Replicating Information in a Power Distribution Management System

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Background

- Ongoing privatization of power distribution utilities.
  - New owners demand increased revenue.
  - Economies of scale to cut costs.
- Authorities exert regulatory pressure.
  - Consumers have to be compensated for outages.
  - Network operators are not allowed to take advantage of their monopoly.
- Higher quality of supply expected.
  - Growing dependency on electricity.
  - Customers' tolerance decreasing.

Background

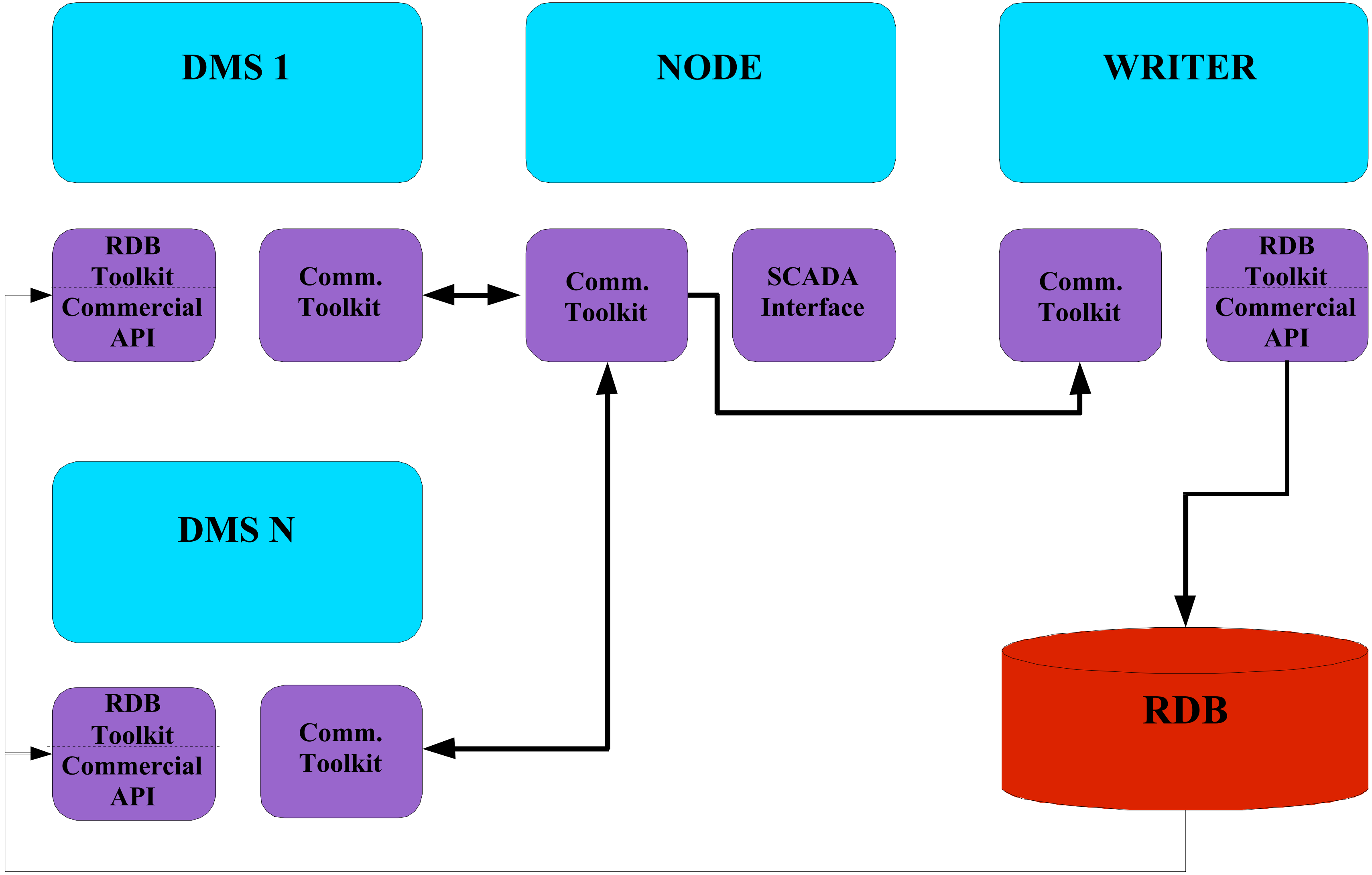
- Utilities increasingly rely on information technology
  - Streamlining operations, automating tasks.
  - Efficient handling of crisis situations.
  - Reporting, analyzing, optimizing.
- Power Distribution Management Systems (DMS) support the operation of an electricity network.
  - Geographical and/or schematic presentation of the network.
  - Real-time, multi-user, interfaces to other systems.
  - Planning, supervision, calculations, simulations, ...

Goal and methods

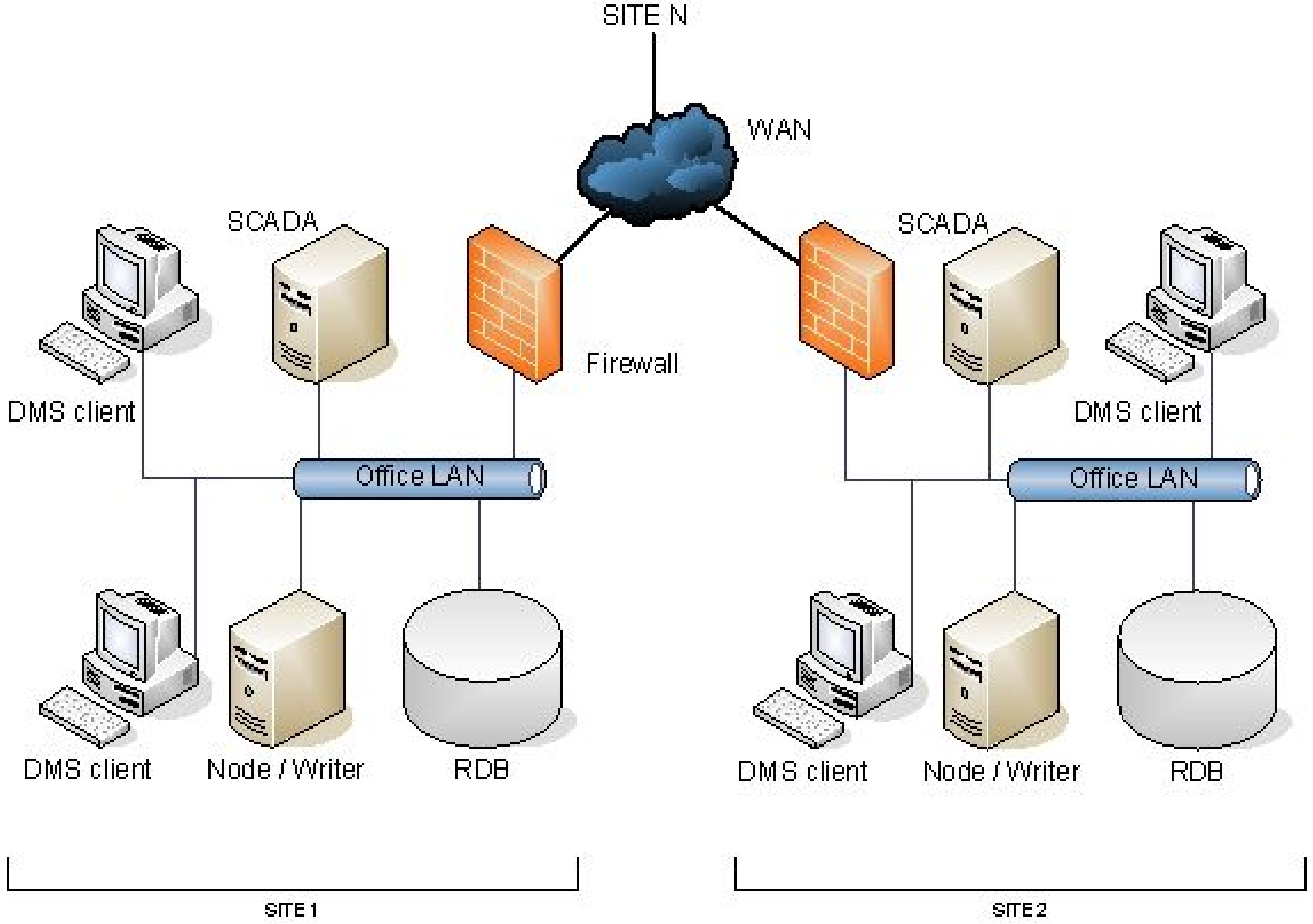
- The goal was to outline a possible solution for expanding a DMS system to a multi-site one.
- The solution should be evolutionary, not disruptive.
- The steps taken were as follows:
  - Analyze the current system.
  - Identify the main issues.
  - Read relevant literature and papers.
  - Apply gained insight to outline a reasonable solution.

The Distribution Management System

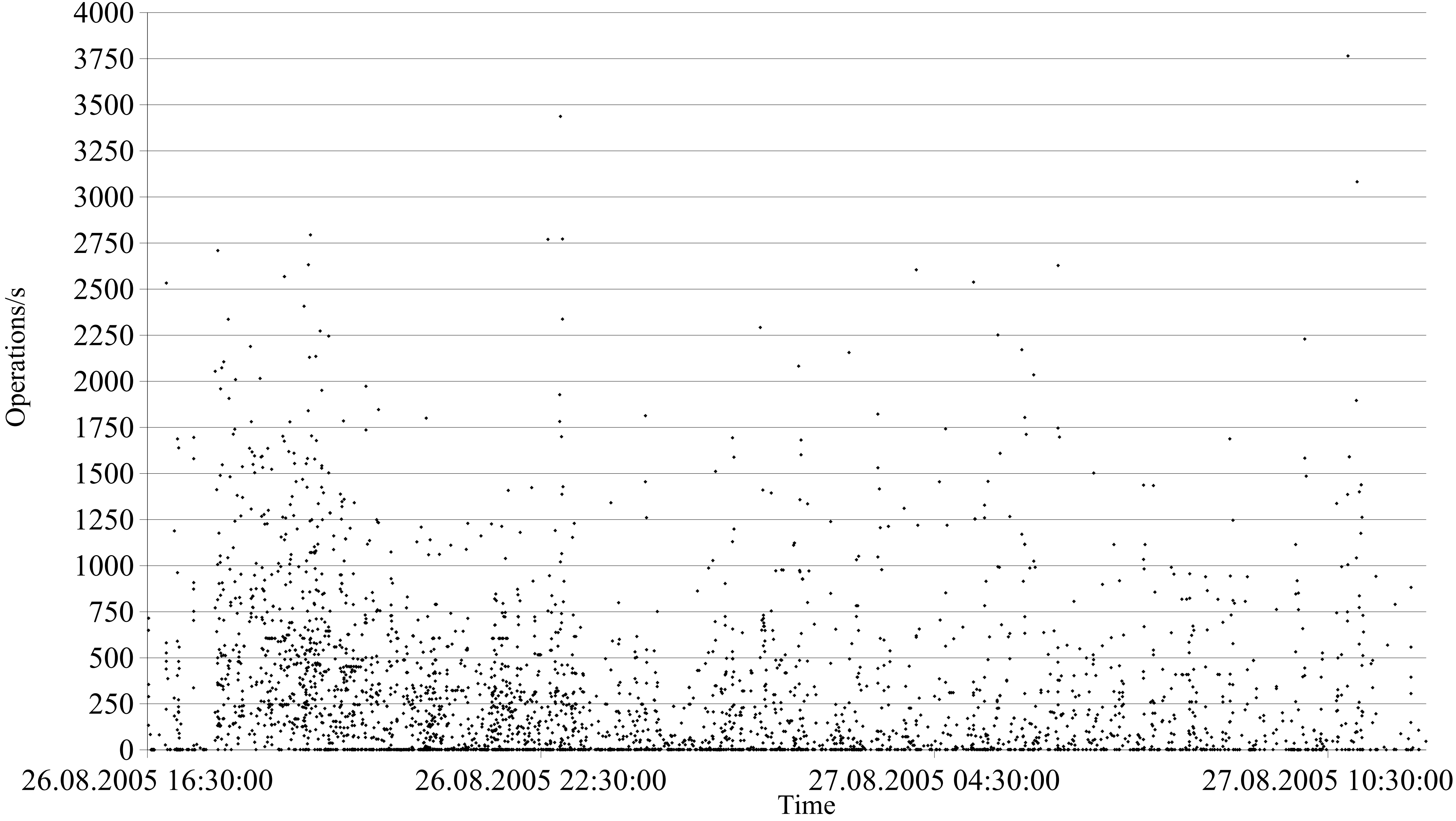
Single site


DMS 1
NODE
WRITER
RDB Toolkit
Commercial API
Comm. Toolkit
Comm. Toolkit
SCADA Interface
Comm. Toolkit
RDB Toolkit
Commercial API
DMS N
RDB Toolkit
Commercial API
Comm. Toolkit
RDB

...to multi-site



Database messages at Writer (Σ=1.04M)



Identified requirements

- Distributed operation.
- Reduced data transfer.
- Prevent loss of data while database is unavailable.
- Exclusive editing of records.
- Possibility to create new records while database is unavailable.
- Platform and technology independence.

Databases and replication

Relational Database

- Based on the relational model by E.F. Codd (1970)
- Stores data using the abstraction of a table.
  - A table's columns have a data type and name.
  - A row is uniquely identified based on the primary key of the table.
  - A foreign key is a reference to a row in another table.
- Queries on the stored data are made using the SQL-language.
  - Manipulation of sets, relational algebra.

ACID properties

- Operations on data are performed as transactions.
  - A transaction is a sequence of requests.
  - The result may depend on the order of execution.
  - One or several requests may fail.
  - Data may be accessed concurrently.
- A transaction should fulfill the ACID properties
  - Atomicity: A transaction either completes successfully, or it has no effect at all.
  - Consistency: A transaction takes the system from one consistent state to another.

ACID properties

  - Isolation: A transaction must be performed without interference from other transactions.
  - Durability: The effects of a successfully completed transaction are saved in permanent storage.
- Atomicity and Isolation are mainly a matter of concurrency control.
- Consistency is mainly defined by an application's business rules. The database management system enforce uniqueness of primary keys etc.
- Concurrency control strategies: serial equivalence, locking, time stamp ordering, optimistic

Replicated Database

- A setup where there are several instances (copies, replicas) of a database. Each contains same set of data.
- Provides:
  - Improved usability through decreased latency (WAN->LAN)
  - Improved availability, fault tolerance
- Changes to data are applied (replicated) to all instances.
- Consistency requirements must be relaxed.
  - Otherwise too much communication overhead.

Replicated Database

- Several approaches to implementation
  - Differences in complexity, throughput, consistency guarantees.
- Primary copy
  - One master, updates propagated to slaves.
  - Clients access only master.
- Update everywhere
  - Clients allowed to operate on any copy.
  - Other copies updated directly by client or by middleware.

Replicated Database

- Propagation of updates
  - Replay operations vs. send only results.
  - In Eager Replication a client has to wait for the updates to be applied at all copies.
  - In Lazy Replication updates are propagated only subsequently. Conflict resolution strategy needed.
- Problems and challenges
  - Distributed deadlock (and detection thereof).
  - High latency, communication overhead.
  - Conflict resolution strategy, system management.

Solution outline

Concurrency control

- Analysis of traffic revealed that 99% of messages are destined to the so called log tables.
  - No concurrency control needed for those.
  - Locking is a feasible solution for other data.
- Lock manager to be implemented at each Node.
  - Global lock server would be a single point of failure.
  - Voting wouldn't address network fragmentation.
- A record needs to know its primary location.
  - Request is forwarded to appropriate Node.
  - Locking is programmer's responsibility.

Network topology

- Complete graph.
  - Estimated number of Nodes ~10. Simple, robust.
  - No re-routing if link breaks.
- Alternative: overlay network.
  - Application layer routing protocol.
  - Optimal use of network resources
  - Non-trivial to implement, difficult to debug.
- Alternative: flooding
  - Lots of data duplication.

Data distribution

- Messages received by the Node from local clients are written to a ring buffer on hard disc.
- Each message is given a sequence number and contains a source identifier.
- A Message can be erased from the buffer once it has been acknowledged by all peers and the local Writer.
- If a message concerns data of another site, it is first sent to that site's Node only. There it is handled as if received from a local client. Thus the master site for a particular data item is guaranteed to be the most up-to-date.

Miscellaneous

- Analysis of traffic revealed that messages to log tables contained mostly redundant data.
  - Extracting duplicate data and coalescing several messages into one reduces burst rate by 84%.
- Id number management similar to locks
  - Preallocation of ranges to sites.
  - File as persistent storage.

Conclusion

- In the end relatively simple solutions were found.
  - Majority of operations have no need for concurrency control.
  - Reliable and robust distribution of data.
- Platform independence can be maintained.

Further development

- Time synchronization
- Monitoring
- Cold stand-by
- Automated Meter Reading