Resilient & Intelligent NextG Systems (RINGS)

Principal Investigator (PI) Project Summary

Moe Z. Win

Massachusetts Institute of Technology

STEVENS INSTITUTE of TECHNOLOGY
THE INNOVATION UNIVERSITY®

RINGS
Resilient and Intelligent NextG Systems

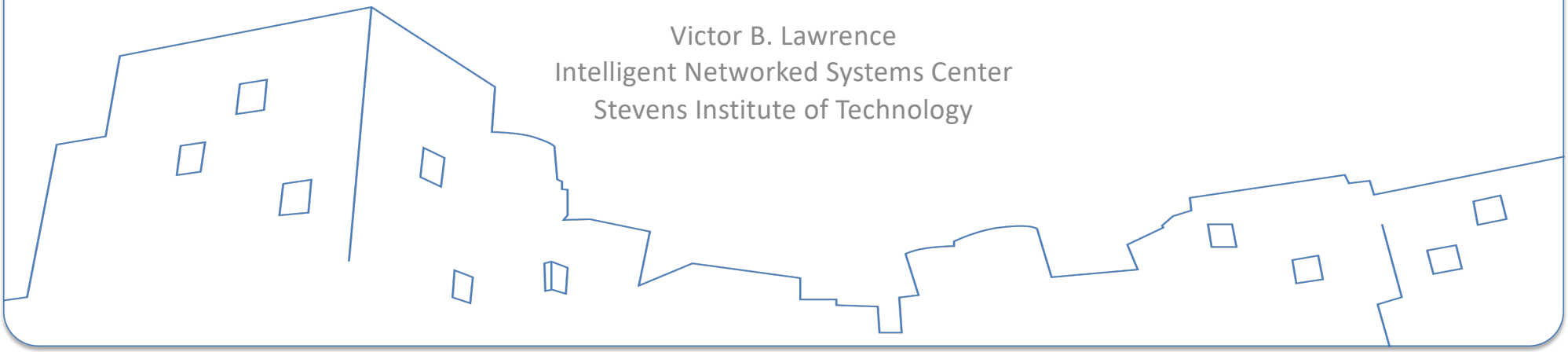
National Science Foundation

NSF · U.S. Dept of Defense · NIST · Apple · Ericsson · Google · IBM · intel · Microsoft · NOKIA · Qualcomm Technologies, Inc. · vmware

Resilient and Low-Latency Networks for Situation Awareness in the Factory of the Future

Moe Z. Win and Dimitri P. Bertsekas
Laboratory for Information and Decision Systems
Massachusetts Institute of Technology

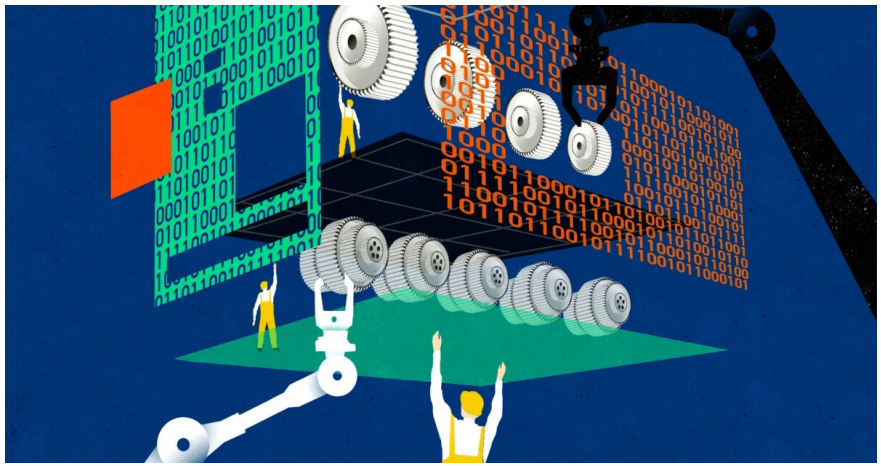
Victor B. Lawrence
Intelligent Networked Systems Center
Stevens Institute of Technology



MOTIVATION

Motivation: Factory of the Future (RV:B4)

- Factory of the future (FoF) is inherently a multi-agent system composed of heterogeneous nodes: machines, workers, workpieces etc.
- Coordination (communication and control) among heterogeneous nodes facilitates operational resiliency: adaptability, autonomy, and reliability
- Dense and dynamically-changing factory environments create harsh conditions for communication and control of networked systems



https://www.bcg.com/publications/2016/leaning-manufacturing-operations-factory-of-future

Latency in FoF

- Two types of latency in the network
  - *communication latency*: delay in successful transmission of data packets due to
    - queueing of data packets in the network
    - resource coordination at edge nodes
  - *computation latency:* delay caused by the processing of data packets due to
    - multimodal data fusion in inference
    - control action generation in decision making
- The latency-accuracy trade-off drives decisions made at the network
  - low latency but low accuracy at the edge cloud
  - high latency but high accuracy at the core cloud

Gaps and Objectives

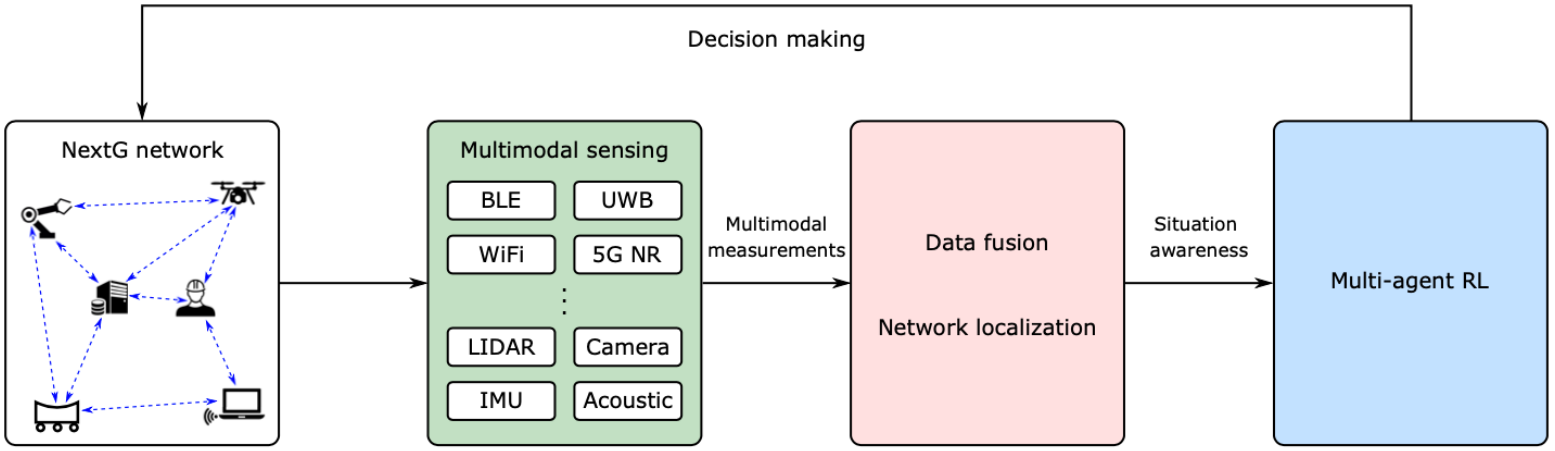
- Gaps
  - existing works on localization do not account for sensing latency and may lead to poor performance when data packets are not readily available
  - a systematic design of localization and decision making accounting for the latency in sensing, communication, and computation is still lacking

- Objective: develop latency-resilient algorithms for network inference and control to facilitate situational awareness and decision making in FoF

HIGH-LEVEL PROJECT VIEW: PLAN AND APPROACH

FoF: Inference and Control Loop

- FoF has the following constituents
  - physical layer: FoF agents
  - sensing layer: multimodal sensors
  - inference layer: processor nodes for localization and navigation
  - control layer: processor nodes for action generations



Project Plan

- Our contributions to NextG resiliency, network intelligence, performance, and security are as follows
  - operational resilience under latency
  - high-accuracy localization and near-optimal control action generation
  - intelligent network resource coordination

- Establish two lines of research to unleash technologies that are essential for resilient networks in the FoF
  - adaptive low-latency network localization
  - latency-resilient decision making

ADAPTIVE LOW-LATENCY NETWORK LOCALIZATION

Goals and Challenges

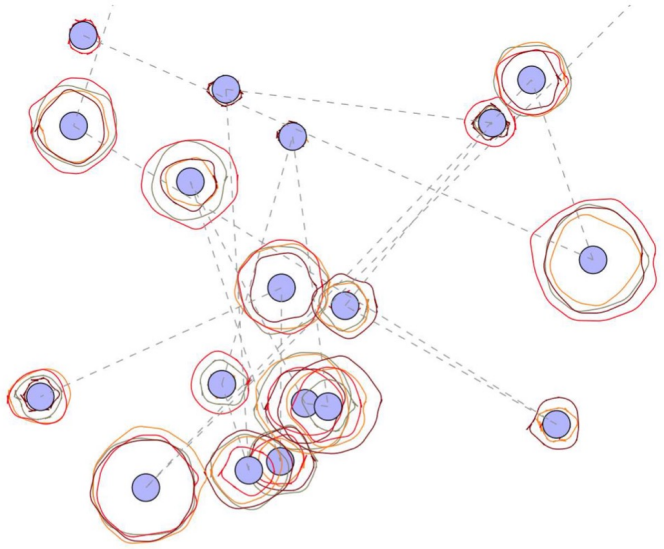
- Localization and tracking is important for FoF
- Multiple sensor nodes observe the system state and communicate within themselves or with processor nodes over a network to accurately infer the state of the system

- Goals
  - design efficient algorithms for high-accuracy localization by fusing sensed data obtained from heterogeneous devices in FoF
  - develop a framework for inference in the presence of network latency

- Challenges
  - heterogeneity of sensors used in FoF
  - communication and computing latency in the network
  - uncertainty in temporal association of sensed data with measurement time

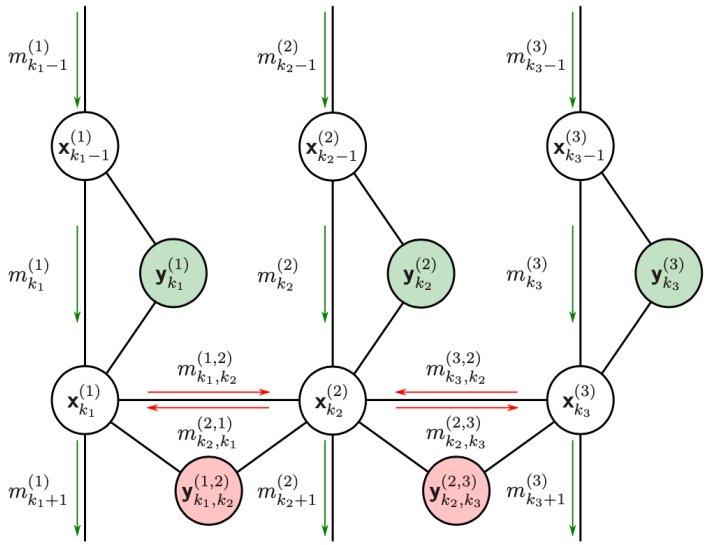
Approach

- Soft information
  - extraction methods for soft feature information and soft context information
  - fusion of soft information from heterogeneous observations using statistical inference theory



Approach

- Belief propagation
  - iterative evaluation of an approximate posterior distribution for the target positions
  - tractable association of sensing data with the time instants at which they are measured



LATENCY-RESILIENT DECISION MAKING

Goals and Challenges

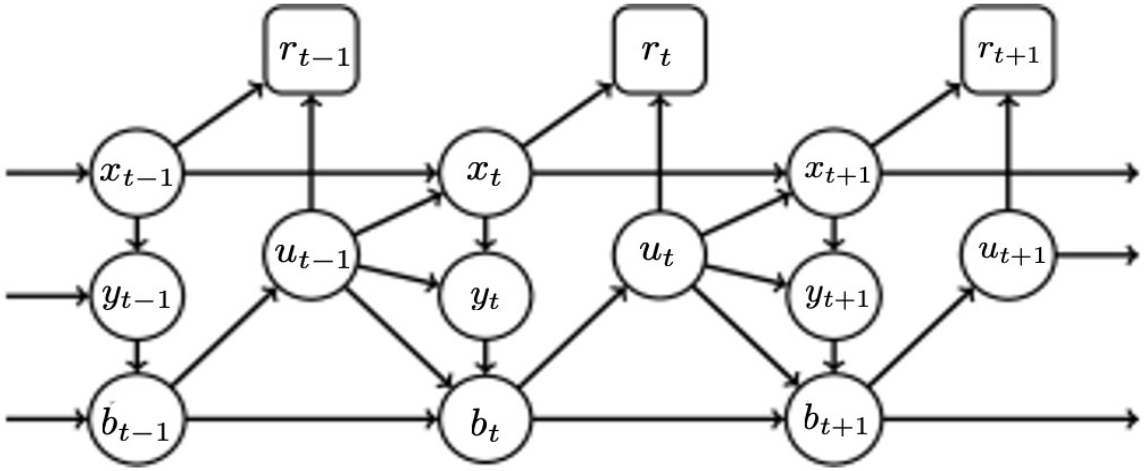
- Resilient decision making and the ability to adapt and coordinate agent resources is crucial for NextG networks
- FoF requires the network to efficiently use its limited energy, communication, and sensing resources for inferring and controlling the states of FoF agents

- Goals
  - design system-wide control policies for partially observable target nodes in the factory
  - develop efficient coordination strategies for sensing and communication

- Challenges
  - performance of the decision layer is limited by the inference layer
  - partial observability of target states is complicated by network-wide latency
  - multi-agent decision problems are difficult to solve

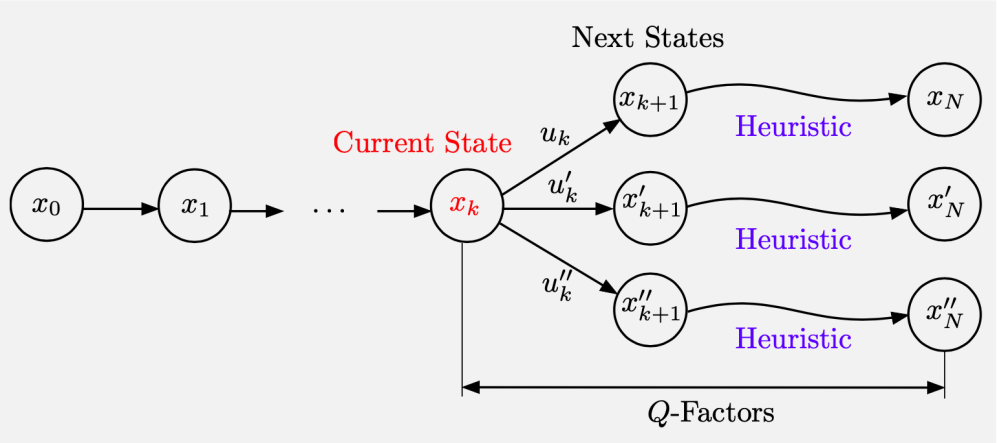
Approach

- Partially observable Markov decision processes (POMDPs)
  - model the decision problem as a POMDP
  - compute the belief state using proposed latency-resilient localization algorithms
  - employ dynamic programming for obtaining near-optimal policies for the POMDP



Approach

- Rollout
  - rollout approach for approximate dynamic programming has two basic constituents:
    - multi-step lookahead optimization
    - a base (heuristic) policy for approximation of reward-to-go
  - approximate the reward-to-go at the end of the lookahead horizon using a heuristic policy
  - obtain a sequence of controls for the lookahead horizon using nonlinear programming or optimal control techniques



STRATEGIC PROJECT SUMMARY

Strategic Project Summary

- Expected research outputs
  - algorithms for latency-aware localization and tracking
  - algorithms for latency-resilient decision making
  - dissemination of research results: journal papers, conference presentations, and tutorials
- Helpful resources
  - specialized knowledge related to FoF
  - sensing and communication data obtained in factories
- Collaboration and synergies
  - standardization bodies for 5G and B5G
  - industrial partners