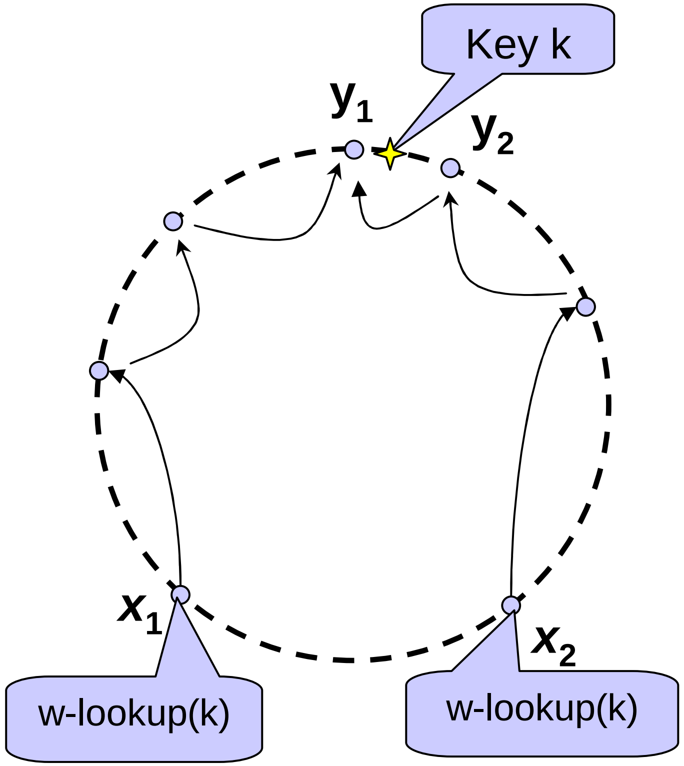
W-KBR properties (consistency related)

- *Eventual Progress*: If membership pattern Π is eventually stable, then there is a time t_1 such that for any key $k \in \mathcal{K}$, if a node $x \in sset(\Pi)$ invokes w-lookup(k) after t_1, then the return value must be some $y \in sset(\Pi)$.

- *Eventual Consistency*: If membership pattern Π is eventually stable, then there is a time t_1 such that for any key $k \in \mathcal{K}$, if two nodes $x_1, x_2 \in sset(\Pi)$ invoke w-lookup(k) after time t_1 and the return values are $y_1, y_2 \in \Sigma$ respectively, then $y_1 = y_2$.



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How to achieve W-KBR?

- Many existing protocols are close but no formal analysis.
  - Chord and some latest self-stabilizing protocols can be proven to achieve W-KBR
- Theoretical result:
  - W-KBR can implement Ω failure detector
    - $\Rightarrow$W-KBR can implement Consensus
    - $\Rightarrow$W-KBR cannot be achieved in purely asynchronous systems with even one crashes.
    - $\Rightarrow$We need some synchrony assumption
  - We assume eventually synchronous and fully connected links
    - Studying minimum synchrony assumption is a future work

Strongly Consistent KBR (S-KBR)

- Intuitively, routings with the same key always return the same answer
- But the system is changing
- Augment with key version number
- Primitive:
  - s-lookup$(k), k \in \mathcal{K}$
  - returns (*x*, *kver*), or return $\perp$

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S-KBR properties

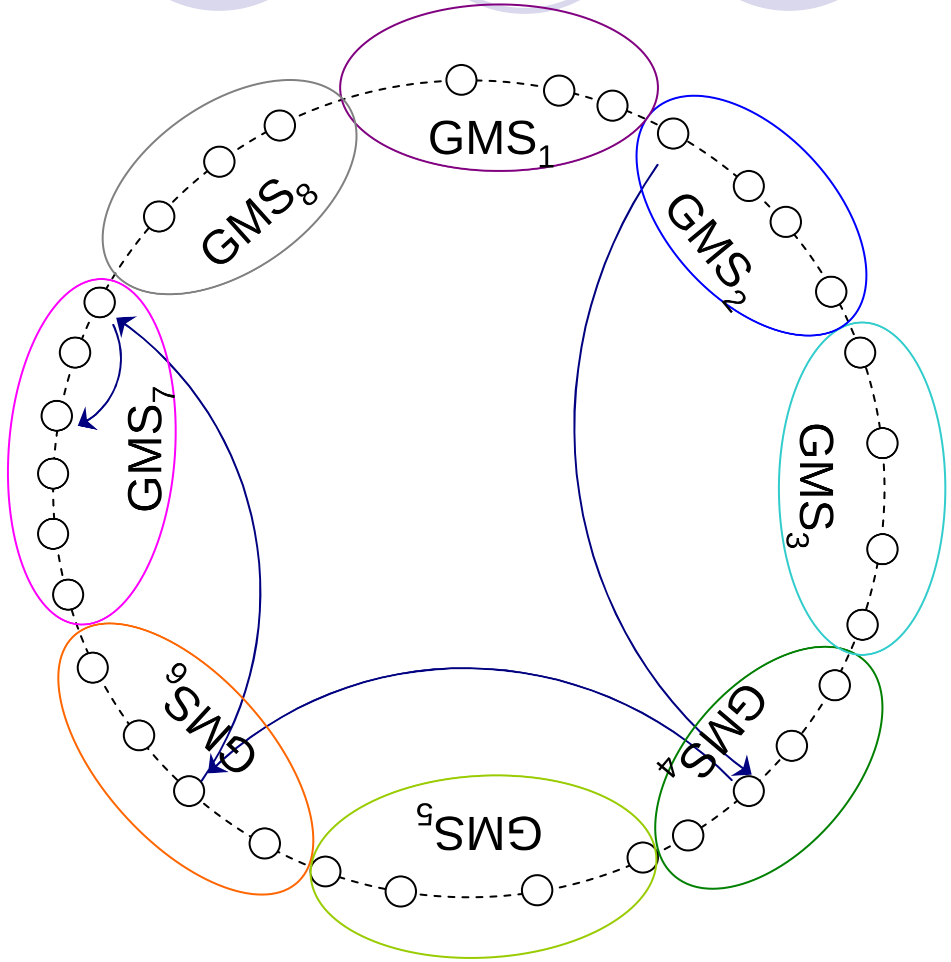
- *Causality Consistency*: If two nodes x_1 and x_2 invoke s-lookup(k) and get return values $(y_1, kver_1)$ and $(y_2, kver_2)$ respectively, and the return of x_1's invocation causally precedes the x_2's invocation, then $kver_1 \leq kver_2$.

- *Strong Consistency*: If two nodes x_1 and x_2 invoke s-lookup(k) and receive return values $(y_1, kver_1)$ and $(y_2, kver_2)$ respectively, and $kver_1 = kver_2$, then $y_1 = y_2$.

- *Eventual Stability*: If membership pattern Π is eventually stable, then there is a time t_1 such that for every $k \in \mathcal{K}$, there is a version number m_k, for every node $x \in sset(\Pi)$, if x invokes s-lookup(k) after time t_1, the return values must be non-$\perp$, and the version number in the return value is m_k.

Zone-Based S-KBR Algorithm

- Peers are partitioned into zones (static)
- Each zone maintained by strong group membership service (GMS)
- Routing between zones use W-KBR (a variant)
- Once routed into the target zone, select a node based on the key and the view, and *kver* is the version of the view.
- If W-KBR fails to reach the target zone, S-KBR fails



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Key Points of S-KBR Algorithm

- Zone partition to increase scalability
- W-KBR for locating the zone, and return failure if not found
  - Tradeoff between progress and consistency
- Provably correct

Proposals for Scalability and Adaptability

- Zone size determination
  - Larger zones, more cost and more consistency and vice versa $\Rightarrow$ continuum of consistency levels
  - Need analysis and simulation support

Proposals (cont'd)

- Zone merge/split
  - Zone merge: when the number of nodes in a zone is too low
  - Zone split: when the number of nodes in a zone is too high
- Changes required
  - Zone version maintenance
  - Zone merge requires inter-zone agreement ⇒ require higher level consistency

Proposals (cont'd)

- Dead zone removal and reactivation
  - A zone becomes dead if a majority of nodes crash or leave the system
  - Dead zone cannot make progress by itself
  - Requires zone monitoring and reactivation by neighboring zones $\Rightarrow$ inter-zone agreement and higher level consistency

Ongoing and Future Work

- Hierarchical design
  - Systematic approach for zone merge/splits and dead-zone handling
  - Higher level only deals with inter-zone level changes $\Rightarrow$ rare invocation, not on critical paths for routing and normal maintenance
  - Applicable to the maintenance of large-scale and dynamic systems
  - Need correctness proof
  - Plan to implement in WiDS and verify by simulations

Ongoing and Future Work (cont'd)

- Weakening network model
  - Do not need eventually synchronous and fully connected links
  - Similar to existing work related to Ω failure detector
  - Apply and adjust to P2P context

Questions?

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