CRDT-based Collaborative Editing in OppNets: a Practical Experiment

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Opportunistic Networks (OppNets)

- **Characteristics**
  - Mobile nodes with often unpredictable mobility
  - Device-to-device communication (short-range radio)
  - Sparse and/or irregular spatial distribution of the nodes

- **Challenge of network-wide communication**
  - Absence of continuous end-to-end connectivity
  - Network partitioned in “islands” with fluctuating boundaries
Opportunistic Networks (OppNets)

- Exploiting the mobility to communicate: the “store, carry, and forward” principle
  - Each mobile node can...
    - store messages for a while
    - carry these messages while moving around
    - forward these messages to neighbor nodes whenever possible

- Main research activity in OppNets
  - Development of routing/forwarding algorithm
  - Hypotheses
    - Need for network-wide message passing (point-to-point or dissemination)
    - Need of message-oriented API

Yet, possible alternative based on shared data structures
Conflict-free Replicated DataTypes

• Target sharing of data structures in distributed environments
  – Support optimistic replication (eventual consistency)
  – Independent local updates + asynchronous synchronization

• Strong theoretical background for several data types (counters, registers, sets, maps, lists, graphs...)
  – Specific update operations
  – Concurrency semantics

• Example: Add-wins sets

\[
\begin{align*}
\text{replica } R_1 & \xrightarrow{\text{add}(a)} \{ a \} \quad \text{Sync} \quad \text{replica } R_2 & \xrightarrow{\text{add}(b)} \{ b \} \\
\quad \text{Sync} & \xrightarrow{\text{add}(a)} \{ a, b \} & \quad \text{Sync} & \xrightarrow{\text{add}(a)} \{ a, b \} \\
\quad \text{Sync} & \xrightarrow{\text{rmv}(a)} \{ b \} & \quad \text{Sync} & \xrightarrow{\text{rmv}(a)} \{ b \} \\
\end{align*}
\]
Synchronization of CRDTs

- CRDTs typically deployed in Internet-based P2P or cloud-based networks
  - *Operation-based CRDTs*: broadcast each update to all other replicas (requires reliable broadcast)
  - *State-based CRDTs*: each replica periodically synchronizes with another randomly-selected replica

- Synchronization in OppNets studied in previous simulations
  - Operation-based: needs epidemic dissemination
    - too many small messages
  - State-based: synchronization with (temporary) neighbors
    - no routing required but large amount of data (full states) transmitted
  - A variant of state-based is the best compromise: delta-state-based synchro.
    - exchange of digests (typically state vectors) to determine the minimum amount of data to transmit

- Practical use of CRDTs in OppNets still to be demonstrated
Experimenting a CRDT-based application for OppNets

• Choice of application: collaborative edition of a document
  – Demanding application: respect of the causality of operations not trivial
  – Meaningful at small scale
  – Some of the needed building blocks already available

• Setting
  – Several contributors to a unique document, during several days
  – Laptops synchronize only when next to each other
    – via wireless D2D transmissions
  – The contributors move
    – their laptops are then switched off
Design and implementation

- **Global architecture**
  - Web-based application
  - Reuse of existing blocks
    - Text editor: Quill (HTML/CSS/Javascript)
    - Text CRDT implementation: Yjs (Javascript)
  - Development of dedicated software
    - Opportunistic communication layer
    - Yjs provider dedicated to OppNets
Design and implementation

- **Opportunistic communication**
  - Neighbor discovery
    - UDP Multicast
  - Synchronization (between two neighbors)
    - TCP session with TLS encryption

- **Yjs provider dedicated to OppNets (opp-provider)**
  - Ensures CRDT synchronization
    - When a user modifies the text: broadcast of the update
    - When two neighbors get in contact: delta-state synchronization
      - exchange of state vectors + exchange of delta states
Experiment

• Collaborative editing of a research report
  – 9 days
  – 6 contributors identified by their initials (PL, YM, FL, LT, NLS, FG)

• Laptop configuration
  – Wi-Fi dongle dedicated to the experiment
  – Systemd service for the opportunistic communication layer
  – Web browser with local server for Quill editor/Yjs CRDT/opp-provider
  – Log for collecting results
Results: activity

- Laptop activity

- Editing stats

<table>
<thead>
<tr>
<th></th>
<th>102 651 characters (36 pages)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of the final document</td>
<td>102 651 characters (36 pages)</td>
</tr>
<tr>
<td>Nb. of editing events</td>
<td>114 612 “ins”, 6 821 “del”, 104 “cut”, 81 “paste”</td>
</tr>
<tr>
<td>Nb. of synchronizations upon radio contact</td>
<td>109</td>
</tr>
<tr>
<td>Nb. of updates transferred during radio contacts</td>
<td>102 561</td>
</tr>
</tbody>
</table>
Results: synchronization

• Size of the messages carrying state vectors and delta-states

• Size of update messages
Results: convergence

- Evolution of the size of the document on each laptop
Conclusion

• Original real-life experiment of collaborative editing based on CRDT on an OppNet
  – Off-the-shelf text editor + CRDT implementation
  – Dedicated software for the synchronization of replicas

• Main outcome of the experiment: demonstration of the feasibility of the approach
  – Realistic conditions (mobility + editing actions)
  – Final convergence / bearable temporary divergences

• In OppNets, the use of CRDT can be a good alternative to network-wide message routing
  – Higher level of programming abstraction for developers