Bridging WSNs to the Internet: Issues on Event Filtering, Aggregation and Correlation

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Event-Based Middleware

- Event-Based Middleware (Publish/Subscribe)
  - Many-to-many Asynchronous Communication
  - Event Correlation Support
- No Pure Wireless Ad Hoc: Connect to Internet

Event Correlation Support

No Pure Wireless Ad Hoc: Connect to Internet
Emergence of WSN

- High Volume of Wireless Sensor Data
- Need to address Global Computing
- Recent Trend: Open API via Service Management

Issues on Event Correlation

- No interoperable event correlation semantics
  - Various Correlation semantics
  - Consumption mechanism, Duplication Handling
  - Temporal correlation over distributed environments
  - Network Wide Correlation vs. In-Network Aggregation
    - TinyDB – Aggregation but no Handling of Duplication
    - TinyLIME – Filtering but no Aggregation

- Need to Defined Generic Semantics
  - Semantics and Parameters

- Wireless Networks Specifics
  - Memory Restriction, Other Resource Restriction
  - Real-Time (time of a real event occurrence)
Unified Semantics for Event Correlation

- **Event Model**
  - Primitive events are instantaneous and atomic
  - Composite events based on composition algebra
  - Timestamp embedded (point-based, interval-based)
  - Spacestamp (location, groupID)

- **Use of Event Algebra to Express Event Patterns**
  - Well-defined semantics
  - Parameters to restrict basic expressions

- **Define Algebra in Two Steps**
  - Algebra Operation
  - Restriction Policy for individual composite event
    - Consumption Policy, Subset Policy, Precision Policy

- **Support Interval-semantics**

Filtering, Aggregation, and Correlation

- **Composite events represent complex patterns of activity from distributed systems**
Event Correlation Basic Operators

<table>
<thead>
<tr>
<th>Conjunction: A+B</th>
<th>Iteration: A*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disjunction: A</td>
<td>Negation: −A</td>
</tr>
<tr>
<td></td>
<td>Selection: A^N</td>
</tr>
<tr>
<td>Concatenation: A B</td>
<td>Spatial Restriction: A_S</td>
</tr>
<tr>
<td>Sequence: A ; B</td>
<td>Temporal Restriction: A_T</td>
</tr>
<tr>
<td>Concurrency: A</td>
<td></td>
</tr>
</tbody>
</table>

Example: Two sensors are placed before (B) and after (A) the stop signs on the road.

- (B;A)_2 : a car did not make full stop at the stop sign

Interval Semantics

- Use Interval Semantics not Point Detection Time
- Composite Event: Occurrence Interval

A: move into the area above 1000m, B: temperature goes down to -4°C
C: humidity goes up to 80%

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>A;C</th>
<th>B;(A;C)</th>
<th>B;C</th>
<th>A;(B;C)</th>
</tr>
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<tbody>
<tr>
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</tbody>
</table>

Single Point Interval Semantics
Temporal Conditions for Composite Events

<table>
<thead>
<tr>
<th>Relation</th>
<th>Timestamps of Primitive Events</th>
<th>Point</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>A before B</td>
<td>( t_p(A) &lt; t_p(B) )</td>
<td>○ A</td>
<td>○ – A – ○</td>
</tr>
<tr>
<td>(A + B)</td>
<td></td>
<td>○ B</td>
<td>○ – B – ○</td>
</tr>
<tr>
<td>(A</td>
<td>B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(A : B)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A overlaps B</td>
<td>( t_p(A) &lt; t_p(B) ) &amp; ( t_f(A) &gt; t_f(B) )</td>
<td>○ A</td>
<td>○ – A – ○</td>
</tr>
<tr>
<td>(A + B)</td>
<td></td>
<td>○ B</td>
<td>○ – B – ○</td>
</tr>
<tr>
<td>(A</td>
<td>B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(A B)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Define Precisely Complex Timing Constraints
  - Relations (before, meets, overlaps, finishes, includes, starts, equals)

Experiment using Active BAT data

- Composite Event \((\text{Andy}_{60} + \text{Brian}_{60})_{\text{machine-room}}\)
Time Model

- W/ GPS and W/O GPS Coordinated Approach
- Use Interval-Based Timestamp for Inaccuracy

- W GPS:
  - NTP
- In W/O GPS Environments:
  - Lightweight Local Clock Propagation
    - Keep consistency at Aggregator/Sink nodes instead network-wide

Conclusions and Future Work

- Unified Semantics for Event Correlation
  - Integrate Filtering, Aggregation and Correlation
  - Interval Semantics
  - Control Event Stream by Policies and Parameters

- Future Work
  - Complete Event Detection Algorithm
  - Integrate with Event Broker Grids
  - Algebra Transformation
    - Create reusable services for composite events
    - Adjust to Device Specific Constraints
    - Transform Complex Expression to Detectable Expression with limited resource
TIME (Transport Information Monitoring Environment)

- Integrate heterogeneous sensor networks into a event-based middleware (10/2005 – 9/2010)

Existing sensors:
- CCTV
- GPS on Bus
- Traffic Signal
- Car Parks
- Pedestrian Cross

New addition:
- GPS on Vehicles
- RF tags
- Video Camera
- …

Thank you!
Questions?

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