A Peer-to-Peer (P2P) Overlay Communication Network Infrastructure for Smart Microgrids

S.Marzal, R. Salas-Puente, R. González-Medina, E. Figueres, Senior Member, IEEE, G. Garcerá Member, IEEE

Abstract— **In order to integrate a large number of distributed energy resources in distribution grids, a robust decentralized information and communication control structure is required. This paper proposes an overlay peer-to-peer (P2P) Chord topology for monitoring smart microgrids in real time, which has features as scalability, reliability, fault resiliency, robustness, and cooperativeness among others. The proposed communication architecture has been implemented and experimentally tested on a microgrid. Real data analysis demonstrates that the architecture has a good performance and could be implemented in low cost systems.**

Index Terms—**Decentralized Systems, Peer-to-Peer Overlay Communications; Chord Topology, Performance Networks Parameters**

I. INTRODUCCIÓN

The communication network plays a critical role in microgrids due to the increase number of renewable resources and microgeneration units (Distributed energy resources, DERs) that are being deployed in it **[1]**, **[2]**. Now, the communication infrastructure must have the ability to easily handle an increasing amount of data traffic and services requests as well as provide a real-time monitoring and control operation of all these nodes. Thus leading move from a centralized communication infrastructure to a decentralized communication infrastructure **[3]**. The evolution towards the future smart microgrid requires the development of distributed communication architectures and protocols [4]**,** [5]**.** In the last decade MAS (Multi-Agent Systems) technology has been adopted in power system management [5] [6]. In this structure each DER unit is consider an agent. An agent is a computer system able to do tasks on an autonomous way and with communication capabilities for solving problems through cooperation, coordination and negotiation. However, these agents cannot simultaneously communicate with other agents, and only one-on-one interactions between individual agents is permitted [7], [8]. The absence of such functionality might result in a lack of knowledge about the microgrid global status and in a sub-optimal allocation and a poor management of the critical resources [7]**.**

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To overcome this limit, a communication infrastructure and protocol in the context of decentralized microgrid monitoring and control is proposed. In such proposed architecture the agents interact over Peer-to-Peer (P2P) overlay network. Therefore, the main contributions in this paper are:

- The development of an overlay communication infrastructure and stack protocol, specially designed for real time microgrid control and monitoring.
- The development of a P2P nodes for DERs power measurements tasks with an active and passive role.
- The development a data frame for transmitting information through peers nodes.
- The experimental setup in an experimental microgrid in order to evaluate the performance of the proposed communication infrastructure.

The remainder of this paper is organized as follows. IN section II the proposed P2P overlay communication model are described. Experimental setup and results for evaluating developed network performance are presented in Section III. Finally Section IV presents some conclusions.

II. PROPOSED ARCHITECTURE

We envisage a P2P-overlay application system as a four-layered structure. The stack protocol builds for this model is based on TCP/IP. Fig.1 illustrates the proposed architecture.

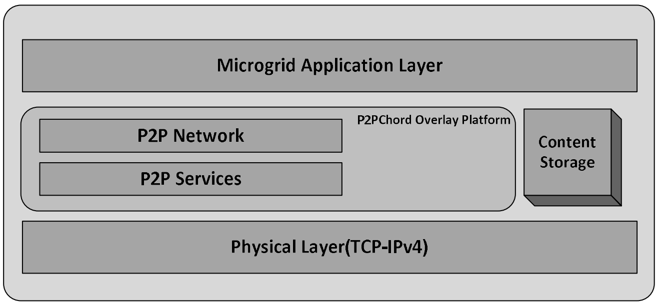


Fig 1. Proposed Communication Architecture and Stack protocol.

To fully support the intelligent capabilities of the microgrids is mandatory to connect electric modules such as inverters, transformers, switches, intelligent electric appliances and others over this information infrastructure. Therefore each peer node is interconnected with electric modules and with such communication infrastructure.

The different layers developed for implementing the proposed P2P overlay network is described below.

A. P2P Chord Overlay Platform

One critical technology in a microgrid is the real time monitoring and control of a large number of power devices as a way to know the current status of the microgrid [1]**.** To reach this objective a communication architecture based on a peer-to-peer overlay network. P2P systems has been developed. This architecture allows to avoid a single point of failure and are scalable because the available resources grow with the number of nodes joining the network. Thus, nodes are capable to cooperate to achieve a common goal and they have self-organization capabilities.

The connectivity between nodes is carried out through a physical IP network while network topology is created in a virtual network, called overlay, which are built on top of the physical networks. Overlays allow increased flexibility, extensibility and adaptive reconfiguration. This implies that each node communicates with each other to create self-organizing overlay structures on top of the subjacent physical networks [9]. The overlay communication network has been designed using a Chord -P2P overlay topology. Chord overlay organizes the total number of peers (N) on a virtual ring. The circle is ranged from 0 to 2^{m-1},where m is the number of bits in the identifiers. To be able to communicate, each peer has to aware its successor node in the ring, due to each peer has a link to its predecessor and successor peer on the ring [Fig2].

Each peer in a m-bit circle maintains a routing table called finger table with m entries. So when node r wants to communicate with node x, node r employs its finger table to localize the successor of the target node's [10]. In order to maintain the internal structure and exchange periodic information between nodes the finger table is dynamically built. Peers can entry and exit constantly in the network without disturb it.

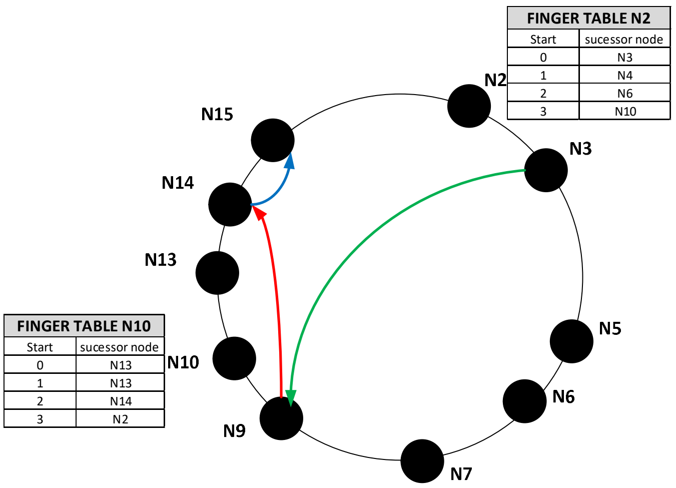


Fig.2. Chord Topology and an example of routing path for a peer.

In addition, in our architecture, the overlay network is used to provide multicast support where real-time monitoring and control signals need to be distributed in a large set of participants [11]. The stack protocol built for this model is based on TCP/IP and the proposed architecture defines two levels or software layers for implementing overlay-P2P services (Fig.1): A first layer which provides networking P2P services over the transport layer which main task are: resource and network discovery, session establishment, routing, data transfer between nodes and entry/exit management of nodes. The second application layer working on P2P service is responsible for the processing and data analysis, event management and status supervisory microgrid for stability maintenance.

B. Content Storage

Content store layer comprehends data bases. Each node is defined in a manner that it will be able: On one side, react in case of the power threshold of electric module is exceeded and on the other side, provide information about its actual status every time. Thus, each node is composed by two parts, as indicated in Fig. 3: The static side where the description of the node itself, IP address and the definition its power limits is done; and the dynamic side where the actual power parameters are obtained periodically during the microgrid operation. Moreover the developed P2P nodes, against traditional client/server concept wherein clients carry out the actual measurements while the acquired raw data are transferred to the server side for further processing, can operate simultaneously as server and client. This feature allows for a node has an active and passive roles to interact with other peers and Plug and Play capabilities.

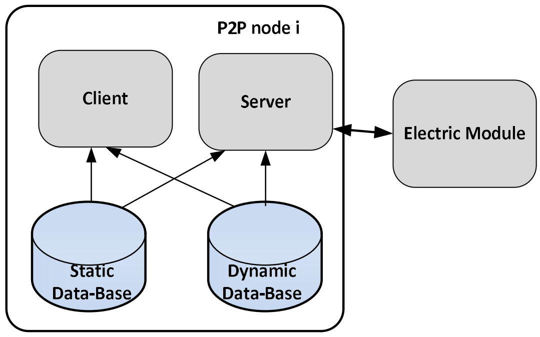
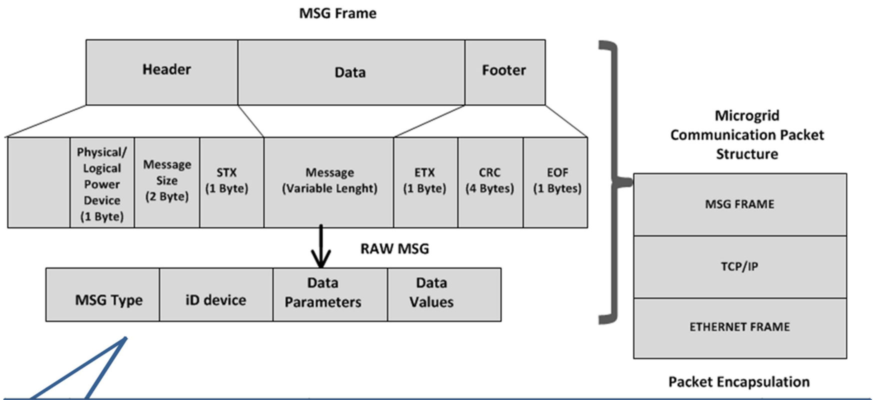


Fig.3. Peer to Peer node connections and capabilities.

C. Application Layer

Knowing the microgrid status at each moment is essential to offer a greatest degree of trustworthiness service. Therefore, the power parameters of underlying equipment of nodes must be measured continuously. In this regard, a communication application protocol for transmitting data between nodes has been developed. An overview of Microgrid communication packet structure for monitoring and control power activities of this application protocol is shown in Fig.4.

In addition to the raw message, each packet is encapsulated with TCP/IP and Ethernet headers. The message header contains type of message (ToM), id device address, and data parameters and values. As shown in Fig. 4, there are five ToMs that the microgrid Controller can send to the Power nodes, and the function and size of each ToM are also described.



	Type of message(ToM)	Description					Size
1	Command/ Request	To update data,to control electric modules, to change power values					Variable length (0-65.536 bits)
2	Microgrid Periodic Data read	Power Consumed (DC bus, AC bus, Hybrid)	State of Charge (SoC)	Micro-generation(DC bus, AC bus, Hybrid)	Voltage (DC bus, AC bus, Hybrid)	Frecuency (AC Bus)	
3	Microgrid Control	Power extracted from the grid to MG	Power injected to the grid from the MG	Energy Dispacht Limit	Loads limits(DC Bus, AC Bus)	On /off MG	
4	Confirm/ Notification message	Failure notifications, messages, etc.					
5	Periodic Ping	Node is alive reports					

Fig.4. Frame structure developed and protocol encapsulation. The IP header is used to transport the proposed packet to each node in P2P Overlay. The encapsulated packet is unwrapped when it reaches its final destination.

It is important to highlight that the overall proposed communication architecture has been developed using Python programming language, due to it is expected that it be implemented in a low cost embedded computer such as Beagle Bone Black (BBB), Raspberry Pi, etc. In microgrids these miniature computers are embedded with the underlying energy resources to form an intelligent electronic device (IED) and allow to interact with them. The implementation of this kind of network architectures is not possible using microcontrollers because the TCP/IP stack protocol is too heavy for these kind of devices and the monitoring and control microgrid operation results suboptimal and inefficient.

III. EXPERIMENTAL RESULTS

An experimental setup to evaluate the performance and behavior of the proposed communication network infrastructure has been built. A communication scenario has been deployed over a LAN network which is employed for controlling the experimental microgrid. Testbeds have been carried out in a virtual environment where HP ProLiant microserver G8 Intel GI610T/16GB is the employed host. VMWare ESXi 6.0 is the infrastructure used for virtualizing and virtual switch have been configured to 100 Mbps bandwidth.

Virtual Machines (VM) running on Ubuntu 14.04 has been raised for carry out the tests. In these tests, measurements of communication network usage, end-to-end network packet latency, number of hops to reach the destination peers and CPU usage according transmitted message size is done.

Fig.5 shows average end-to-end latency per node. This latency is stabilized around 15 milliseconds. There are latencies peaks of around 25 milliseconds corresponding to the incorporation of new peers to the network.

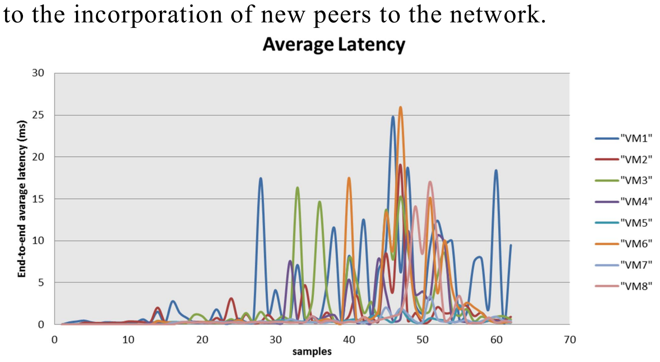


Fig.5. Average Latency (in milliseconds) per peer on a network of N=8 peers

Fig.6 shows that the number of hops to reach the target node is stabilized around 4 hops from 7 to 12 nodes in the network. These results are getting due to the routing table used by the chord peers which allows to find the optimal path to reach the target node. This characteristic allows to provide lower latencies and lower number of hops as they not have to query all nodes in the network for the searching.

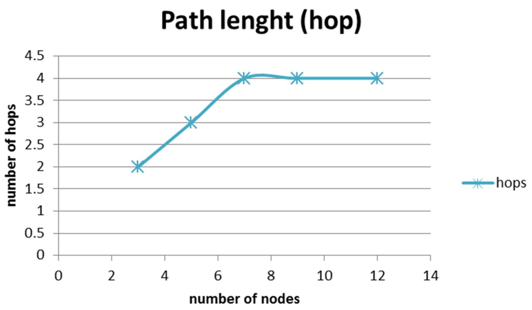


Fig.6.Number of hops according of number of peers in the network

Fig.7 shows CPU average usage in percentage per peer node. The scenario reproduces CPU usage when different sizes of packets are transmitted in the network. TCP Maximum Transmission Unit (MTU=1500 bytes) is the maximum packet size transmission on the network (100% of packet load). Measurements with 25%, 50%, 75% and 100% of MTU have been taken.

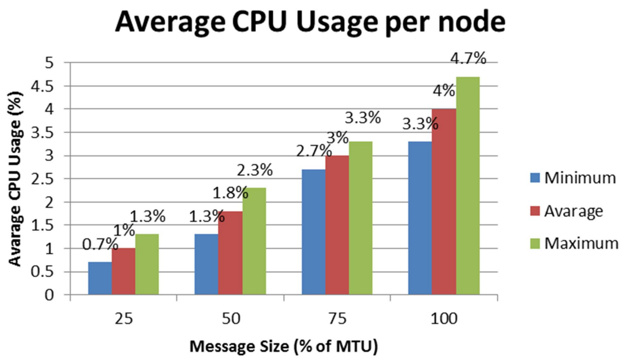


Fig.7. CPU usage (in percentage) per node according of the transmitted message size.

As shown in the figure, CPU average usage increases with the message length. However, the average CPU use is around 3% per node of the total CPU, relatively low. Thus enabling implement it in low cost systems.

IV. Conclusions

In this paper a decentralized control strategy based on peer-to-peer overlay technology for the integration a high deployment of distributed energy resource into the microgrids has been proposed. It has shown that the peer-to-peer paradigm can be applied to build up the communications layer of microgrids, allowing robustness, efficiency, scalability and flexibility. Finally, it has been tested the network performance through parameters as latency, number of hops to reach target nodes and CPU usage with different packets length. These results show that either end-to-end latency or number of hops has tended to stabilize with number of nodes. The CPU average use could allow to incorporate the developed protocol stack in low cost systems.

Acknowledgment

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