# Fault Tolerant Network Routing through Software Overlays for Intelligent Power Grids

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## Abstract

*Control decisions of intelligent devices in critical infrastructure can have a significant impact on human life and the environment. Insuring that the appropriate data is available is crucial in making informed decisions. Such considerations are becoming increasingly important in today's cyber-physical systems that combine computational decision making on the cyber side with physical control on the device side. In an intelligent power system, power management of energy is provided in a highly distributed and scalable manner. The system has to insure that intelligent devices have the appropriate data to make control decisions for microgrids and with respect of microgrid connectivity to an upstream utility power grid. The job of insuring the timely arrival of the data falls onto the network designed to support these intelligent devices. This network needs to be fault tolerant. When nodes, devices or communication links fail along a default route of a message from A to B, the underlying hardware and software layers should ensure that this message will actually be delivered as long as alternative routes exist. Insuring multi-route pathways and discovery of these pathways is critical in insuring delivery of critical data. In this work, we propose methods of developing network topologies of smart devices that will enable multi-route discovery in an intelligent power grid. This will be accomplished through the utilization of software overlays (1) that maintain a digital representation of the physical network and (2) allow new route discovery in the case of fault. Our vision is that the application of this approach in an intelligent power grid will enable intelligent power devices to make automated, decentralized decisions and to maintain state of lower-level devices.*

## 1. Introduction

Failures of network equipment in intelligent systems can result in incorrect decisions regarding device failure, faulty decisions made due to lack of data, system reconfigurations, or degradation of system performance. In modern network topologies, network failures resulting in these issues may be avoided through smart routing technologies that can take faulty equipment out of the loop. However, such fault tolerance is only feasible in situations where the faulty equipment does not constitute a single point of failure of communication within the network. Therefore, it is important to maintain redundant pathways through networks.

Routing decisions are an important part of networking. Concrete routes are configured statically in many networks. When a networking device on a static route fails, any messages sent along that route will timeout and result in communication failure with respect to this end point. In these scenarios, many systems will assume the end point to be out of service. This does not have to be the case. Networks of devices can be designed to contain multiple pathways to connect clusters of nodes in a redundant manner. If these pathways exist, a network needs to be able to alternate and utilize them in times of fault.

Another consideration to make when designing a network is its shape / topology of connectivity. The shape of the network can have a significant impact on its performance. For example, networks with a ring topology can only sustain a single link failure. Fully connected mesh networks offer the greatest amount of fault tolerance but this comes at the cost of one connection per pair of nodes, which imposes exponential resource needs.

In this work, we present a method of utilizing software network overlays to provide shape and meta information about connectivity. Utilizing knowledge of shape/topology and meta information, the network is able to react in case of faults and generate new routes through the network in manner that is transparent to the user by providing a software overlay middleware.

## 2. Software Overlay Network

Using software overlays to improve network resilience is an idea first described by Anderson et al. [1]. In their work, they presented the basis for a resilient overlay network (RON) partitioning distributed nodes that may contain a different topological perspective than the external, physical network topology. Their work assumed nodes to potentially be separated geographically across the Internet. Our work utilizes a similar partitioning for the routing of messages but deviates in that it utilizes this approach in a much smaller local area network (LAN) to facilitate fault-tolerant communication. In our approach, devices are organized into software partitions that are calculated locally based on their IP address. Partitions are created as a side effect of subnet masks. Each partition is assumed to be fully connected. These partitions are then grouped together in clusters of a certain static size. The combined group of clusters and partitions are interconnected with horizontal and vertical uplinks. An example is depicted in Figure 1. Utilizing vertical uplinks, we then organize our

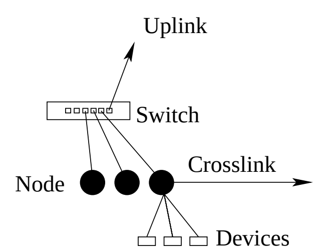

Fig. 1. Device Cluster

software overlay network into a tree-based topology. Similar work has been performed in the High Performance Computing domain by Varma et al. [2]. Uplinks will serve as the default routing path for general message communication in the absence of failures. Figure 2 depicts the vertical uplinks and shows the resulting tree formed by them. Uplinks are necessary to provide inter-cluster communication. They constitute the network backbone of the system. To increase fault tolerance, it is necessary to introduce horizontal crosslinks that will serve as secondary paths through the network, as depicted in Figure 2.

This abstract software overlay can fit onto arbitrary intelligent power grids. Most importantly, it provides redundant communication pathways and the potential to connect the network in alternate ways in case of faults in the system via its software middleware layer. This capability is crucial for allowing intelligent nodes in the system to maintain appropriate state and to coordinate the actions of system control tasks.

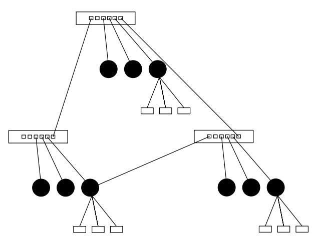

Fig. 2. Cluster Tree

In Figure 3 communication pathways are primarily used through the switching interface composed of uplinks as depicted in the first half of the figure. Our system differs from a regular network in the composition of a series of intelligently placed crosslinks that can occur as node to switch or node to node lines. In the event of a loss of a uplink, the abstract network will enter into a reorganization mode. Reorganization mode is typically defined in the system as what to do in the case of a sent message timeout. In this work, the reorganization mode will explore the possibilities of alternate routing in the network by using meta-information describing the characteristic of the network. In using software overlays part of the network information that is provided to a node is its partition information that the node can use to determine its neighbors on a switch and the partitions above and below it in a tree. From this information a node in reorganization mode can begin communicating with its neighbors to determine important information. The most important of this information being the location of crosslinks, and through using the crosslinks determining if this is a node failure on the recieving end or a link failure along the switching path. The second half of Figure 3 depicts the utilization of a crosslink in an attempt to resend a previously failed message. A proper response from the recieving node would indicate to the reorangized node that the failure was in the switch link.

A system like this could be very useful in an intelligent powergrid utilizing a distributed network. This system will aid the distributed grid intelligence of the intelligent power grid to insure more stable reorganizations in the case of wide

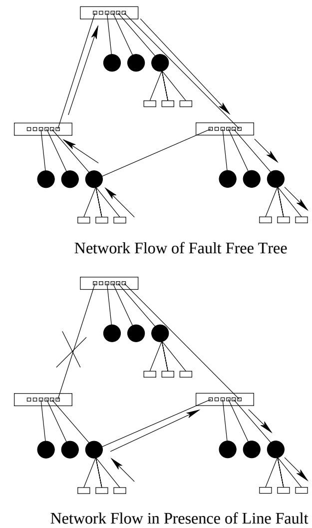


Fig. 3. Message Pathways

area faults in the power grid. One of the primary issues at hand is distributed leader election of intelligent energy management nodes. A central theme in leader election is dealing with non-determinism in the network. This work by enabling more effective communication will aid in creating node reorganizations that provide a more stable service.

## 3. Conclusion

The vision of this work is to enable intelligent power nodes to communicate, even in the events of multiple link failures. The first step to accomplish this is through introducing increased but intelligent redundancy in the links of the network. We introduced a middleware framework that utilizes software overlays to support fault-tolerant communication in a network with redundancy through alternate communication paths. Our development of low overhead route detection algorithms to assist in the presence of single and multiple link failures constitutes the key contribution to provide such fault tolerance in a transparent manner to other control software. Overall, our software middleware architecture for fault tolerant network overlays realize the vision of sustainable and decentralized energy management on the software side in intelligent energy systems and beyond.

## References

[1] D. G. Andersen, H. Balakrishnan, M. F. Kaashoek, and R. Morris. Abstract the case for resilient overlay networks.

[2] J. Varma, C. Wang, F. Mueller, C. Engelmann, and S. L. Scott. Scalable, fault-tolerant membership for MPI tasks on hpc systems. In *International Conference on Supercomputing*, pages 219–228, June 2006.