Resilient & Intelligent NextG Systems (RINGS)

Principal Investigator (PI) Project Summary

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RINGS
Resilient and Intelligent NextG Systems

National Science Foundation

Resilient Edge Networks with Data-Driven Model-Based Learning

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Motivation: Why did we choose this topic?

- Cloud-native Wireless Edge Networks Increasingly Complex
  - embedded functions/services to support NextG applications
  - software-based implementation/management

- Availability/Reliability/Resilience Top Design Priority
  - expected resource and demand variations
  - unexpected level-shifts of operating conditions

- Level of resource over-provisioning viable more limited than mega-data centers/backbone networks
  - communication and computation resources tightly coupled
  - more cost-effective solutions
    - agile and fine-grained joint adaptation of provisioning, allocation and scheduling

Methodology: What technical gaps to address

- Traditional Model-Based Solutions
  - driven by user, traffic, network models
  - non-stationarity? inaccurate/in-complete models? complexity?

- Recent Data-Driven Solutions
  - learn traffic/network dynamics from operational data (model-free)
  - generalizability? expressiveness? curse-of-dimensionality ?

- Our approach: Data-Driven Model-Based Learning

Models

- **Domain Knowledge**
- **Structured Algorithms**
- **Formal Analysis**
- **Sample Efficiency**

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Data

- **Data-Driven Exploration**
- **Adaptive Algorithms**
- **Model Correction**
- **Unmodelled Dynamics**

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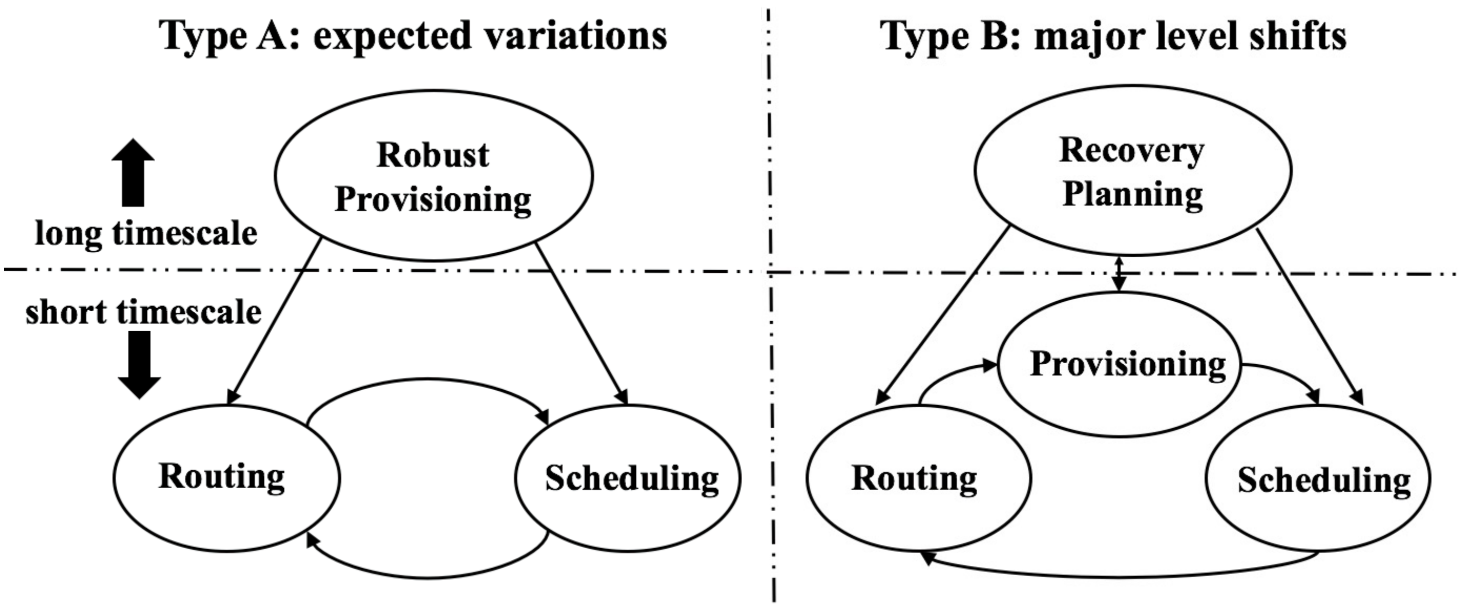
Hybrid Learning for Resilience

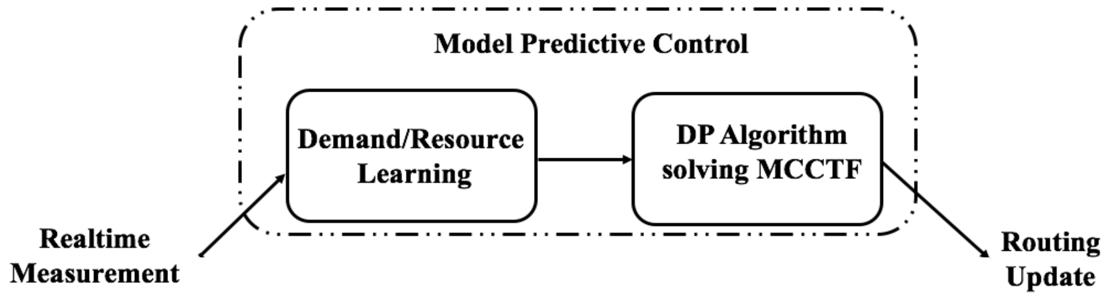
High-level Project Summary

- Two Loosely Classified Classes
  - Type A: expected demand and resource variations
    - diurnal traffic variations, random signal impairments, isolated link/node failures,
  - Type B: unexpected major shifts in demands and resources
    - unexpected flash-crowd, natural disasters, coordinated attacks



Type A: Adaptive Routing with In-network Processing (RINP)

- RINP: Finding Routes in Edge Networks
  - meeting traffic & computation demands of application flows
  - balancing loads on communication links and compute nodes
  - adapting to demand/resource variations
- Hybrid Learning: data-driven adaptive control



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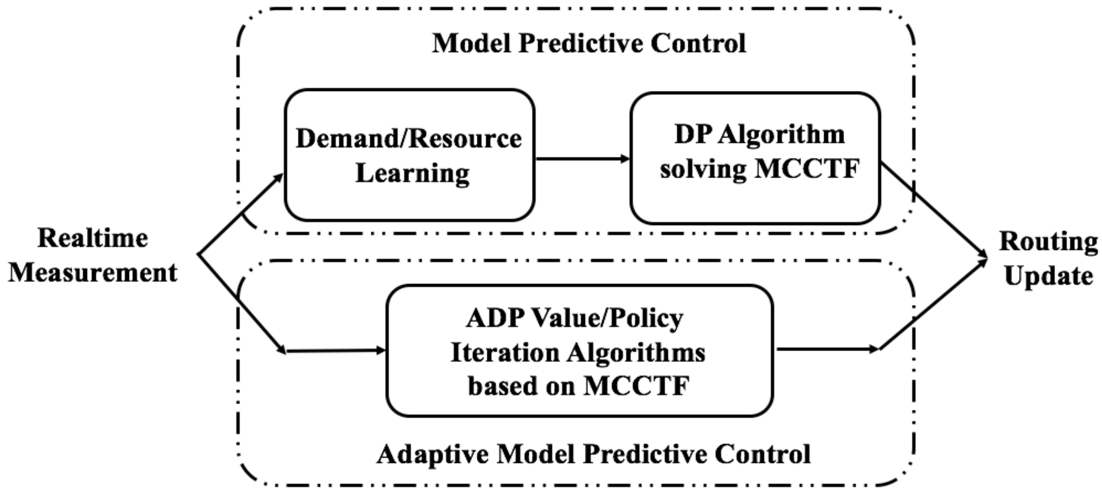


Type A: Hybrid Learning-Based Adaptive Scheduling

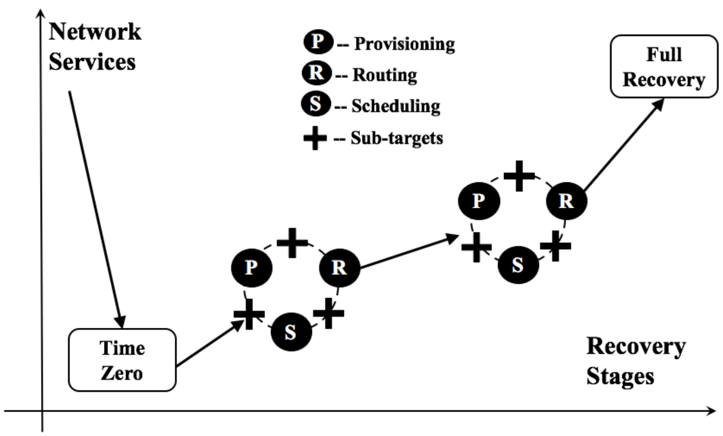
- Workloads routed to edge compute nodes highly dynamic
  - offline traffic models inaccurate -> low scheduling efficiency
  - pure data-driven scheduling suffers curse-of-dimensionality

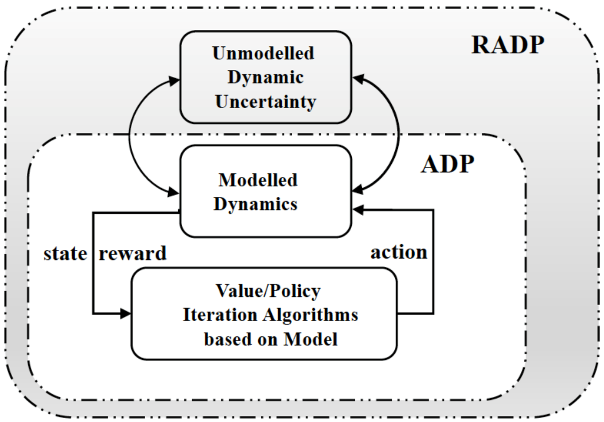
- Index-based Reinforcement Learning
  - index policies exploiting inherent structure of scheduling problem to achieve sample efficiency
  - online learning to adapt to traffic dynamics

- Interaction between hybrid-learning based adaptive routing and scheduling

Type B: Progressive Emergency Recovery

- After unexpected major disruptions:
  - surviving capacity insufficient to carry all demands
  - boost capacity using backup/helper resources
  - strategically block non-essential services
  - multi-stage recovery through joint provisioning, routing and scheduling.
- Robust/Adaptive DP (RADP): maintain stability of recovery process under "structural changes" in network resources and demands



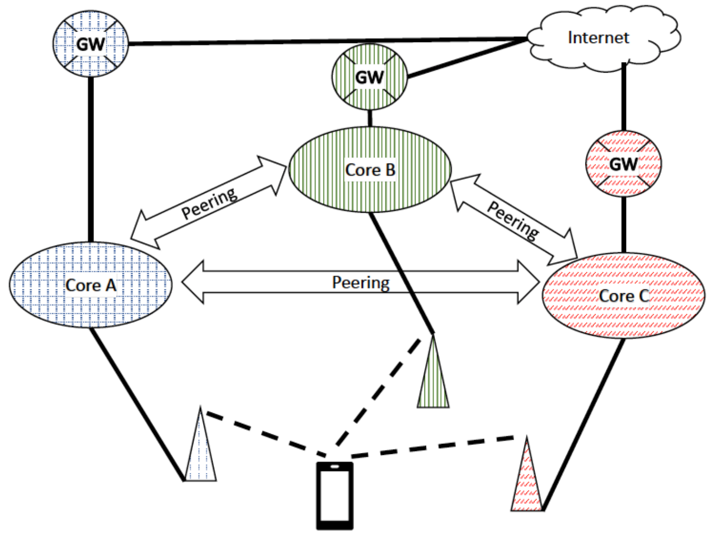


Type B: Service Provider Cooperation for Resiliency

- Information and infrastructure sharing between service providers to improve resiliency during and after emergencies and disasters.

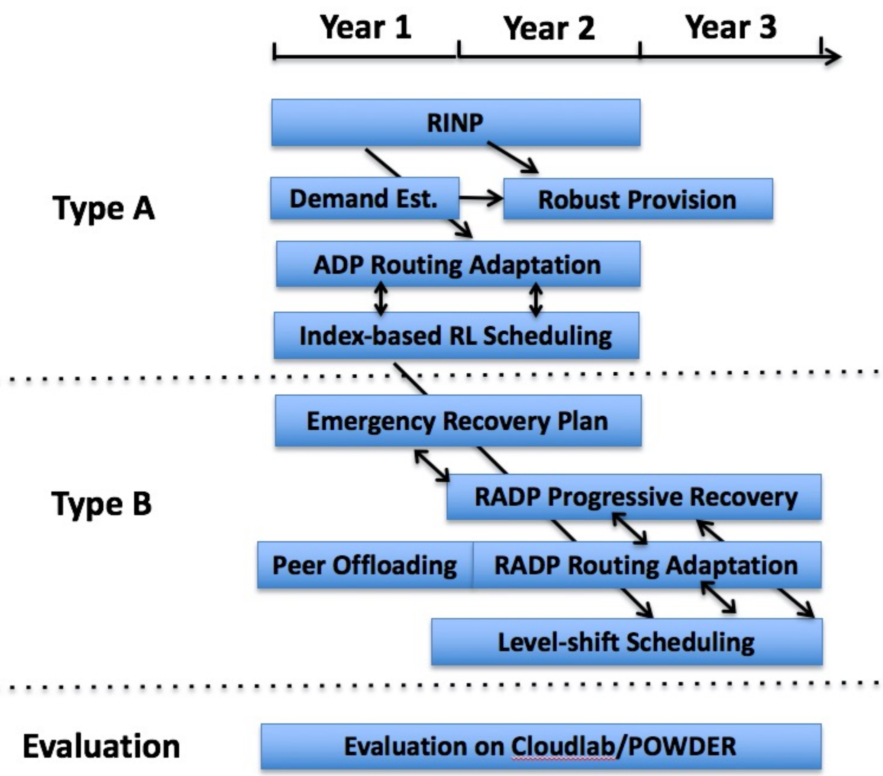
- Online learning based inter-Cellular Service Provider (CSP) routing

  - how to route traffic to blackbox peer CSP networks?
  - hybrid learning-based inter-CSP routing adaptation
  - stability of inter- and intra-CSP routing interaction



Research Outputs & Timeline

- ❑ MEC Algorithms and Software
  - provisioning/routing/scheduling
- ❑ Experimental Results & Findings
  - data-driven model-based networking
- ❑ New Theory and Tools for Broader Complex Systems
  - robust hybrid learning



Collaboration with Industry Sponsors and Other Teams

- ❑ Realistic MEC Data
  - topology, traffic, failure/attack scenarios …

- ❑ Feedbacks
  - current practices & needs,
  - assumptions, design considerations
  - complexity, implementability
  - … …

- ❑ Open to collaborations
  - sponsors and other teams
  - similar & complementary directions.

Thanks & Questions?