Weak State Routing for Large Scale Dynamic Networks

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Which area should we **not** be working on in MOBICOM anymore?

**Ans:** Routing!

- Victor Bahl, Mobicom 2007 panel
Routing in Large-scale Dynamic Networks

- Routing table entries: "state" = indirections from persistent names (ID) to locators
- Due to dynamism, such indirections break
- Problematic on two dimensions
  - Dynamism/mobility => frequent update of state
  - Dynamism + large scale => very high overhead, hard to maintain structure
- We propose constructing routing table indirections using probabilistic and more stable state: **WEAK STATE**
A new class of State

- **Strong State**
  - Deterministic
  - Requires control traffic to refresh
  - Rapidly invalidated in dynamic environments

- **Weak State**
  - Probabilistic hints
  - Updated locally
  - Exhibits persistence
Hard, Soft and Weak State

Weak State is natural generalization of soft state
Random Directional Walks

Both used to announce location information ("put") and forward packets ("get")
Outline

- Our Weak State Realization
- Disseminating Information and Forwarding Packets
- Simulation Results
- Discussion & Conclusion
An Instance of Weak State

- The uncertainty in the mappings is captured by locally weakening/decaying the state.
- Other realizations are possible:
  - Prophet, EDBF etc...

Set of IDs

GeoRegion

Probabilistic in terms of membership

{a,b,c,d,e,f}

Probabilistic in terms of scope
Example: Weak State

- Consider a node \( a \).

- Where is node \( a \)?
  - \( \checkmark \)(i): It is in region AB with probability \( \mathbb{P}_1 \).
  - \( \checkmark \)(ii): It is in region B with probability \( \mathbb{P}_2 \).

\( \mathbb{P}_1 \leq \mathbb{P}_2 \)
How to “Weaken” State?

Larger Geo-Region

Aggregation

SetofIDs -> GeoRegion
Aggregation: setofIDs

- setofIDs: We use a Bloom filter, denoted by $B$.
Decaying/Weakening the set of IDs

- Randomly reset 1’s to 0. Same as EDBF [Kumar et al. Infocom’05]

\[
\begin{align*}
h_j(m) & \quad h_1(m) & \quad h_i(m) \\
0 & \quad 1 & \quad 0 & \quad 0 & \quad 1 & \quad 0 & \quad 0 & \quad 1 & \quad 1 & \quad \ldots & \quad 1 & \quad 0 & \quad 1
\end{align*}
\]

- Let \( \mathcal{Y}(m) = \mathcal{W}_{i=1}^m B(h_i(m)) \)
- Large \( \mathcal{Y}(m) \) → fresh mapping
- \( \mathcal{Y}(m) / k \) is a rough measure of \( P\{x_m \in A\} \)
Weakening State (Contd)

\[ |B| \leq \frac{u}{2} \]

\[ |B| \geq \frac{u}{2} \]

- setofIDs small, time passes:
  - \textbf{Decay GeoRegion}

- Either setofIDs large \textbf{OR}
  - GeoRegion Large \implies \textbf{Decay SetofIDs}
Random Directional Walks

- Both used to announce location information ("put") and forward packets ("get")
When a node receives a location announcement, it:
- creates a ID-to-location mapping
- aggregates this mapping with previously created mappings if possible
WSR involves unstructured, flat, but scalable routing; no flooding!

Forwarding decision: similar to longest-prefix-match. “**strongest semantics match**” to decide how to bias the random walk.
Simulation Objectives

- How does WSR perform?
  - ✔ Large-scale
  - ✔ High Mobility

- Comparisons:
  - ✔ DSR: works well for small scale, high mobility
  - ✔ GLS+GPSR: works well for large scale, low mobility

- Short answer: 98%+ packet delivery despite large scale AND high mobility.

- Tradeoffs: longer path lengths, \( \mathcal{O}(N^{3/2}) \) state overhead
Simulation Setup

- **Benchmarks**
  - DSR and GLS-GPSR
  - Random waypoint mobility model with $v_{\text{min}} = 5$ m/s and $v_{\text{max}} = 10$ m/s
    - WSR is robust against dynamism (please see the paper for details)

- **Performance Metrics**
  - Packet delivery ratio
  - Control packet overhead
  - Number of states maintained
  - Normalized path length
  - End-to-end Delay
Packet Delivery Ratio

- GLS breaks down due to overheads.
- DSR only delivers a small fraction of packets.
- WSR achieves high delivery ratio.

Graph showing the packet delivery ratio for different network sizes with WSR, GLS-GPSR, and DSR.
Maintaining structure requires superlinearly increasing overhead in GLS.
Number of States Maintained

The total state stored in the network increases as $O(N^{3/2})$ instead of $O(N \log N)$.
Per-Node State Dynamics

![Graph showing the relationship between time (seconds) and the number of states maintained. The graph indicates a state generation rate that matches state removal rate.]

State generation rate matches state removal rate.
Distribution of Per-Node State in the Network

The states are well distributed with a C.o.V 0.101
GLS sends packets only to destinations that are successfully located.

Packets take longer paths with WSR.
But, E2E Delay is Lower!

WSR uses random walks for discovery & dissemination => end-to-end delay is smaller
Weak State Routing also relates to
- DTN routing
- Unstructured rare object recall in P2P networks
- Distributed Hashing

Future work:
- Such extensions (especially DTNs)
- Theoretical analysis
Conclusion

- Weak state is soft, updated locally, probabilistic and captures uncertainty
- Random directional walks both for location advertisement and data forwarding.
- WSR provides scalable routing in large, dynamic MANETs
- WSR achieves high delivery ratio with scalable overhead at the cost of increased path length
Thank you

Questions?