GOSSIP ALGORITHMS FOR SMART GRIDS
Bibliographic Review

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Abstract: Motivated by the need of application of reliable distributed algorithms in modern power systems, we study gossip algorithms. The inspiration of gossiping can be adapted to communication, computation or spreading information needs of power grids related to the control of voltage and frequency, to the load balancing and to every aspect of control and measurement in a power network. A short reference on related applications is the evidence of capabilities of gossip algorithms.

1 INTRODUCTION

Modern power grids integrate gradually an increasing number of dispersed micro-generators and new kind of loads, such as electric vehicles. Apparently, customers tend to become more conscious of their electricity consuming behaviours and they want to fully understand and take control of the costs related to energy, while they are waiting to enjoy uninterruptible power. Therefore, power grids tend to become smart grids and dispersed generation must be followed by distributed intelligence enabling grids to take advantage of ICT infrastructures.

In this paper we attempt a bibliographic approach of gossip algorithms, as fully distributed algorithms of processing and disseminating information, and we argue that they should be implemented on smart grids of the future. Specifically, gossip algorithms could be applied to power quality control, to information dissemination of smart meters, to local load balancing, to determination of the best operation point of a dispersed generation unit.

2 GOSSIP ALGORITHMS

Gossip Algorithms were firstly described, under the name epidemic algorithms, in 1987 (Demers, 1987) as a tool for rapid update awareness among database replications. The core idea of Gossip Algorithms is the fast information dissemination among a group of nodes, such as a rumour is spread within a social network or like a virus infects a group of humans. So far Gossip Algorithms have been variously used in routing in ad-hoc networks, in data aggregation, in peer sampling. Gossip Algorithms may not offer the optimally best solution to a problem, but they give distributed systems a powerful tool for solving a distributed problem in a good inexpensive way. In a smart grid, a candidate to participate in gossiping could be every part having the ability to communicate with other parts and holds some kind of data.

2.1 Description

A Gossip Algorithm consists of a sequence of steps, which are periodically followed by all nodes interconnected in a network. The scope of the procedure is the spread of new information in exponential rate.

A common Gossip Algorithm includes three main steps: peer selection, decision about the exchanged data and data processing. Each of these steps includes a certain procedure, which can be deterministic or not. The peer selection for the information propagation can be either probabilistic or defined under a specified metric. Let the node A to be the initiator of communication. Node A has a

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partial knowledge of the candidate nodes, with which a connection can be established. This set of nodes is a subset of the nodes of network, which is known to node A through a network map or through a periodical procedure, in which each node identifies its neighbourhood nodes within its communication range area. Therefore a type of peer selection algorithm may contain an internal priority list according to the distance of neighbours. Another option is to leave the nodes select their peers randomly according to a possibility density function. In any case gossiping ensures the new information will be spread exponentially. The second step of the gossiping procedure includes a decision about the data exchanged in each round of communication. The content of the message sent depends on the final scope of the algorithm. If the final scope is data aggregation, the message may contain an average value. If the scope is the control of a critical growth, the message may contain the current measurement of the growth. The third step of gossiping is apparently connected to the second step and deploys a number of comparisons or calculations internally.

Formally expressed, gossip algorithms include operations at any node of a network of n nodes, which satisfy the following properties (Shah, 2009):

(1)The algorithm should only utilize information obtained from its neighborhood

(2)The algorithm performs at most O(di logn) amount of computation per unit time.

(3) Let |Fi| be the amount of storage required at node i to generate its output. Then the algorithm maintains O(poly(logn) +|Fi|) amount of storage at node i during its running.

(4)The algorithm does not require synchronization between node and its neighbors

(5)The eventual outcome of the algorithm is not affected by 'reasonable' changes in the neighborhood during the course of running of the algorithm.

The classification of gossip algorithms is based on the final scope of the algorithm and on the time between gossiping rounds. The final scope of the algorithm can be information dissemination, simple overall computations (e.g. averaging) or locally computations of separable functions (e.g. load balancing). According to the timing of the message transmissions, a gossip algorithm can be either synchronous or asynchronous. Furthermore, the direction of information transmitted is an important parameter of a gossip algorithm. When gossip initiator nodes are asking for information from their partners, we have pulling type of gossiping, while the action of pushing new information to their partners, means pushing type of gossiping. There is also a mixed type of gossiping, which is names as push-pull, when gossiping nodes inform each other. The research so far presents best convergence for push-pull gossiping type.

According to the convergence criterion there are two different types of gossip algorithms (Renesse, 2008), (Jelasity,2007) : anti-entropy and rumor-mongering. Anti-entropy gossiping includes information propagation until it is replaced by newer information, while rumor-mongering means that new information is spread until there is high probability that all the nodes have received the information. The information spreading with rumor-mongering can be stopped by when the receiver is aware that rumor has spread sufficiently

Gossip algorithms gather a variety of characteristics, which make them ideal for distributed applications in a changing environment like a power system.

Gossip algorithms are by default implemented distributed and there is no need for central coordination. They do not rely on a static network topology and are resistant to communication failures. They are fast and scalable to large systems.

3 RELATED APPLICATIONS

We provide a short description of some of the related applications. We describe a group of power grid problems or generally sensor network problems solved by gossip algorithms.

3.1 Peer-to-Peer Architectures

In (Beitollahi, 2007) authors describe four peer-to-peer architectures and evaluate them according to their ability to deploy an overlay network over nodes of the power grid. As nodes we can see physical part of the grid, such as circuit breakers or transformers, or agents representing distributed generators and loads. Some of the proposed architectures and routing algorithms are proved to meet better the needs of modern power grids, to fulfil basic operations like demand and production matching, intelligent load shedding, secondary and tertiary control.

3.2 Decentralized Aggregation

3.2.1 Accelerated Gossip Algorithms for Distributed Computing

In (Cao, 2006) authors propose an accelerated gossip

algorithm with application in averaging measurements of sensor networks. The need of acceleration in gossip algorithms for sensor networks proves their importance.

The core of the algorithm is based on the idea that each sensor has at its disposal local memory (e.g. a register), where the sensor stores the current and previous measurements. The content of the message transmitted in every round of the gossiping is deployed by a mixture of these stored values. The accelerated gossip algorithm offers a tenfold convergence rate by decreasing only the local computations, and performs quite well when applied to overlay networks of more than 20.000 nodes.

3.2.2 Randomized Gossip Algorithms

In (Boyd, 2006) authors have designed a gossip algorithm suitable for averaging and for decentralized optimization in an arbitrarily connected network. We can see the results both of the synchronous and the asynchronous implementation of the algorithm. The asynchronous model of gossiping shows better convergence speed. We can find a description of a fast aggregation algorithm for wireless sensor networks, modelled as Geometric Random Graphs.

3.2.3 Geographic Gossip

In (Dimakis, 2008) authors propose a gossip algorithm, which exploits the geographic information contained in nodes. The application evaluated is on data aggregation of sensor networks. The algorithm differs from random gossiping in the way of determination of gossiping peer. The initiator of gossiping searches the candidate partner having knowledge of the geographic properties of its neighbourhood.

3.3 Control of Microgrids

In (Brabandere, 2007) authors implement a set of distributed control algorithms based on gossiping. The nodes participating in gossip are distributed energy resources of a microgrid and the final scopes of gossip algorithms include the voltage/frequency control to ensure stable operation, power generation following local load deviations and the economic optimization of power production based on a totally distributed matching. The results show a very encouraging view of the capabilities of gossip algorithms as decentralized computational entities serving the need of modern power systems.

3.3.1 Control of Microsource Generation

Electric generation within a microgrid can consist of different renewable and conventional fuel technologies. The selection of operating period and power level of generators is quite complicated and depends on cost of fuel, cost of deferral of electric power, and impact of emissions and differs on respect with the most important goal of the microgrid (e.g. energy saving, load-generation balancing). Modern power systems encompass dispersed generators with different technical limitations and interests. The control of this diverse portfolio matches well to gossip algorithms as the core of distributed computation.

3.3.2 Domestic Loads Control

Controllable domestic loads can participate in the optimization process followed by the microgrid. They can form a group of loads, which can follow a specified schedule. However, in future power grids controllable domestic loads should be able of participating themselves in a more dynamic way in the energy market.

3.3.3 Load Shifting and Shedding

The microgrid undertakes the load and generation balancing employing different policies. The control of generation is a choice already described. Apart from that, microgrid should find smarter ways to avoid a black-out during peak hours. Shedding of loads could be an option, while an elegant way would be to utilize energy storage or renewables with pump-storage facilities so as to store energy during value periods, when conventional generation is inexpensive and when there is excess of renewable energy production. The scheduling and coordination of these complex operations could be a very interesting field of application of gossiping. A mesh network could be constructed, containing a group of nodes (e.g. generators, loads, renewables, storage facilities).

3.3.4 Ancillary Services

The other side of the microgrid should be selling power to the main utility grid during overall peak load period aiming to maximize its profit. Microgrid could provide valuable ancillary services to the main utility grid. However, providing these ancillary services means that the microgrid as an entity has established a fast and reliable communication with the main grid, as well as that every node of the

microgrid itself communicates well with each other.. Microgrids may participate in deregulated energy markets market as both suppliers, and customers of electricity services, leading to global optimization of exploitation of natural resources. The key of the success of this operation is the deployment of reliable distributed algorithms resistant to communication failures, such as gossip algorithms.

4 MESH NETWORKS OVER POWER SYSTEMS

A prerequisite of gossiping is the existence of mesh networks. The main idea of introducing gossip algorithms into power grids is to build mesh overlay networks above the existing structures. The wide spread of smart meters in low level voltage will allow the structure of new mesh networks over power grids. However, there is a need of careful selection of the adopted communication technologies. An improved selection could be the exploitation of wireless low-range communication technologies, such as Radio Frequencies or WiMAX, to enable the construction of an overlay mesh network.

According to Gupta and Kumar an ad-hoc wireless network can be modeled by a Geometric Random Graph. The wireless ad hoc network of nodes is modeled with transmission radius. Nodes are placed randomly on a grid and are connected with other nodes in their neighborhood within their transmission range. An example of such a graph is shown in the following figure.

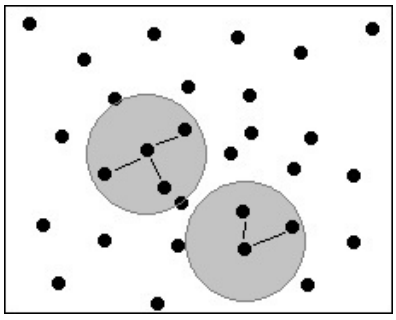

Figure 1: Geometric Random Graph.

The representation of power grid parts as nodes of an overlay mesh network, transform it to smart grid and enable the implementation of gossip algorithms to improve performance. Gossip algorithms should prove themselves as a powerful distributed tool for information exchange and decentralized computations in a dynamically changing network relied on external changes (e.g. increased load, environmental conditions, unit and grid failures).

5 CONCLUSIONS

In the context of liberalised energy markets, modern power grids should play an active role. Distributed generation and renewable energy resources should be integrated in a manner that does not harm the stability and economic operation of the system. The available options of maintaining the stability and the cost effectiveness of modern power systems include flexible management of controllable loads, the curtailment or shifting of the production of renewable resources, the use of energy storage devices. The central control and coordination of these operations does not always ensure the best outcome, as it stresses the communication resources and lacks on reliability due to communication failures. The choice between the different available solutions should economic notions, having in mind the technical limitations. The application of gossip algorithms on mesh networks, which have been built over power systems, gives the wanted distributed impetus and integrates a fairly new ICT infrastructure with the domain of smart grids.

6 FUTURE WORK

As a future work, we intend to make an evaluation of different communication technologies for smart meters and elaborate the results of implementation of gossip algorithms over these communication technologies. The simulation of communication is intended to be held on Network Simulator 3. The main problem is that the communication simulation is based on discrete time events, which is in contrast to the continuous character of the power grid operation.

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