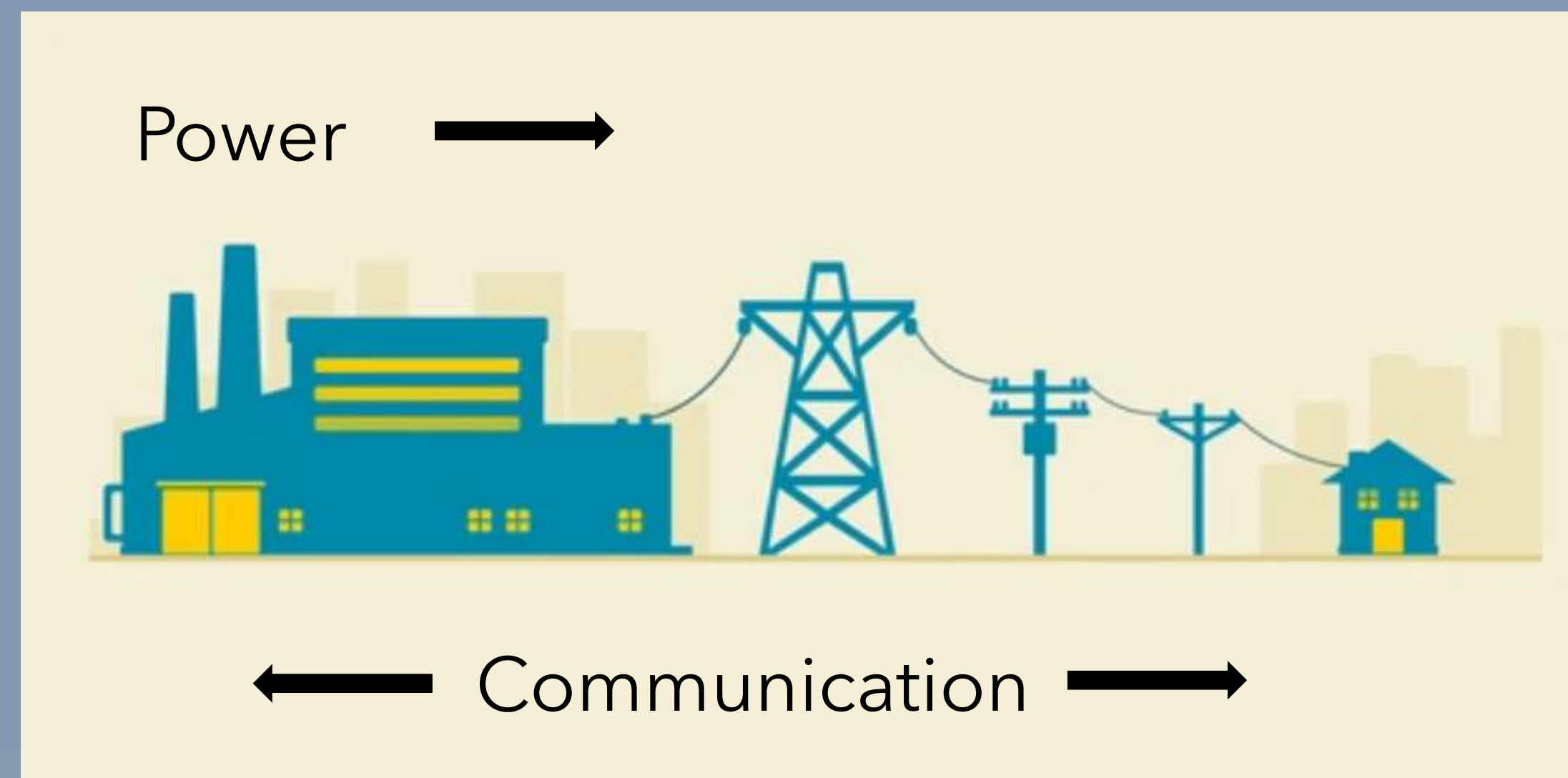
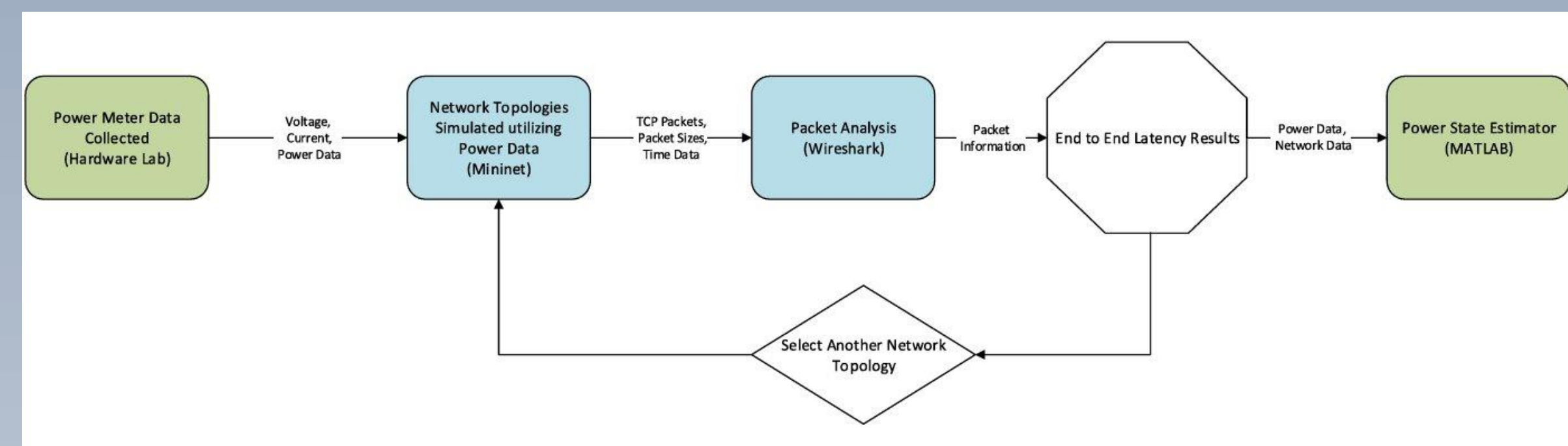


Background

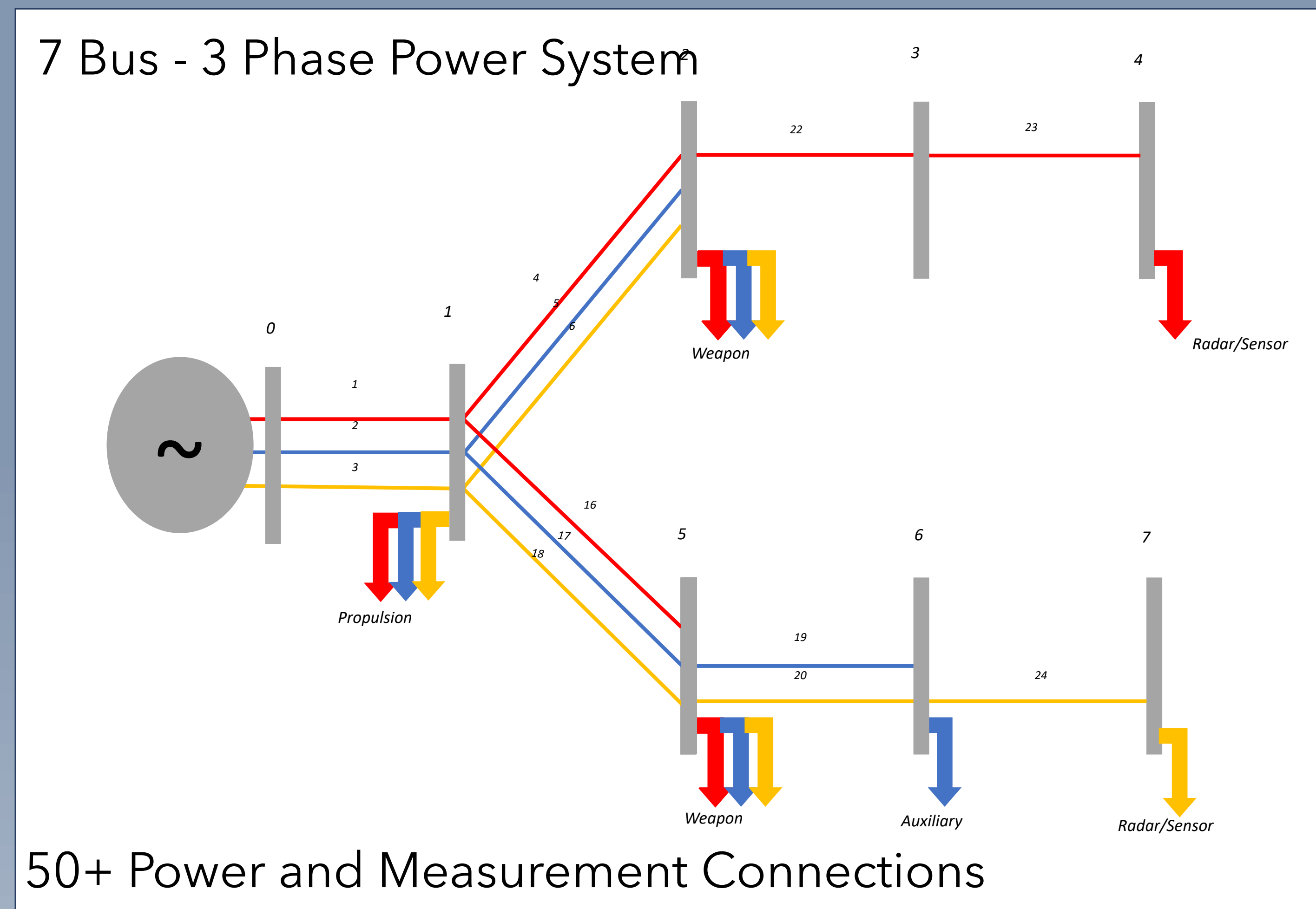


Technical Overview



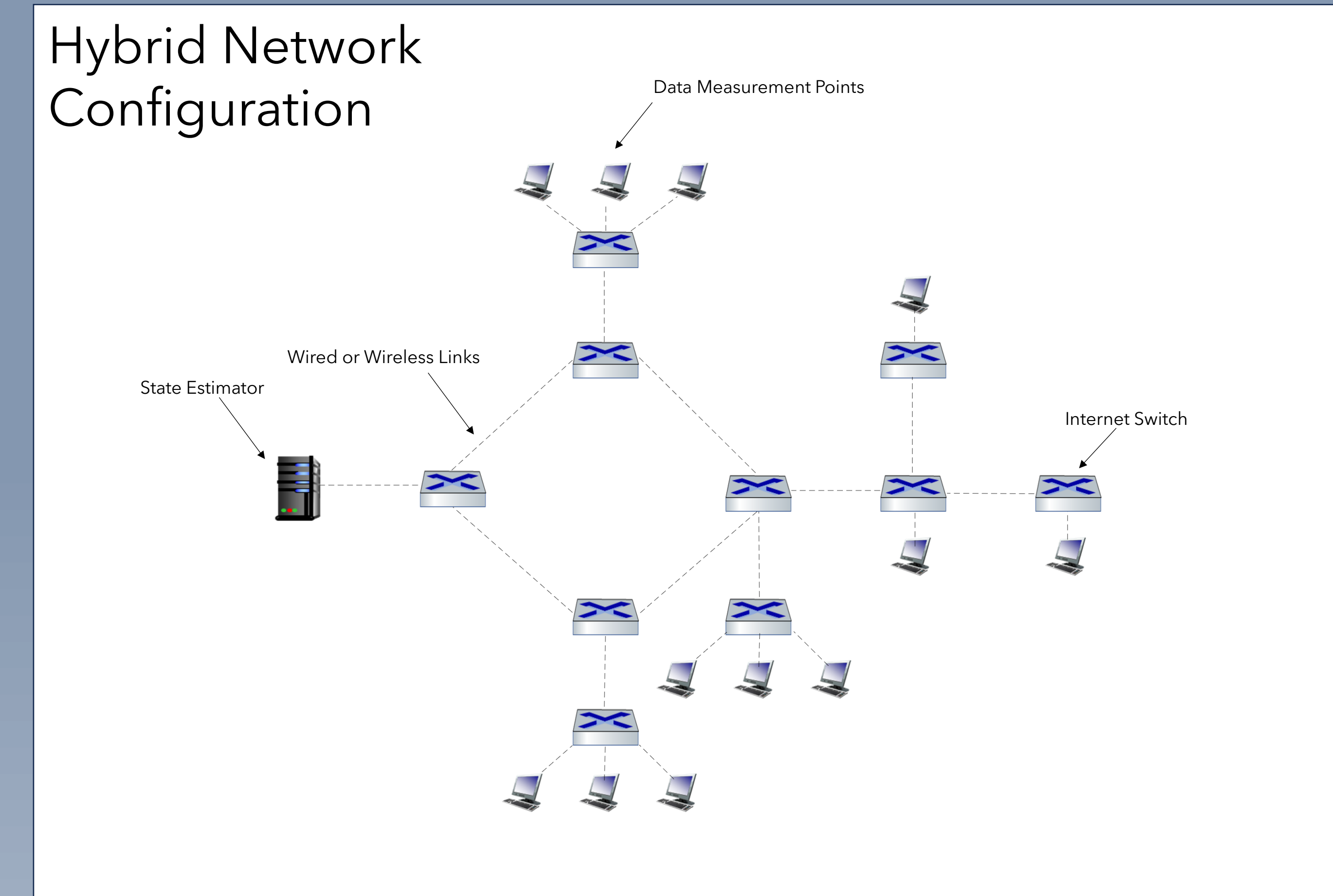
Overview of Project Flow of Project

Power System Emulation



7 Bus - 3 Phase Power System Diagram

Network Simulation and Topology



Example Network Configuration: Hybrid Network (Star and Ring Combination)

Mininet Virtual Network

- Created with Mininet Python API
- Specify Bandwidth for each link
- Create additional hosts to generate internet traffic
- Send lab results in packets through network
- Star, ring, and hybrid topologies

```

Info( "**** Add switches(n)")
s1 = net.addSwitch('s1', failMode='standalone')
s2 = net.addSwitch('s2', failMode='standalone')
s3 = net.addSwitch('s3', failMode='standalone')
s4 = net.addSwitch('s4', failMode='standalone')
s5 = net.addSwitch('s5')
s6 = net.addSwitch('s6')

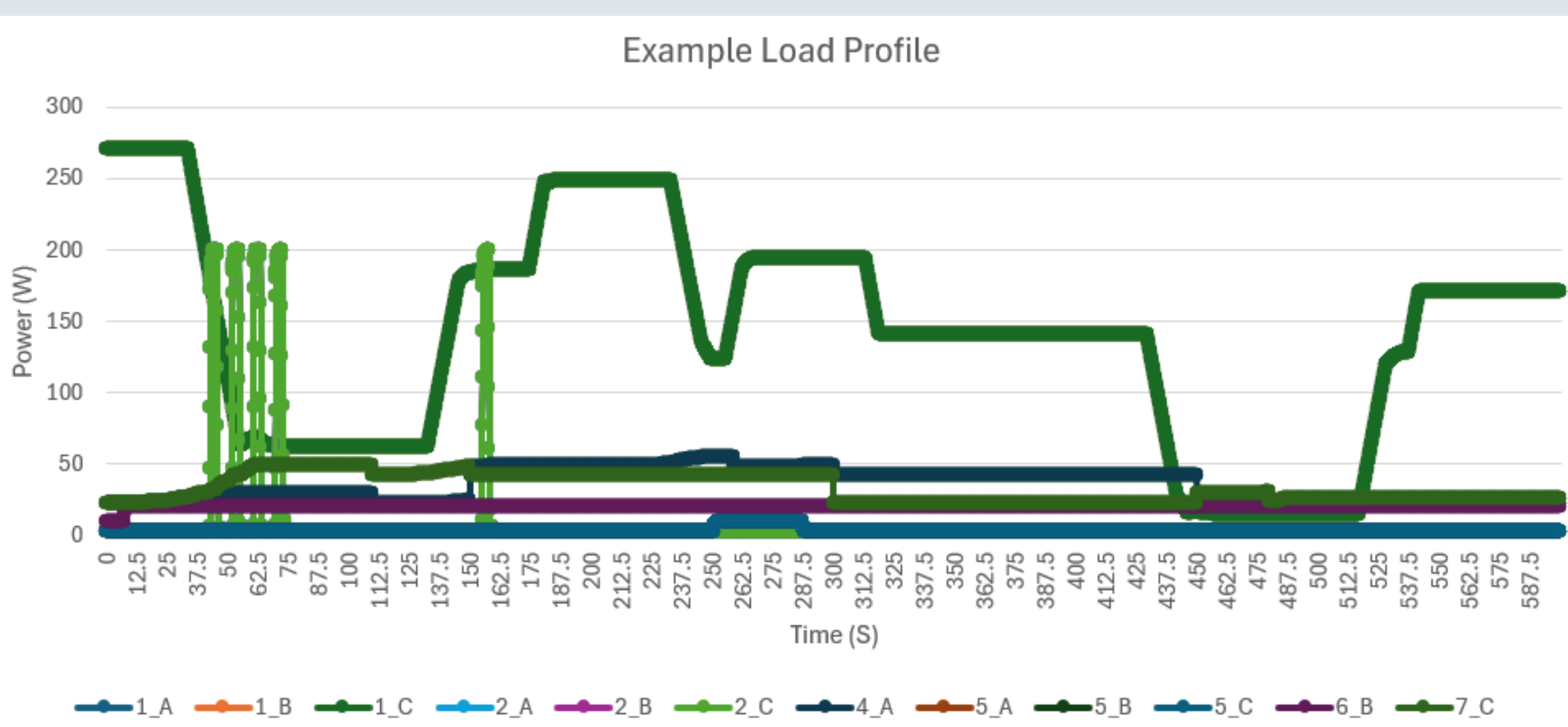
Info( "**** Add hosts(n)")
h1 = net.addHost('h1', cls=Host, ip='10.0.0.1')
h2 = net.addHost('h2', cls=Host, ip='10.0.0.2')
h3 = net.addHost('h3', cls=Host, ip='10.0.0.3')
h4 = net.addHost('h4', cls=Host, ip='10.0.0.4')
h5 = net.addHost('h5', cls=Host, ip='10.0.0.5')
h6 = net.addHost('h6', cls=Host, ip='10.0.0.6')
h7 = net.addHost('h7', cls=Host, ip='10.0.0.7')
h8 = net.addHost('h8', cls=Host, ip='10.0.0.8')
h9 = net.addHost('h9', cls=Host, ip='10.0.0.9')
h10 = net.addHost('h10', cls=Host, ip='10.0.0.10')

Info( "**** Add links(n)")
h1s1 = ('bw:100')
net.addLink(h1, s1, cls=TCLink, **h1s1)
h2s1 = ('bw:100')
net.addLink(h2, s1, cls=TCLink, **h2s1)
h3s2 = ('bw:100')
net.addLink(h3, s2, cls=TCLink, **h3s2)
h4s2 = ('bw:100')
net.addLink(h4, s2, cls=TCLink, **h4s2)
h5s2 = ('bw:100')
net.addLink(h5, s2, cls=TCLink, **h5s2)
h6s3 = ('bw:100')
net.addLink(h6, s3, cls=TCLink, **h6s3)
h7s3 = ('bw:100')
net.addLink(h7, s3, cls=TCLink, **h7s3)
    
```

Example Code from Mininet Simulation

Example Load Profile

- Different types of load
- Bus 1: Motor / Propulsion load
- Bus 2,5: Large pulse loads
- Bus 4,6,7: Constant, small load
- Large changes in load lead to instability in models
- Difference between estimated and actual load value



Example Load Profile Showing Different Buses Modeled Load in Power System Shown Above

Power Lab Setup

Physical Setup Consisted of:

- 2 Experiments (5 Trials Each):
 - Experiment 1:
 - 12,000 Load Settings
 - 50 ms Delays
 - Small Data Packets
 - Experiment 2:
 - 150 Load Settings
 - Non-uniform Delays
 - Large Data Packets
- Trial Completion in ~1hr each



Power Lab Data Collection Experiment Setup

Delay Impact

System Real Power Loss:

- Undelayed: 1.08% of System Power
- Delayed: 3.36% of System Power
- Delay Difference: 2.24% of System Power

Impact Scenario

Cost Difference Delayed vs Undelayed:

- 15MW distribution substation
- 2.24% loss difference found experimentally (curve averaged)
- Generation costs of 49.74/MWH (PJM)
- 1 year -> 8760 hours/yr
- \$73,000 dollars in cost difference for single distribution substation

Network Topologies			
	Star	Ring	Hybrid
Packets lost (%)			
Delay (ms)			
MSS (bytes)			
Sending rate (bps)			

Network Topologies			
	Star	Ring	Hybrid
Voltage (Mag)			
Voltage (Angle)			
Current (Mag)			
Current (Angle)			
Power (kW)			
K-Var			
kW-h			

Example Final Results Tables

Next Steps

- Form packets from the lab data (RFC 1191)
- Run Mininet Emulations using Hardware Data
- Send packets through network and observe latency (RFC 768 & 9293)
- Populate tables with the findings
- Integrate results into Power State Estimation Model