Suitability of Energy-Autonomous Point-to-Point Radio Networks for Wireless Backhauling

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- Example Deployments
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Autonomous Wide Area Networking

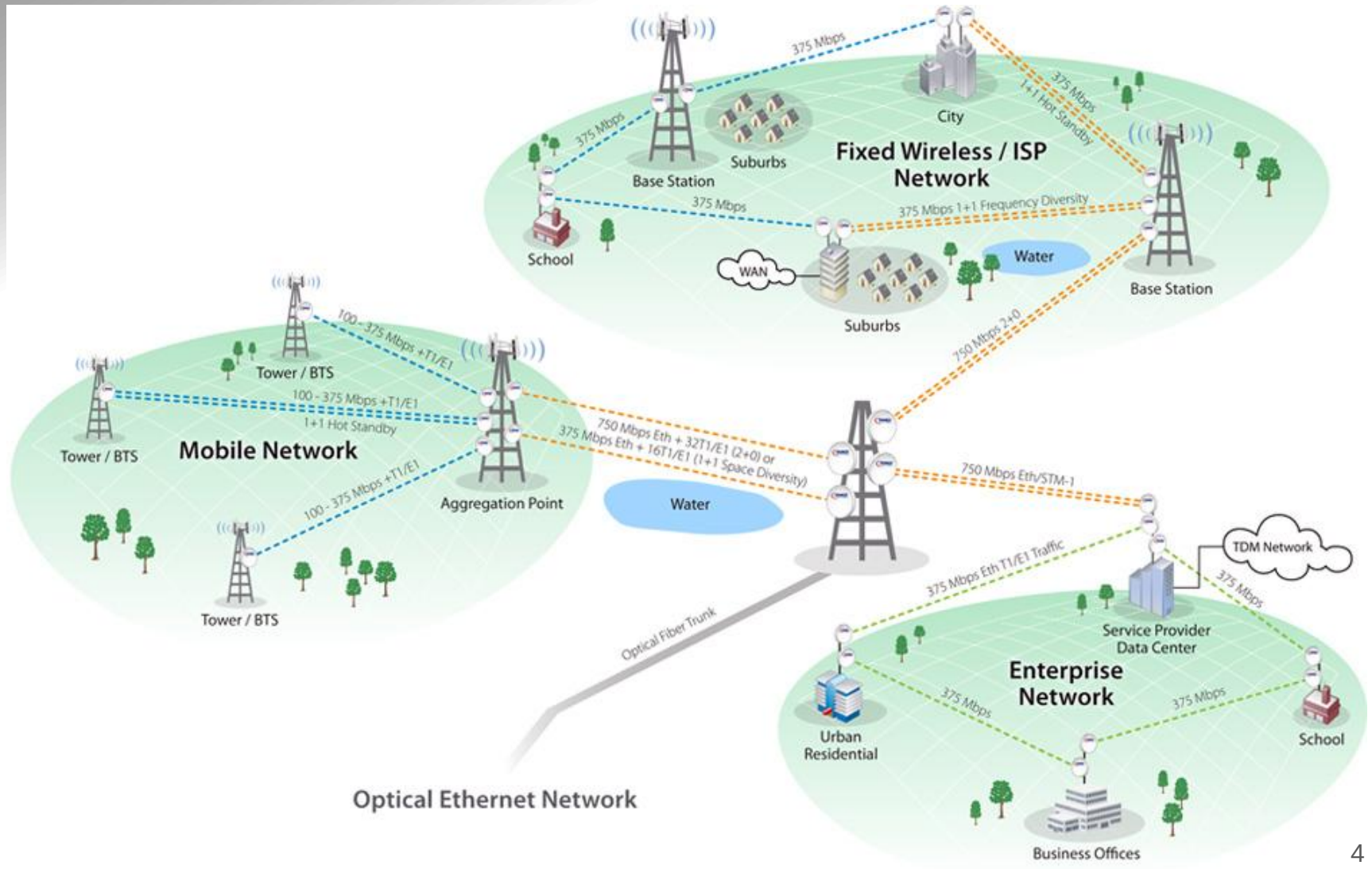
- Deployment in challenging environments
  - Sub-Saharan Africa (e.g. Tanzania)
  - Rural/remote areas (Alps, Canary Islands)
- System setup and operation have to provide solutions for
  - Unreliable energy supply
  - Lack of trained maintenance personnel
  - Hardly reachable deployment sites (e.g., cliff edges)

  ⇒ Autonomous network operation (e.g. selected SON functions)

  ⇒ Self-sustainable energy supply using alternative sources (commonly PV modules)

  ⇒ Graph theory, QAPs, k-connected sub graph problems

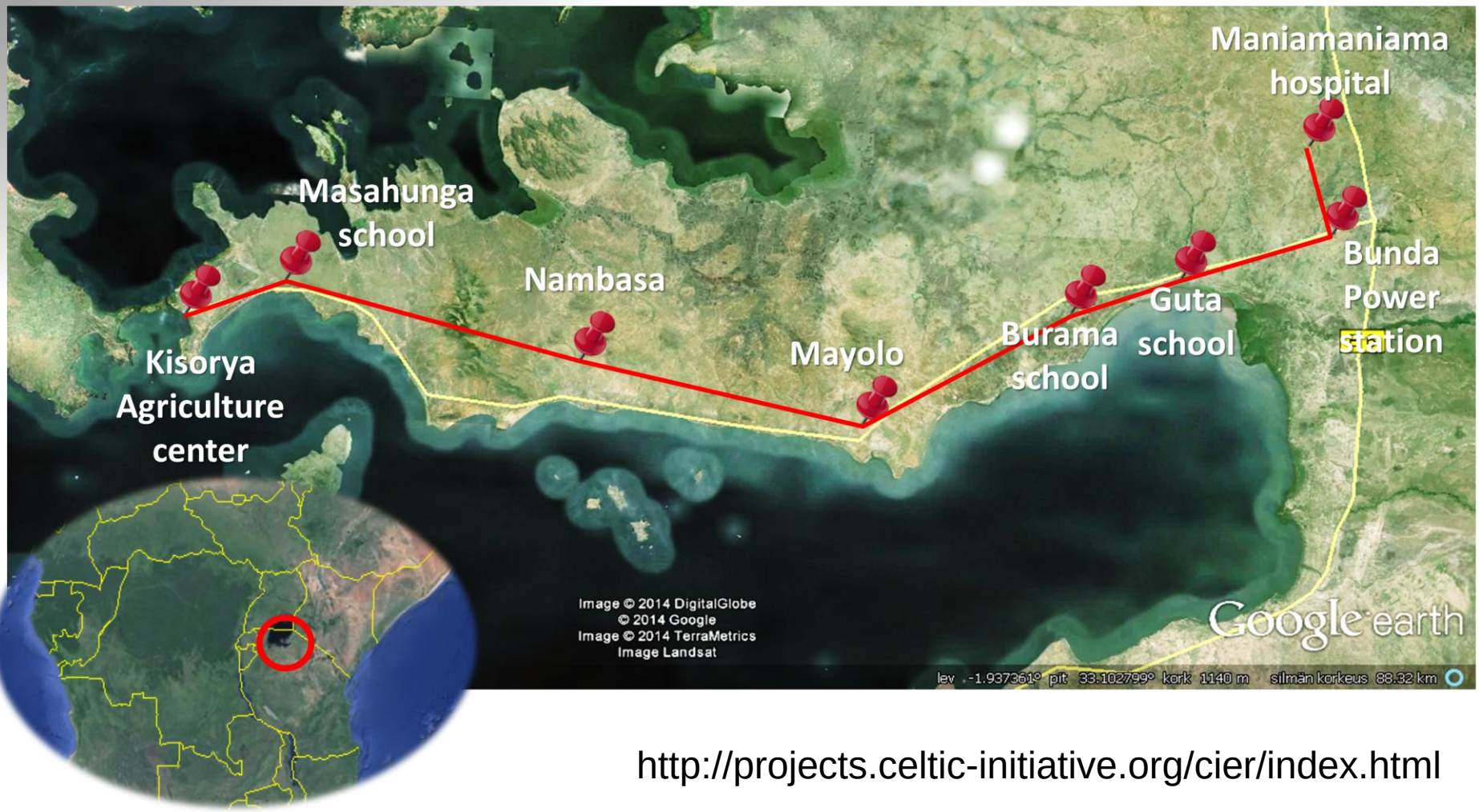
Typical Scenario



Campus Testbed

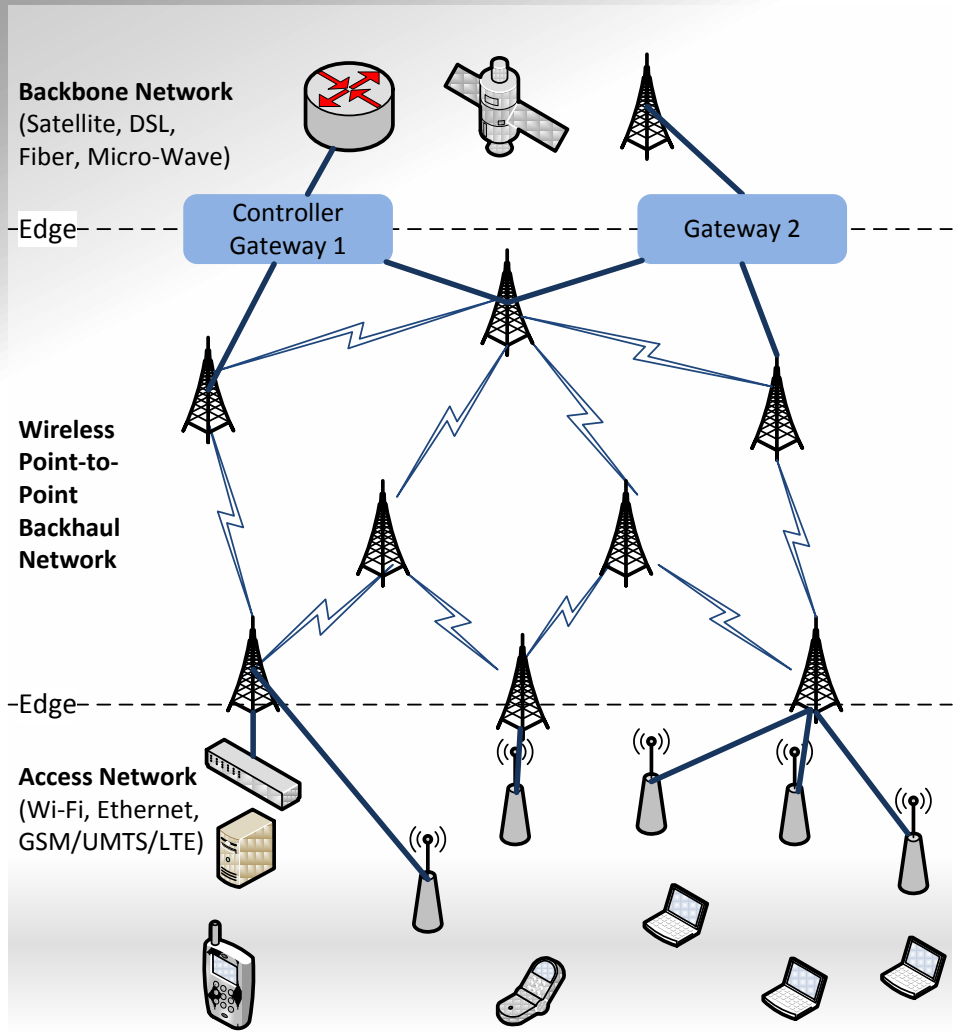
- Multi-purpose, high performance wireless routers for campus testbed
  - Low energy conumption per node (~ 20-30 W)
  - 2 - 4 WiFi radio interfaces for backhaul or access purpose
  - Carrier-grade (guaranteed) service
  - Transparent Layer 2 bridging
  - Automatic radio planning, radio link calibration, and topology management
- Planned testbed extensions
  - Autonomous energy supply using photo-voltaic modules and batteries
  - Extend network to incorporate multiple gateways

CELTIC-CIER
Tanzania Setup



http://projects.celtic-initiative.org/cier/index.html

Network Structure

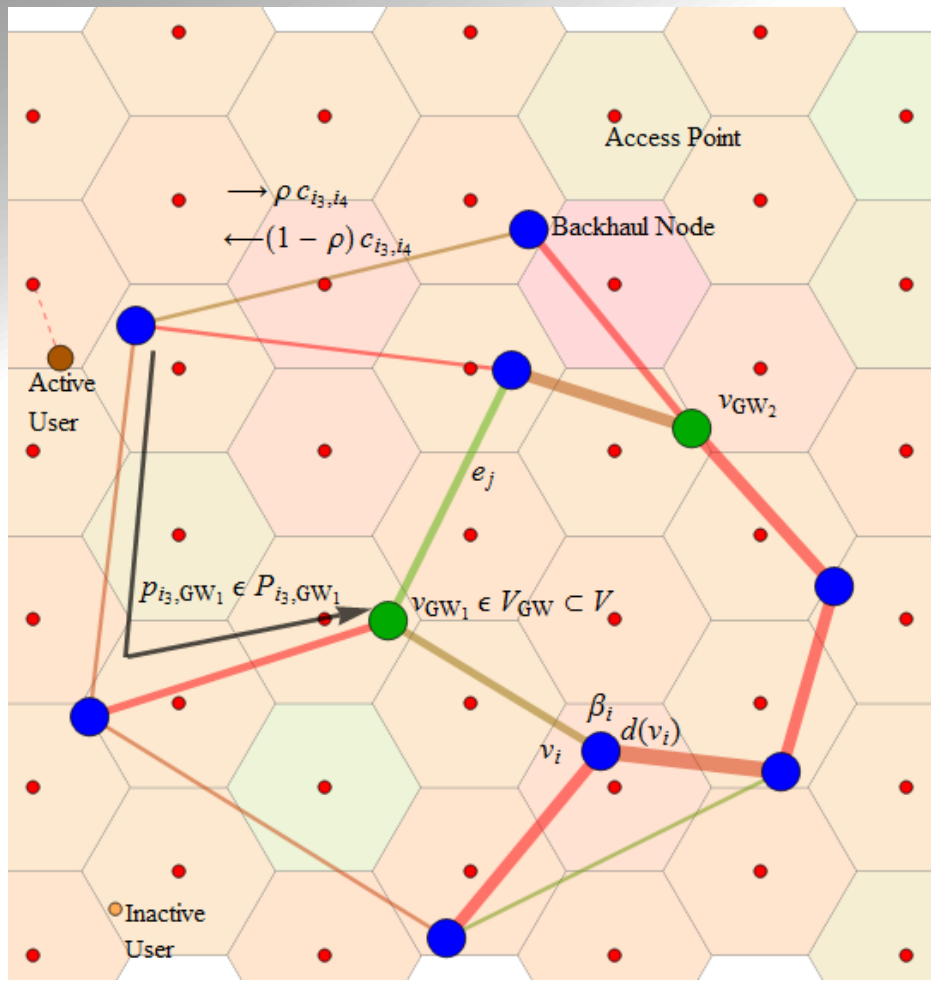


- Separation into
  - Backbone
  - Backhaul
  - Access
- Wireless backhaul network with multi-radio multi-channel nodes
- Impact of topological configuration
  - Overall capacity
  - Fairness of resource allocation
  - Lifetime of nodes with autonomous energy supply

Research Questions

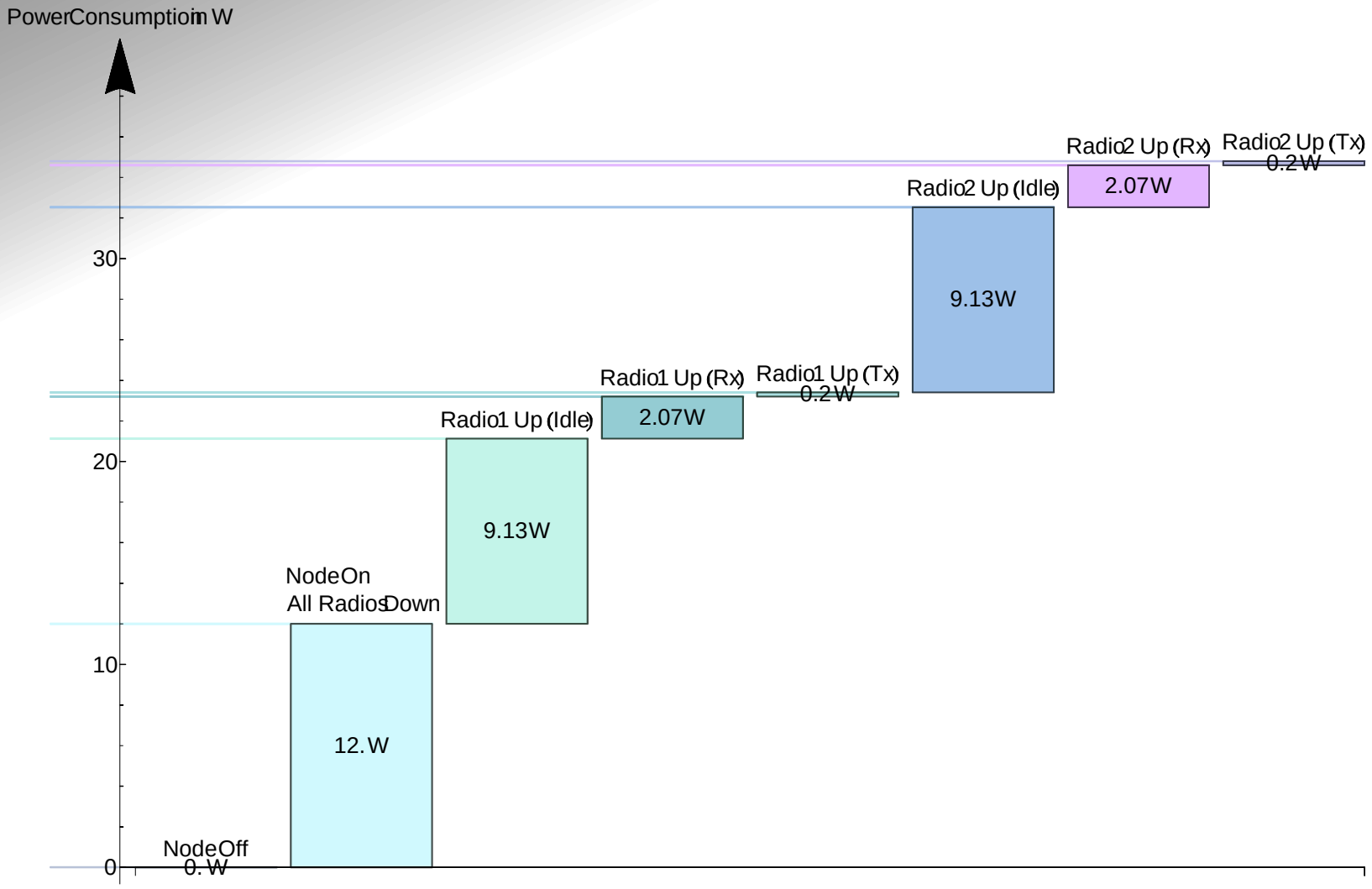
- Under which conditions can energy-autonomous backhaul networks operate in a self-sufficient manner?
- Major constraints:
  - weather conditions, geographical latitude, time of year
  - network load, mobility and service requests of users
  - renewable (thus volatile and discontinuous) energy supply
- What are sufficient dimensions for battery capacity and panel surface to assure <5% probability of node failure?
  - Battery capacity => What are longest periods without solar irradiation?
  - Panel surface area => What power yield is required to fully recharge battery?

Evaluation - Methodology

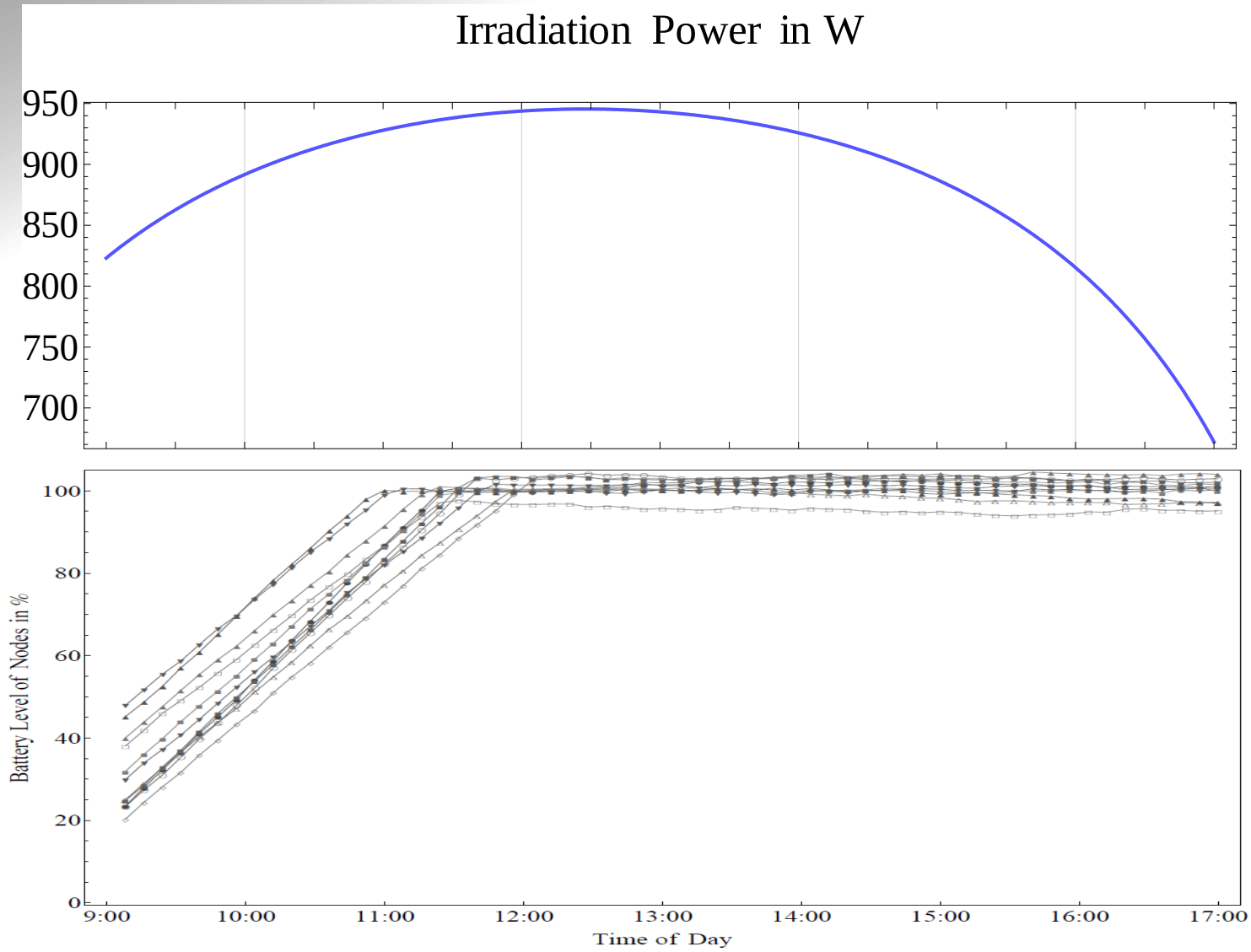


- System-level network simulator
  - Mesh nodes
  - Gateway nodes
  - Users
- Models for
  - Traffic classes
  - User Mobility
  - Solar energy supply (PV)
  - Energy consumption of nodes
  - Etc.
- Models for energy supply (and consumption) of backhaul nodes with PV modules

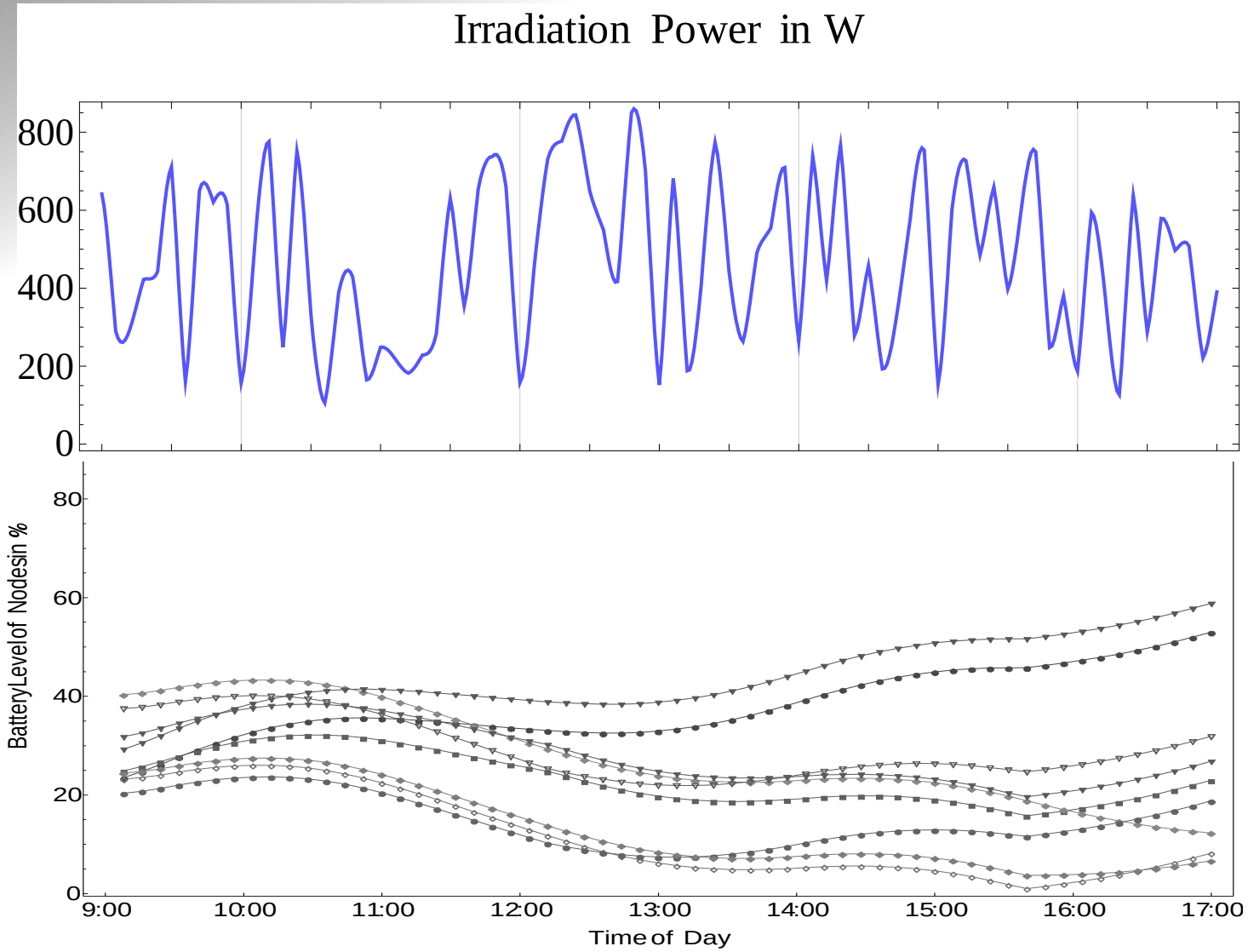
Energy Modeling



Tanzania – Clear Day in March

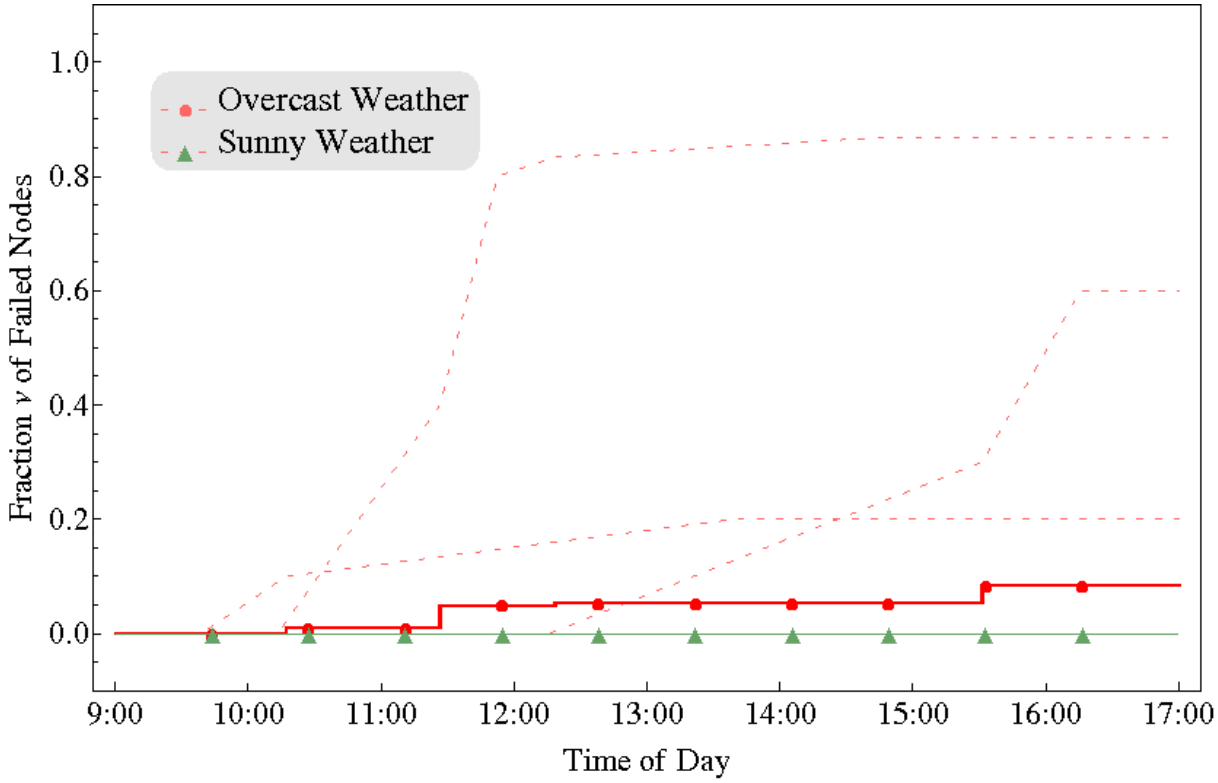


Tanzania – Overcast Day in March

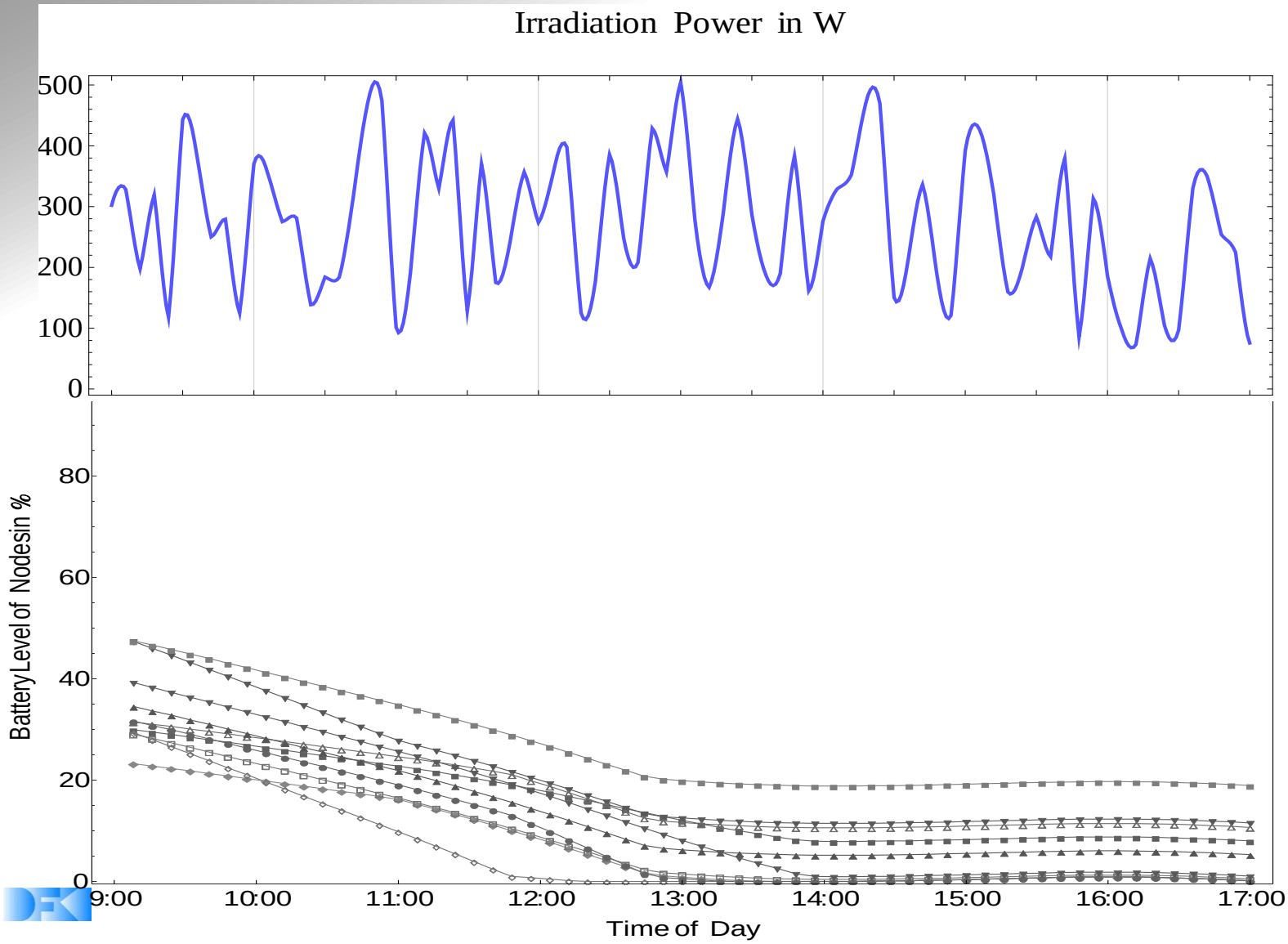


Autarkic Energy Supply - Component Dimensioning

- Sufficient sizes (empirical, ~1000 simulation runs)
  - Battery capacity: 12 Ah
  - Panel surface: 0.5 m²

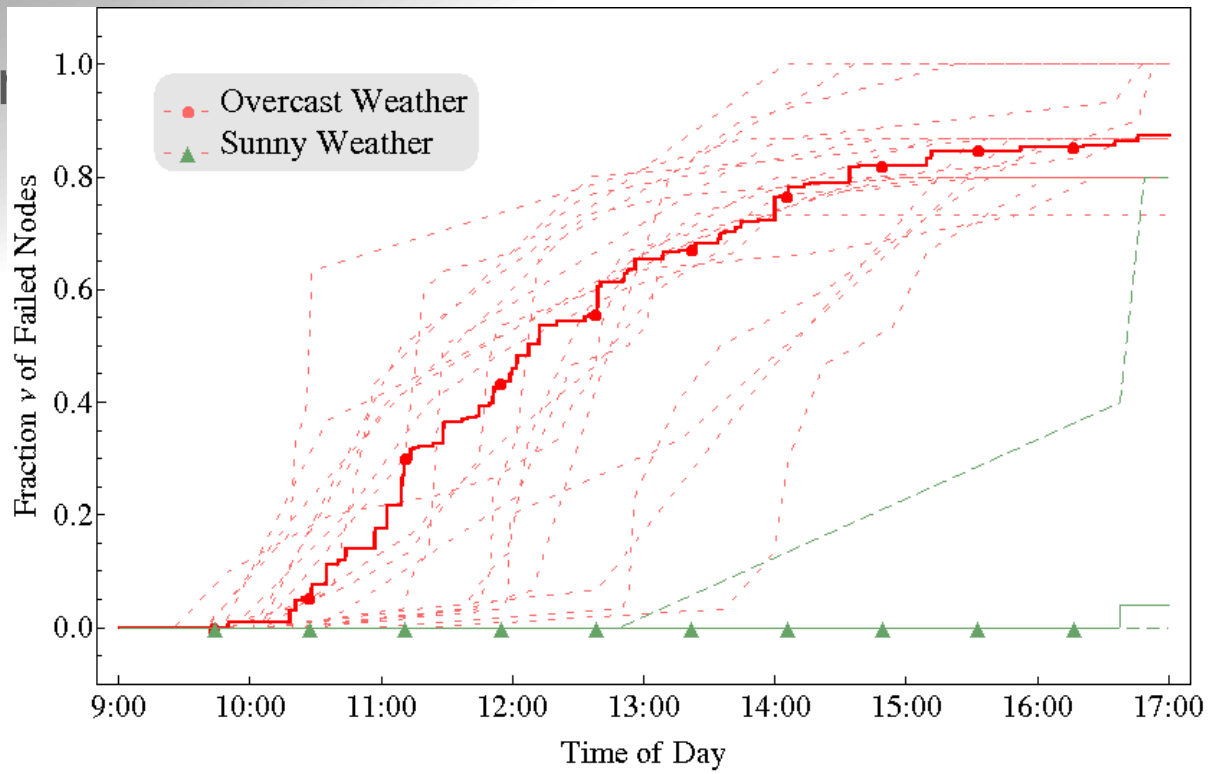


Alps – Overcast Day in March



Autarkic Energy Supply - Component Dimensioning

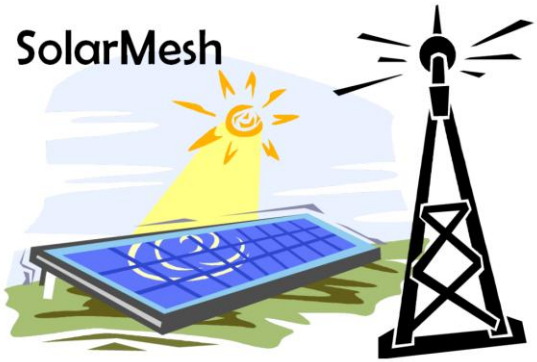
- Assu



- Continuous adaptation until failure probability below 5%
  - Battery capacity: ~ 19 Ah, panel surface: ~ 1.3 m²
  - In winter: 5% failure probability cannot be realistically guaranteed

Conclusion

- Coordinated **multi-radio** point-to-point networks form a suitable, cost-efficient solution for carrier-grade wireless backhauling
- Specific constraints considered in this talk:
  - Energy-autonomous operation
  - Sustained throughput and user outage statistics
- Contributions and results. This work has
  - Presented a modeling framework for wireless backhaul networks, in particular energy consumption and supply models
  - Performed a simulation-based evaluation, including analysis of energy budget
  - Derived requirements on battery capacity and PV module surface
  - Evaluated the reliability and suitability of solar-powered network nodes for Sub-Saharan and Alpine regions
- Future work
  - Analytical evaluation



Thank you

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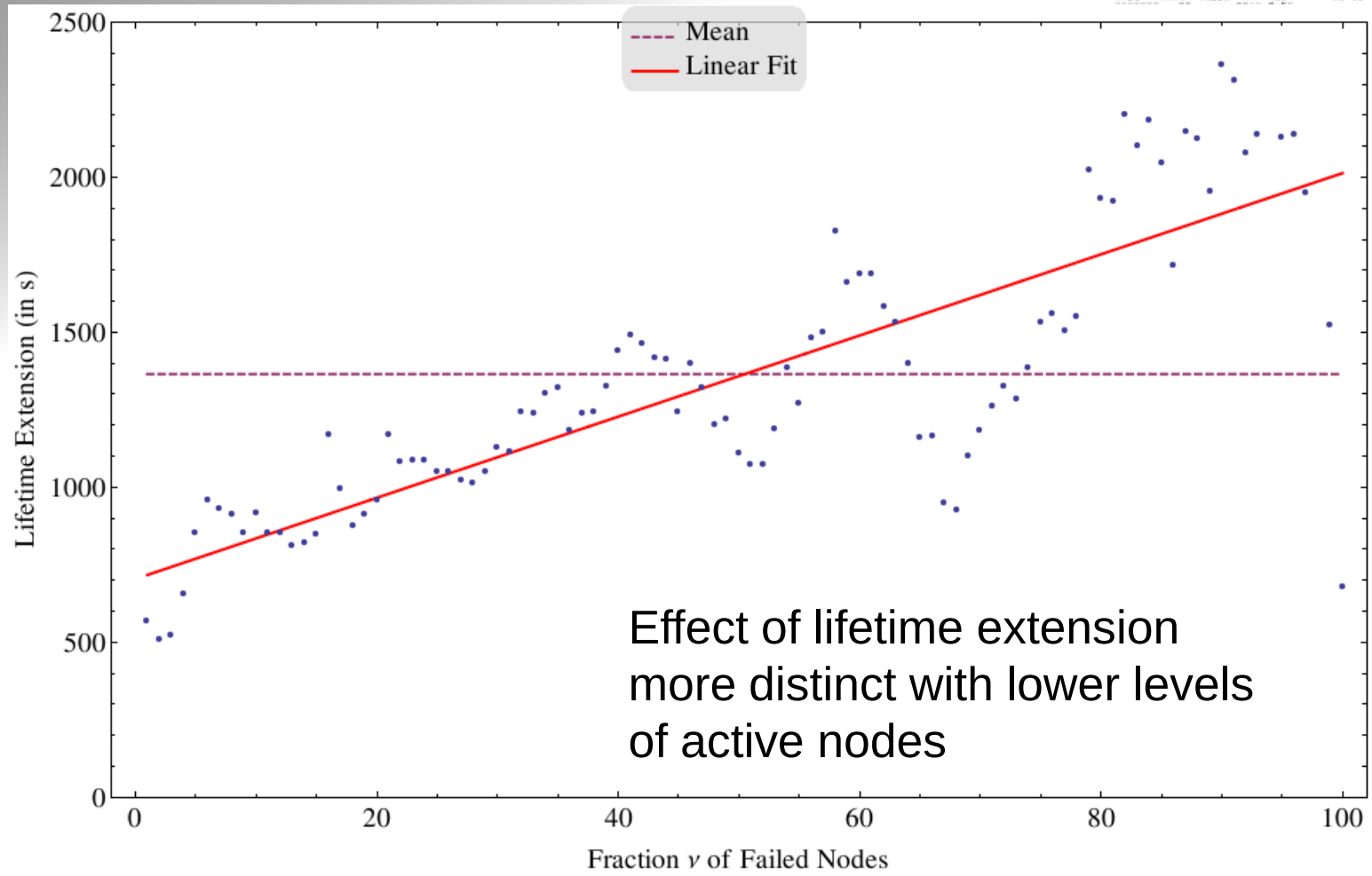
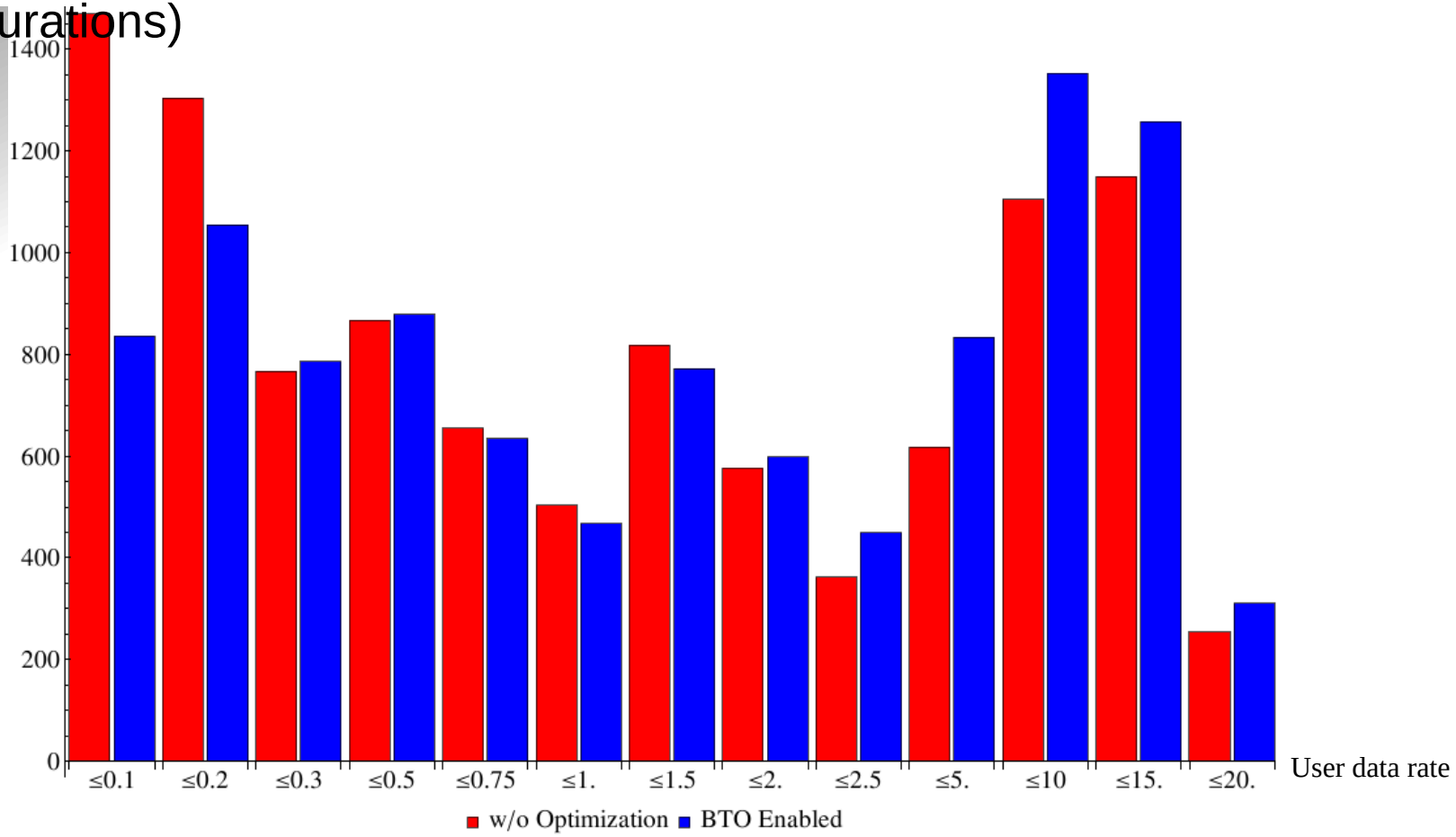
Evaluation – Results



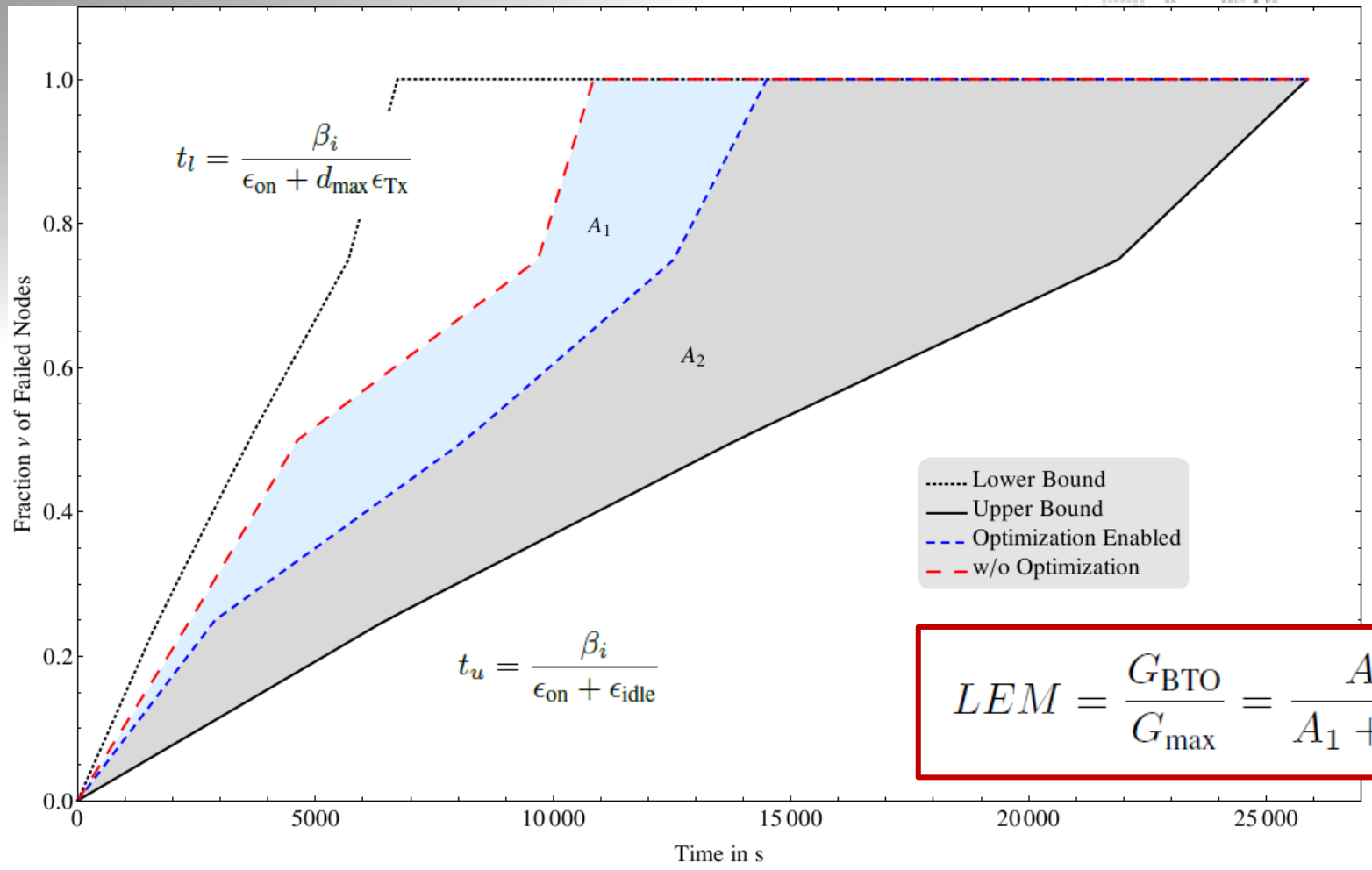
Effect of lifetime extension more distinct with lower levels of active nodes

Evaluation – Results

Histogram of average data rate per user (aggregated over 50 configurations)



Lifetime Extension Metric



$$LEM = \frac{G_{\text{BTO}}}{G_{\max}} = \frac{A_1}{A_1 + A_2}$$

Evaluation – Results