Network Coding in Smart Grids

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Motivation

- Change of paradigm in electricity distribution
- Smart grid communication involve bi-directional communication :
  - From distributed sensors (meters) to a base station
  - From centralized controllers to flexible devices
- Two families of technologies under consideration :
  - Wireless communications
  - Power line communications

Motivation

- Need of resilience, efficiency and security in smart grid communications
- Communication architecture should explore communication channels at the fullest, exploiting :
  - the broadcasting properties of MV/LV networks
  - the storage capacities of individual nodes
- Potential application of alternative protocols
- Particular focus on network coding

Services involved with smart grid communications

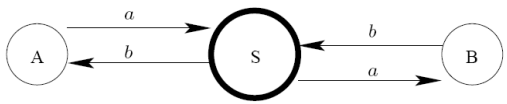
- Two main types of communications
  - many-to-one
  - one-to-many
- Two different visions in smart grid communications :
  - Periodic (e.g. 15-60 min) communication
  - Real-time communication (within 5-10 sec)

Requirements for smart grid communications

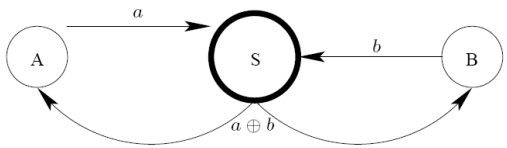
- Data rates
  - $\approx$ 10 kbps to a base station (15 min periodicity)
  - similar for advanced management functionalities (10 sec, periodicity)
- Time criticality
- Reliable communications
- Security and privacy

Network coding basics

- Applies to multicast communication
- Intermediate nodes mix different data flows through linear combinations



(a)

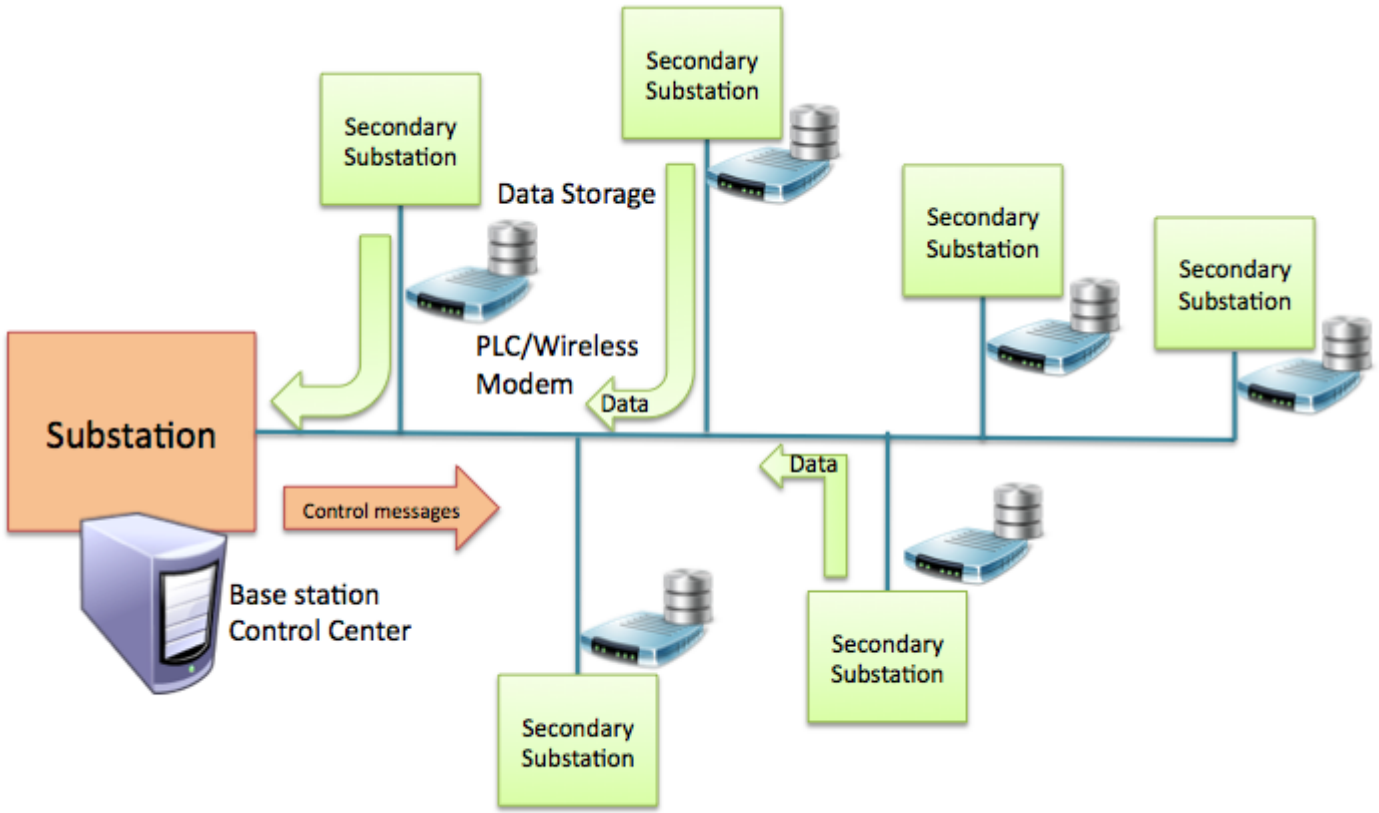


(b)

- Achieves the maulticast capacity of a network
- Benefits in terms of throughput, reliability, and fault tolerance

Typical communication infrastructure

- Typical communication infrastructure for a MV network



Data gathering

- Typical data collection based on master-slave approach
- Multi-hop Vs Single-hop
- Data aggregation and opportunistic collection
- Network coding :
  - data emission (based on schedule or opportunistic)
  - overhearing
  - sharing network-coded information
  - sending aggregated info to the base station

Control traffic

- solutions for one-to-many communication
  - flooding
  - controlled flooding
  - coded flooding
  - network routing
- Automated repeat request

Security aspects

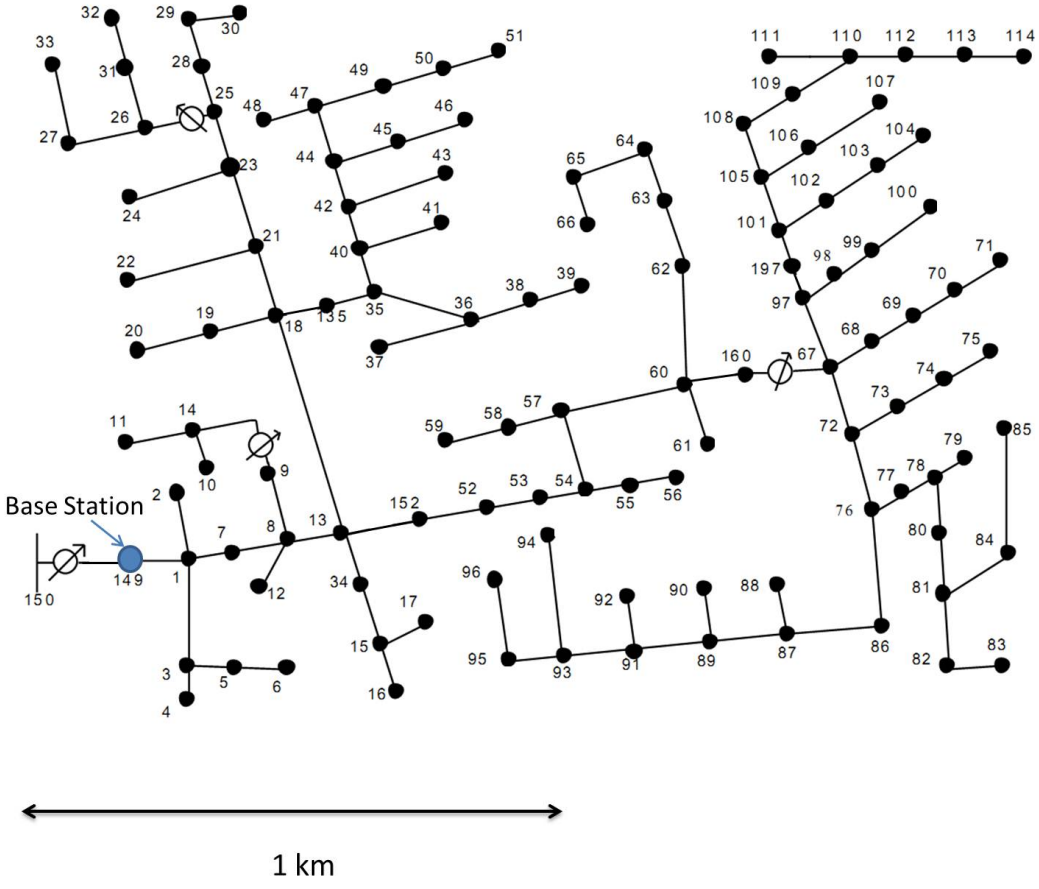
- Challenge of resilience to cyber attacks
- Potential solutions :
  - Use redundancy for legitimate flows
  - Use hash functions to identify corrupted information
- Consumer privacy
  - Network coding can be secure against eavesdroppers
  - Possible combination with cryptography

Topology issues

- Impact of network topology on network coding performance
- Study of a IEEE MV benchmark network (4.16kV - 123 buses)
  - Electrical topology (connection graph and length of cables)
  - Geographic topology (localisation of the buses)
- Connectivity rule :
  Two nodes are connected if their distance is below a treshhold r

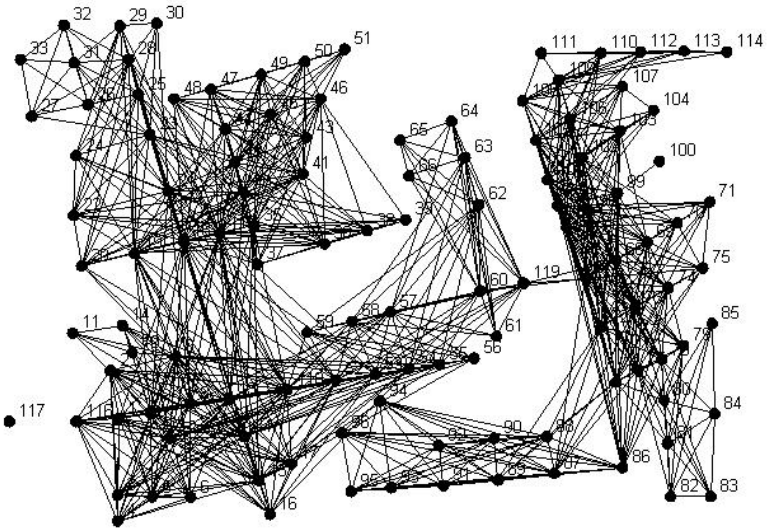
Example System

IEEE 123 node test feeder

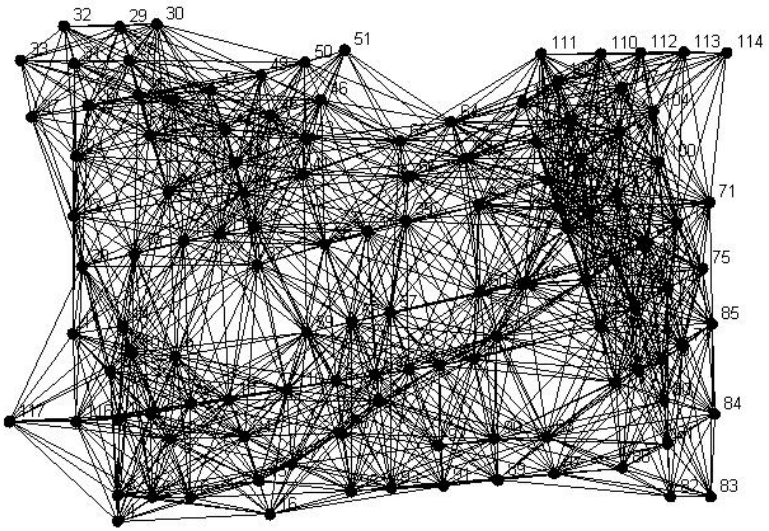


Connectivity graph

Connectivity graphs with $r = 500m$

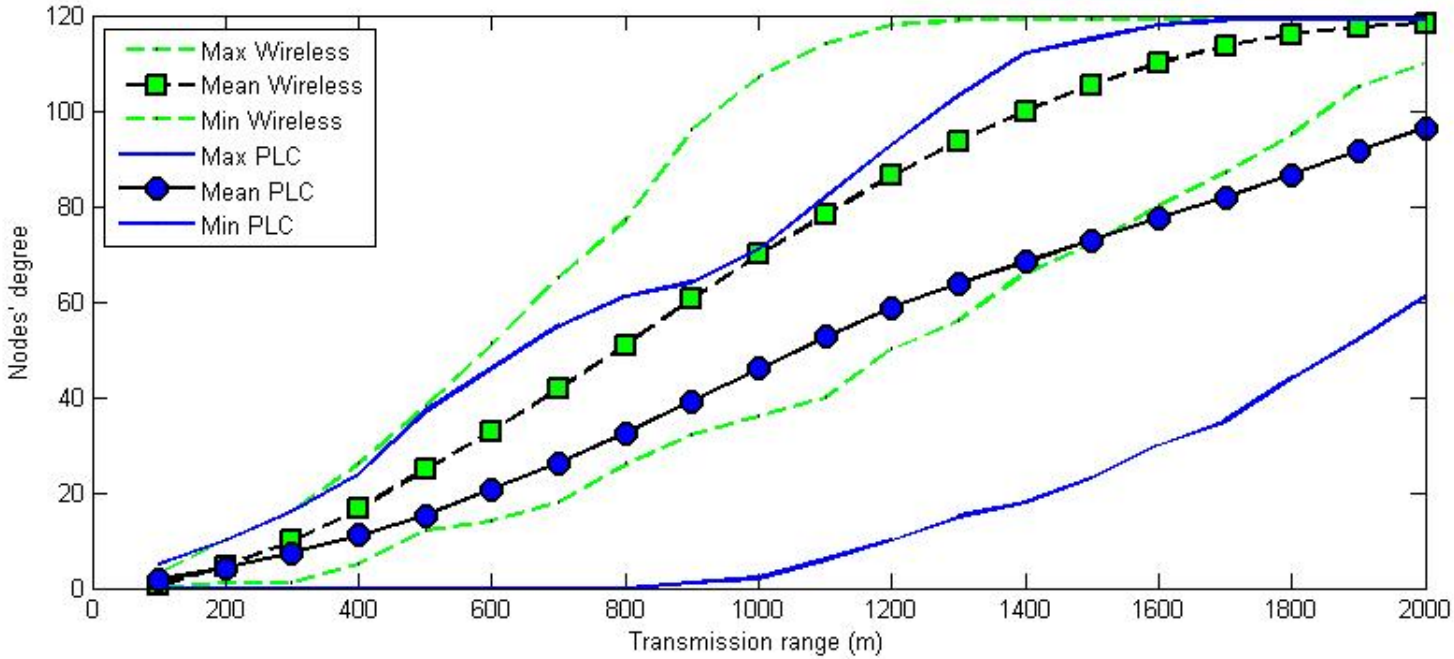


PLC



wireless

Node degree in MV networks



- highly clustered networks
- most nodes are able to overhear transmissions and send coded to five or more nodes.

Contribution

- Provide insights on the potential use of network coding for communications in distribution grids.
- Introduce protocols to communicate along a network coding paradigm
- Show that the smart grid communication infrastructure has broadcasting properties, which are suitable to network coding.
- On-going work on network coding benefits for smart grid communications