Distributed Diagnostic Simulations for the Smart Grid

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ABSTRACT

Energy efficiency is usually achieved by reducing the energy consumption as far as possible. With the growing amount of renewable energy sources, energy efficient usage also has to consider what kind of and when power is consumed. By matching the availability of electrical power with the current demands, the amount of unused energy and therefore overall energy production can be reduced. The so called smart grid aims to provide this matching with a broad deployment of smart meters to acquire the current demand. However, current approaches to the smart grid cannot handle the huge amount of sensors and energy sources involved in a scalable way. Most data acquisition systems focus on the lookup and reading of single sensors and therefore do not fit the requirements of a large scale power grid simulation. We propose a Global Sensor Grid (GSG) which provides consumers with data preprocessed to their needs instead of delivering raw sensor data. With this decoupling from the actual sensors, multiple consumers can benefit from improvements in data acquisition and avoidance of the redundant processing of data by each consumer. By integrating so-called diagnostic simulations into the GSG, gaps in sensor coverage can be filled with higher precision than normal interpolation.

Categories and Subject Descriptors

C.2.4 [**Computer Systems Organization**]: Computer Communication Networks—*Distributed Systems*

General Terms

Algorithms, Management, Performance

Keywords

Diagnostic Simulation, Global Sensor Grid

1. INTRODUCTION

With the increasing deployment of sensors and sensor networks it has become possible to use their data for a wide range of applications on a global scale [1, 2, 3]. Especially the simulation of global weather has gained interest over recent years. With the increasing deployment of renewable energy sources their power output strongly depends on the current wind and light conditions. Up to now, the required atmospheric data has been mostly provided by weather forecasts. Such forecasts involve very complex simulations and therefore take a long time to provide the required data.

In contrast to these forecasts, so-called diagnostic simulations (DS) are used to provide data for regions where no sensor measurements are available. Diagnostic simulations run in real-time parallel to the real world. By continuously integrating current sensor measurements the simulation converges towards the real world. Accurate data can thereby be provided for virtually every point in the observed area in real-time. However, as the resolution of such simulations increases, a huge amount of data has to be stored and processed. In the context of wind fields, for example, future systems aim to provide a spacial resolution of 5 meters to cover local turbulences, resulting in over 20 bn data points worldwide. This also requires high bandwidth to the applications that use those wind fields in a high resolution.

Existing global sensing systems lack support for the integration of diagnostic simulations. Although they are designed for a high number of sensors, the number of data points from a diagnostic simulation is still orders of magnitude higher than the number of sensors supported. The synchronization between and distribution among brokers in a sensing system, which are required to get the highest quality results from the DS, are not supported at all. The GSG is designed to directly address these requirements and provide the necessary methods for runnign distributed diagnostic simulations.

In this poster we present an overview of the Global Sensor Grid and the integration of diagnostic simulations into it. Research challenges that have to be faced in order to provide data required for efficient operation of renewable energy sources and other components of the smart grid are pointed out. In addition, approaches to reduce the power consumption of the Global Sensor Grid itself are introduced.

2. THE GLOBAL SENSOR GRID

The Global Sensor Grid consists of three main parts: the sensors at the lowest level, the consumer that queries the data, and a broker network of computing nodes that connects the two other parts. Sensors include all types that are currently deployed in the field ranging from single very complex ones like weather stations over smart meters to simple small sensor nodes in a wireless sensor network (WSN). To address the scarcity of resources of the sensors, data is not sent directly to the end user but is rather reused to supply multiple users at once.

The consumers that use the GSG as a source of information usually pose their request as a continuous query. Such a query at least consists of the area of interest, the type of sensors to query, and either a fixed update interval or a predicate that specifies when new information should be sent. Some consumers, like simulations, require a complete grid of measurements even if the area of interest does not provide full sensor coverage. The GSG closes this gap with diagnostic simulations to provide a high density of information for the whole observed area. Consumers can also specify the required spatial resolution of the DS. By integrating such diagnostic simulations directly into the Global Sensor Grid, multiple applications can benefit from the increased measurement density without additional effort. To find an optimal partitioning of the observed area to brokers, algorithms and methods from domain decomposition approaches are combined with those for load distribution found in peer to peer systems.

All the aforementioned processing will be performed by a Global Sensor Grid Middleware (GSGM) which is executed on the nodes of the broker network. The tasks of the GSGM comprise the execution of diagnostic simulations, the division of the whole observed area amongst nodes, and the routing of queries and results. Especially the routing in the overlay network formed by broker nodes poses new challenges since the diagnostic simulations introduce new dependencies between neighboring nodes to synchronize their boundary conditions. These horizontal dependencies are also not supported by other sensor middleware approaches because their queries each usually form a cycle free query graph.

3. RESEARCH CHALLENGES

The greatest challenge that has to be faced for the Global Sensor Grid is of course the huge amount of data in the system. The synchronization of boundary conditions between the brokers of the GSG, required to conserve the accuracy of the simulation, even introduces additional traffic. Traditional content delivery approaches do not suit this task since consumers can request information from arbitrary areas and not specified channels. Furthermore, traditional in-network processing approaches that aggregate data cannot be used because consumers require all measurements rather than an aggregated estimation. However, since many queries overlap there is still potential for data reduction by identifying the intersecting parts of queries and reusing partial results for multiple consumers. To achieve this, requested grids have to be aligned despite different mesh resolution and query boundaries. The trade-off between maximal data reduction and minimal latency depending on the degree of reuse has to be found.

Another problem is the huge and massively increasing number of sensors available worldwide. There are already billions of mobile phones equipped with sensors, wireless sensor networks for habitat and building monitoring, weather stations, surveillance devices and many more present. With the comprehensive deployment of smart meters and the ongoing web-enablement of sensors, the management and lookup of this huge number of devices becomes very difficult. Again, while existing approaches can be used to provide the lookup of single sensors, they do not support the identification of reusable data sources. Even if these sources could be identified, the question remains in which way to route the results between them. Additionally, energy constrained sensing devices have to be used as efficiently as possible to ensure a possibly long operating time.

Latency is one of the most important QoS properties for the efficient control of the smart grid and other smart environment approaches. In a globally distributed system like the GSG, the provision of low latency results becomes a challenge. On the global scale, signal propagation delays become an important factor. And as the number of brokers increases with more sensors and higher resolution of data, the number of intermediate hops in the broker network also grows. One approach to compensate the communication latency are predictors, which provide the capability to provide real-time estimates of measurements to consumers. They have originally been introduced in the domain of WSN [4, 5] to reduce communication, which is also essential for the GSG.

We will further investigate the challenges in cooperation with other projects of the Stuttgart Research Centre and Cluster of Excellence SimTech. Especially the distributed diagnostic simulation of wind fields as foundation for dispersion simulations is currently in our focus. Such wind fields also provide the input for power output prediction of wind power stations.

4. ACKNOWLEDGMENTS

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5. REFERENCES

[1] K. Aberer, M. Hauswirth, and A. Salehi. A middleware for fast and flexible sensor network deployment. In *VLDB '06: Proceedings of the 32nd international conference on Very large data bases*, pages 1199–1202. VLDB Endowment, 2006.

[2] M. Balazinska, A. Deshpande, M. Franklin, P. Gibbons, J. Gray, S. Nath, M. Hansen, M. Liebhold, A. Szalay, and V. Tao. Data management in the worldwide sensor web. *Pervasive Computing, IEEE*, 6(2):30–40, April–June 2007.

[3] P. Gibbons, P. Gibbons, B. Karp, Y. Ke, S. Nath, and S. Seshan. Irisnet: An architecture for a worldwide sensor web. *IEEE Pervasive Computing*, 2(4):22–33, 2003.

[4] S. Santini and K. Römer. An adaptive strategy for quality-based data reduction in wireless sensor networks. In *INSS'06: Proceedings of the 3rd International Conference on Networked Sensing Systems*, pages 29–36, 2006.

[5] D. Tulone and S. Madden. *Wireless Sensor Networks*, chapter PAQ: Time Series Forecasting for Approximate Query Answering in Sensor Networks, pages 21–37. Springer Berlin / Heidelberg, 2006.

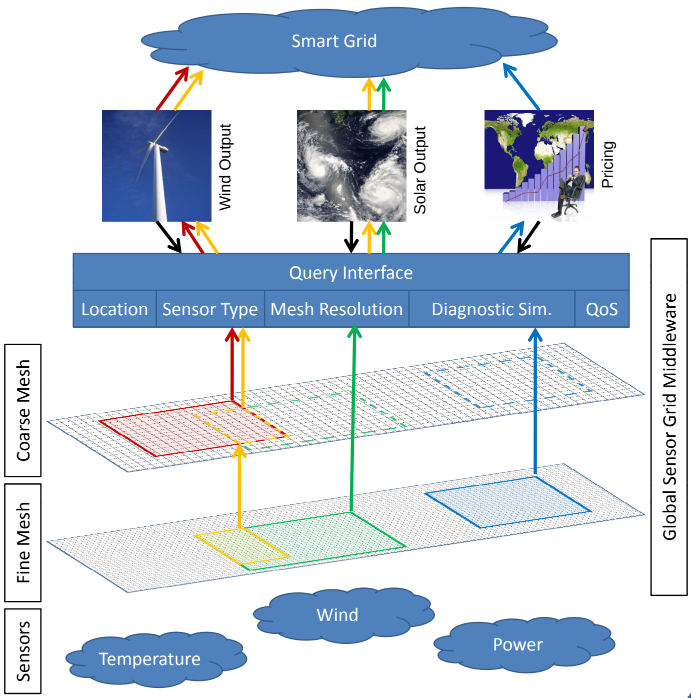
Distributed Diagnostic Simulations for the Smart Grid

Introduction

With the increasing deployment of renewable energy sources their power output strongly depends on the current wind and light conditions. Up to now, the required atmospheric data has been mostly provided by weather forecasts. Such forecasts involve very complex simulations and therefore take a long time to provide the required data. We propose a Global Sensor Grid which provides real-time data by tightly integrating and distributing so-called diagnostic simulations.

Diagnostic Simulations for the Smart Grid

- Provide power predictions for the smart grid with access to measurements
  - Full availability of data despite low sensor coverage
  - Higher quality of data than raw interpolation or just measurements
- Support real-time access to time-lagging sensors



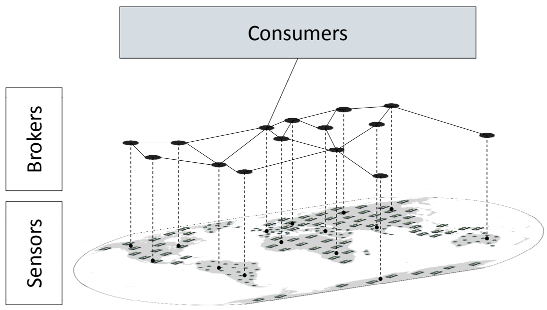
Applications Key Challenges

- Huge amount of data has to be processed and transmitted
  - High density query results from high number of consumers
  - Synchronization of boundary conditions between brokers
  - Common approaches for in network processing unsuitable
  - New mechanisms for data reduction based on reuse of results required
- Increasing number of data sources has to be managed and indexed
  - Efficient lookup of sensor nodes and sources for reuse required
  - Smart meters, weather stations, and running queries
  - Horizontal dependencies of data producers on the base level
- Provision of low latency to the consumers
  - Spatial distribution entails increased number of hops and signal delay
  - Tradeoff between low latency and bandwidth conservation
  - Extension of predictors from WSN to multi-hop operation in GSG

Global Sensor Grid Architecture

The Global Sensor Grid includes the following three main parts:

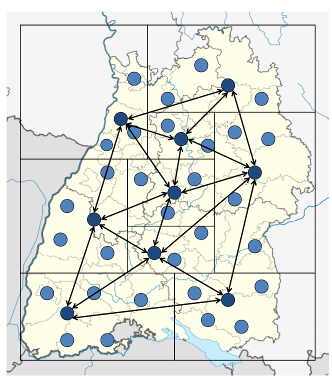
- Brokers provide computation and communication backbone
- Sensor nodes are assigned to brokers according to management areas and might also lack persistent power supply (wireless sensor networks)
- Continuous queries are used by applications to specify the geographic region of interest with spatial and temporal resolution



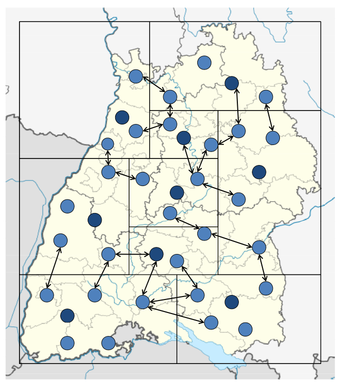
Global Sensor Grid System Architecture

Distribution of Diagnostic Simulations

- Integration of the diagnostic simulation into the Global Sensor Grid
  - Partitioning of simulation and mapping to communication backbone
  - Equal distribution of load among brokers
  - Rearrangement of partitioning with changing load situations
  - Routing of queries from and results to consumers
- Synchronization between brokers required
  - Exchange of boundary conditions for higher accuracy
  - Alignment of simulation grids for better performance
  - Data dependencies between adjacent nodes have to be met



Communication Backbone



Data dependencies between adjacent nodes

Current and Future Work

- GSG is under evaluation of distributed wind field calculation
  - Challenges in real application scenarios
  - Projects in the SimTech cluster of excellence
- Wind fields are used for multiple simulations
  - Dispersion of substances in the atmosphere
  - Prediction of wind energy output for efficient adaptation of power grids

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