Application of Middleware and Agent Technologies to a Representative Sensor Network

John S. Kinnebrew*
john.s.kinnebrew@vanderbilt.edu

William R. Otte*, Douglas C. Schmidt*, Gautam Biswas*, and Dipa Suri**

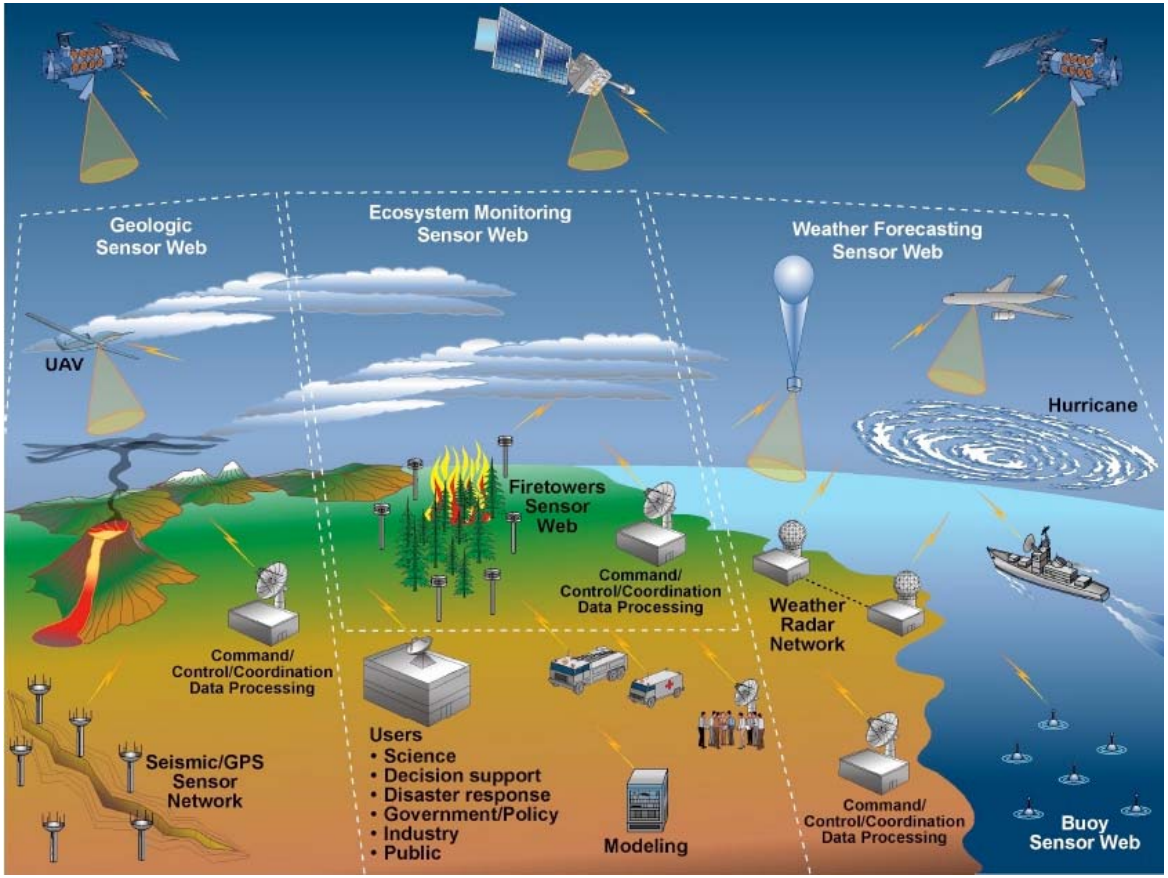
* Vanderbilt University
EECS Department & ISIS
Nashville, TN 37203

** Lockheed-Martin Space Systems
Advanced Technology Center
Palo Alto, CA. 94304

Supported by NASA ESTO (AIST-ROSES program)

Sensor Webs

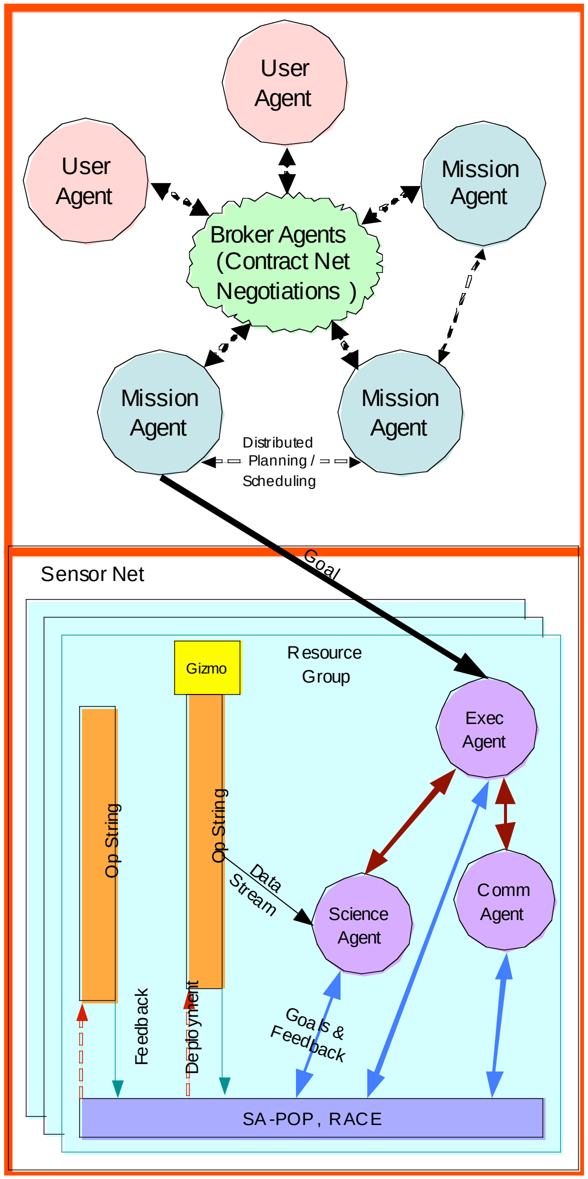
- Embedded systems
  - Soft/hard real-time
  - QoS requirements
  - Limited computational resources
- Power management
- Distributed resources
- Intermittent communication
  - Temporary/ permanent loss of access to data
  - Changing network topology



- Top-down and bottom-up forces affect utility of tasks/configurations
  - User requests provide goals for data collection and analysis (top-down)
  - Local conditions determine appropriate tasks to achieve goals (bottom-up)

Multi-agent Architecture for Coordinated Responsive Observations (MACRO)

- Mission level
  - Mission agent controls a sensor net
  - User agents provide interface for applications and scientists
  - Brokers mediate contract net negotiations
- Resource level
  - Exec agent in control of local resource group
  - Other agents as necessary
  - Component middleware infrastructure

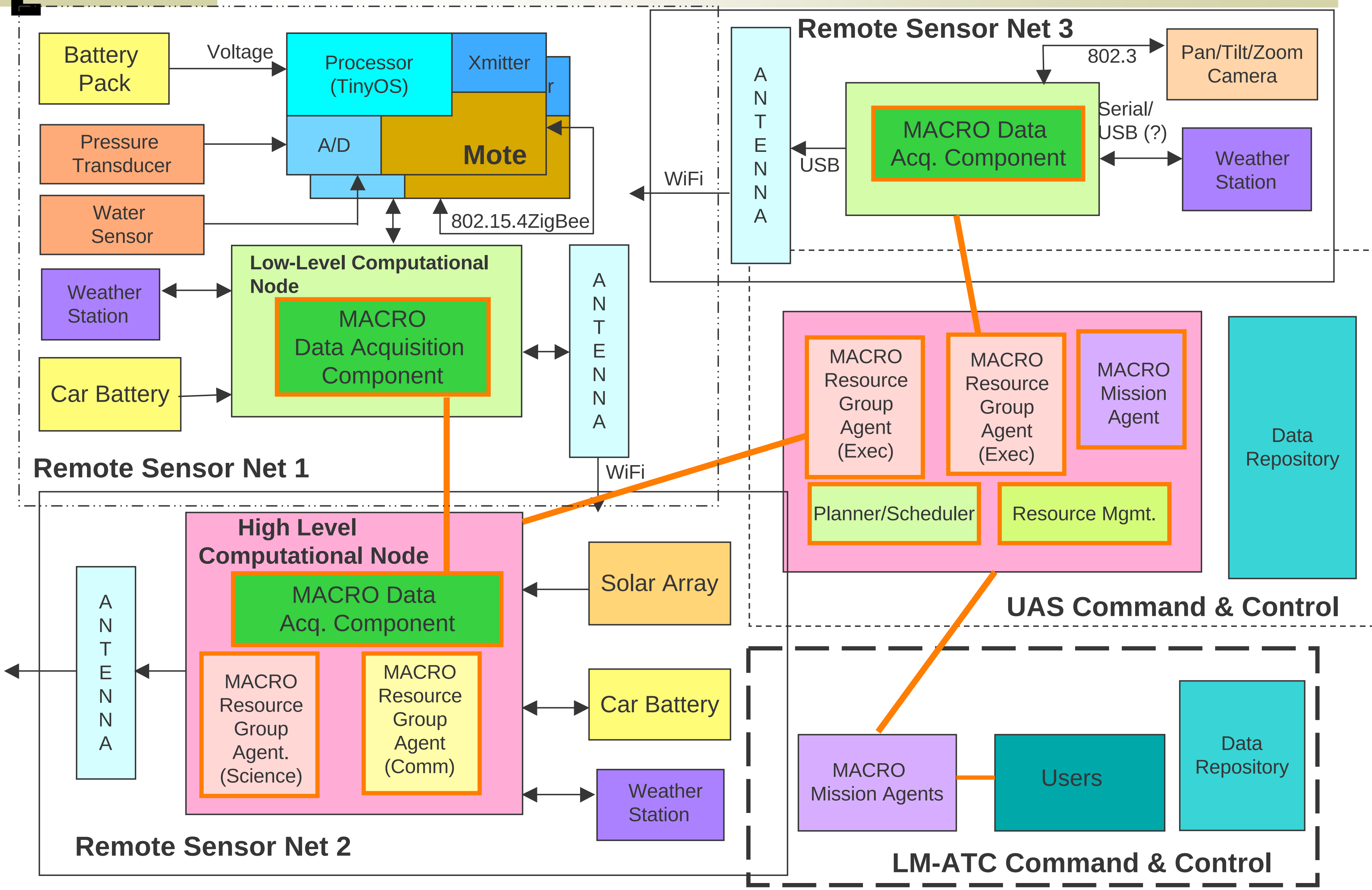


SEAMONSTER Objectives

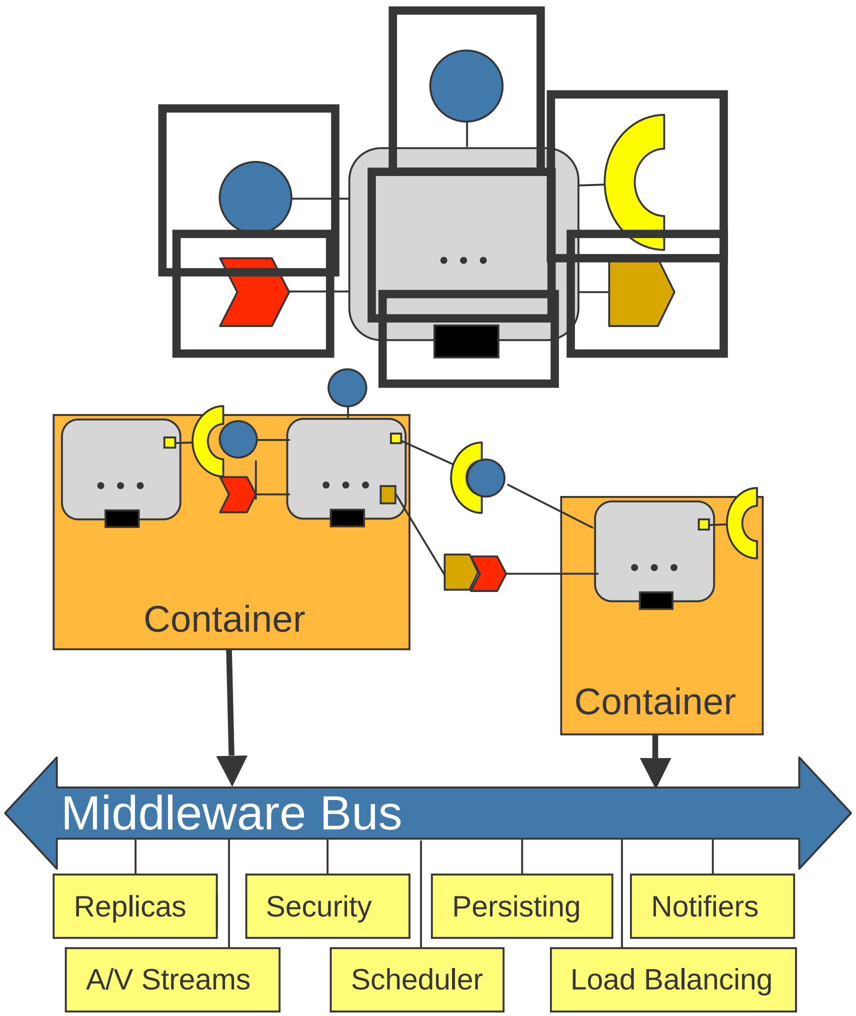
SouthEast Alaska MOnitoring Network for Science Technology Education and Research

- Scientifically Motivated
  - Technology Development funded by NASA ESTO (AIST)
- Path for Technology Infusion
  - Scientific Collaborations
- Testbed Sensor Web
  - Technology Collaborations

MACRO for SEAMONSTER



CORBA Component Model (CCM) – Overview



- Components encapsulate application "business" logic
- Components interact via ports
  - Provided interfaces, e.g.,facets
  - Required connection points, e.g., receptacles
  - Event sinks & sources
  - Attributes
- Containers provide execution environment for components with common operating requirements
- Components/containers can also
  - Communicate via a middleware bus &
  - Reuse common middleware services

Deployment Infrastructure Overview

- **Repository Manager**
  - Database of components that are available for deployment (“staging area”)
- **Target Manager**
  - R… available nodes & res…s)
- **Execution Manager**
  - Execution of an application according to a “Deployment Plan”
- **Domain Application Manager**
  - Responsible for deploying an application at the domain level
- **Domain Application**
  - Represents a “global” application that was deployed across nodes
  - …Responsible for managing a portion of an application that’s …
- **Node Application Manager**
  - Responsible for deploying a locality constrained application onto a node
- **Node Application**
  - Represents a portion of an application that’s executing within a single node

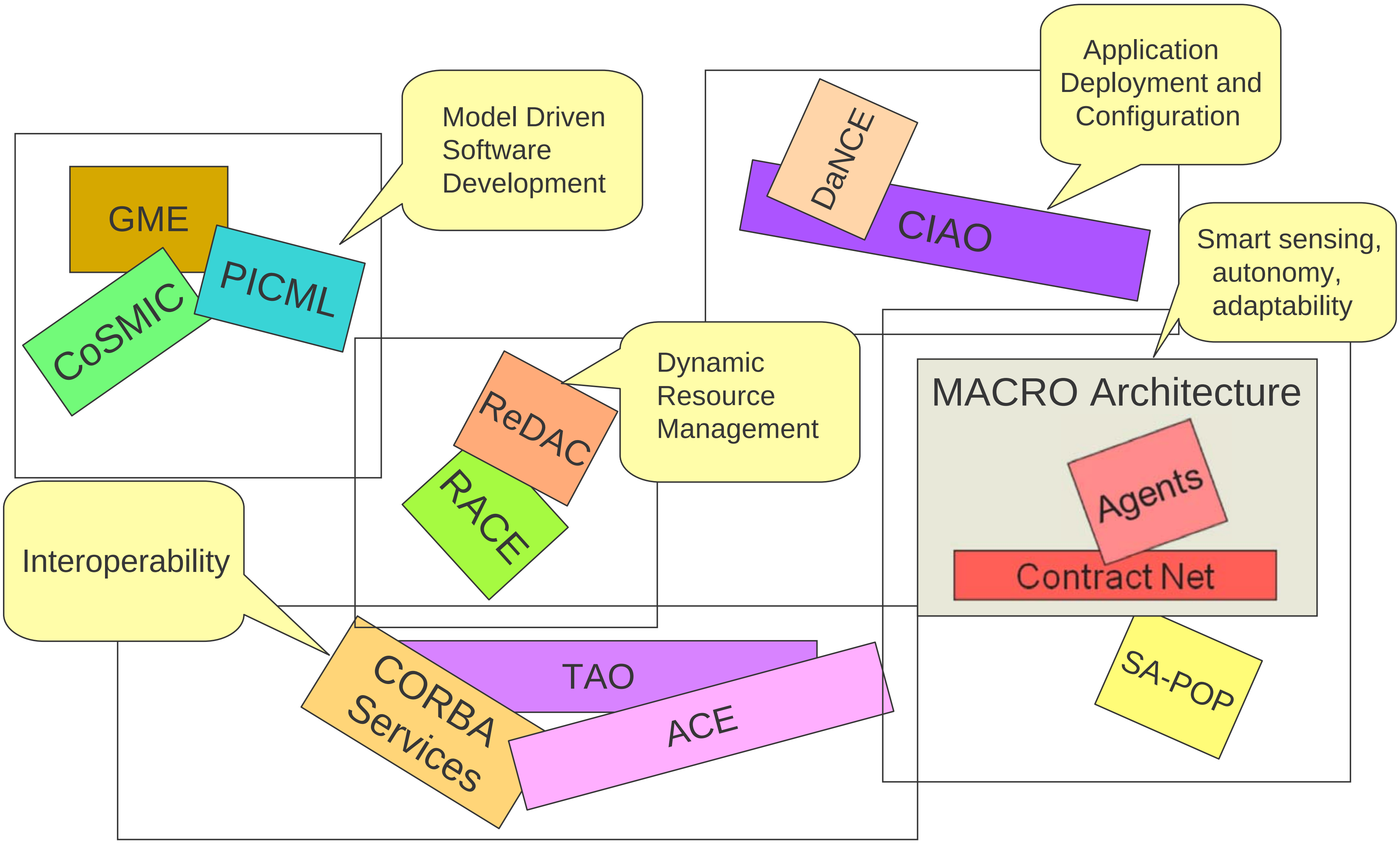
“Component Software” Runtime Model

“Execution” Runtime Model

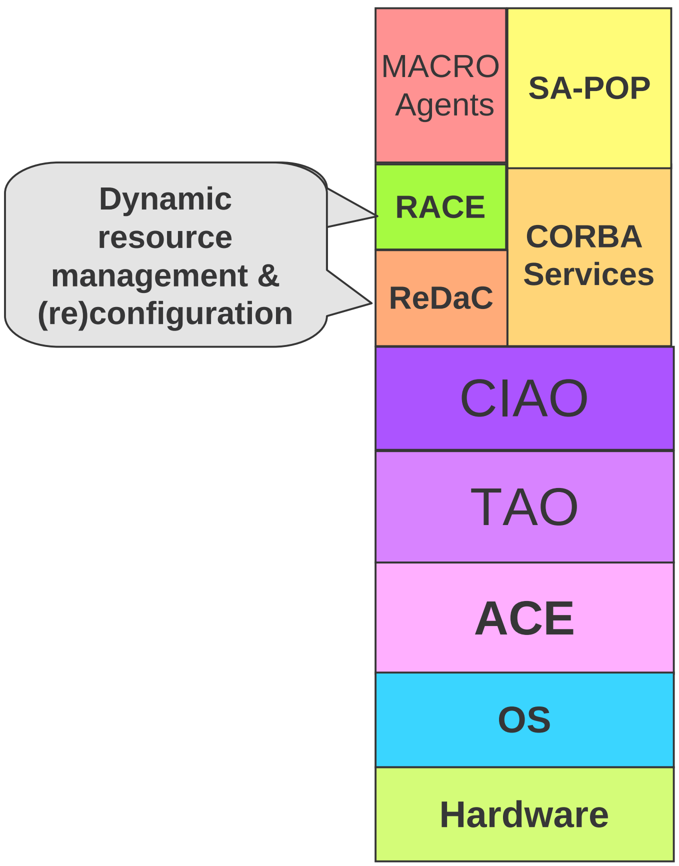
“Target” Runtime Model

www.cs.wustl.edu/~schmidt/PDF/DanCE.pdf

System Constituents



System Construction



Planner – Agent reasoning; used as a service

Naming Service: Agent locator (white pages)

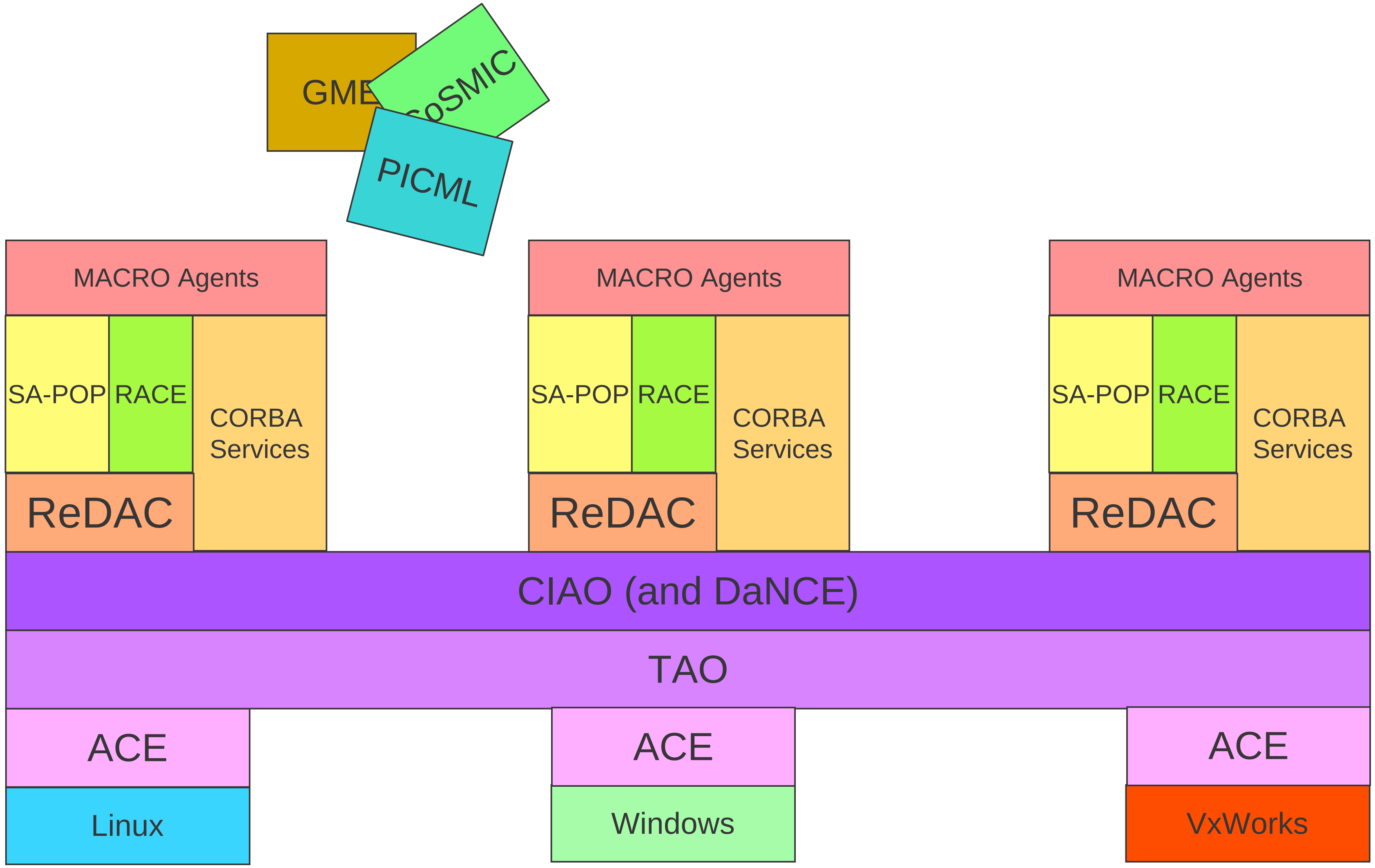
Event Service: Agent Communication (publish/subscribe paradigm)

Middleware Level 3; based on CORBA 3 specification; distributed components, system configuration, & deployment

Middleware, Level 2 based on CORBA 2 specification; distributed objects, interoperability for distributed heterogeneity

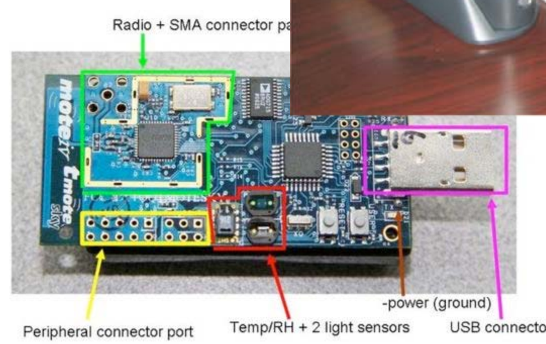
Middleware, Level 1; portability for hardware, operating system

Integrated System



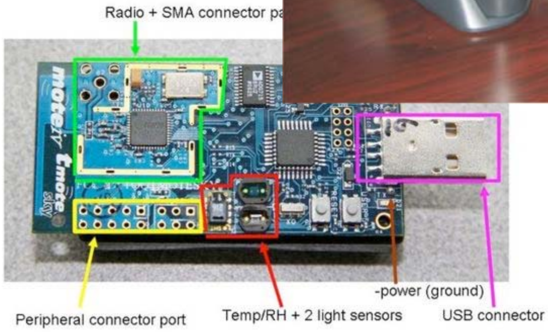
MACRO Testbed Hardware (1/2)

- Closely emulate SEAMONSTER environment
  - 2 Vexcel Microservers
  - 3 SLUGS w/ WET54G Wireless/Ethernet bridges
  - 10 Motiev tMote Sky
- Vexcel (Microsoft) Microservers
  - Low-power ARM Single Board Computers
  - Power Conditioning Subsystem
  - COTS Wi-Fi/Ethernet bridge
  - WiFi Signal Amplifier
  - GPS
  - Solar charging regulator
  - Weather/Cold/Bear-proof case



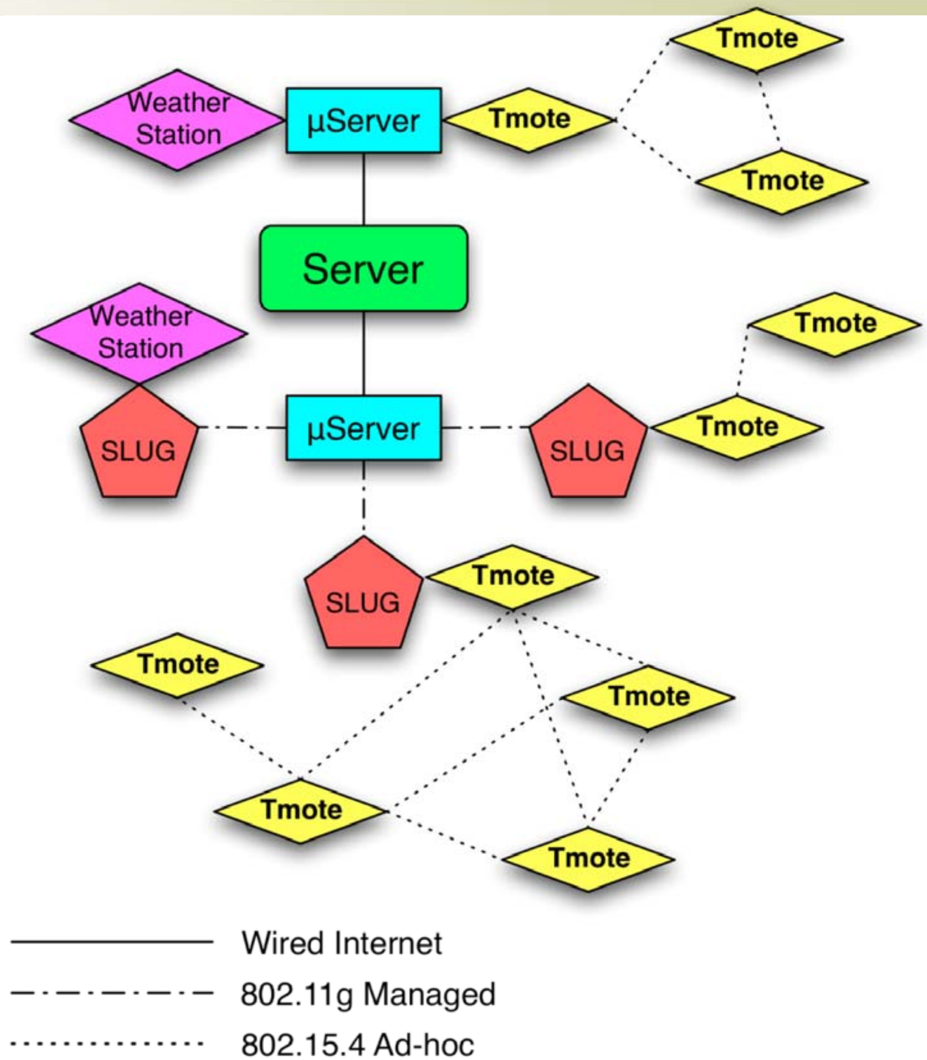
MACRO Testbed Hardware (2/2)

- SLUGS
  - Re-purposed Linksys NSLU2 Network-Attached-Storage
  - Low-cost ARM Single Board Computers
  - Communicate using WET54G Wi-Fi/Ethernet bridges
- Moteiv tMote Sky
  - Low-power field sensors
    - Temperature
    - Humidity
    - Light
  - 2.4 Ghz 802.15.4
  - USB connector for base station or external sensor



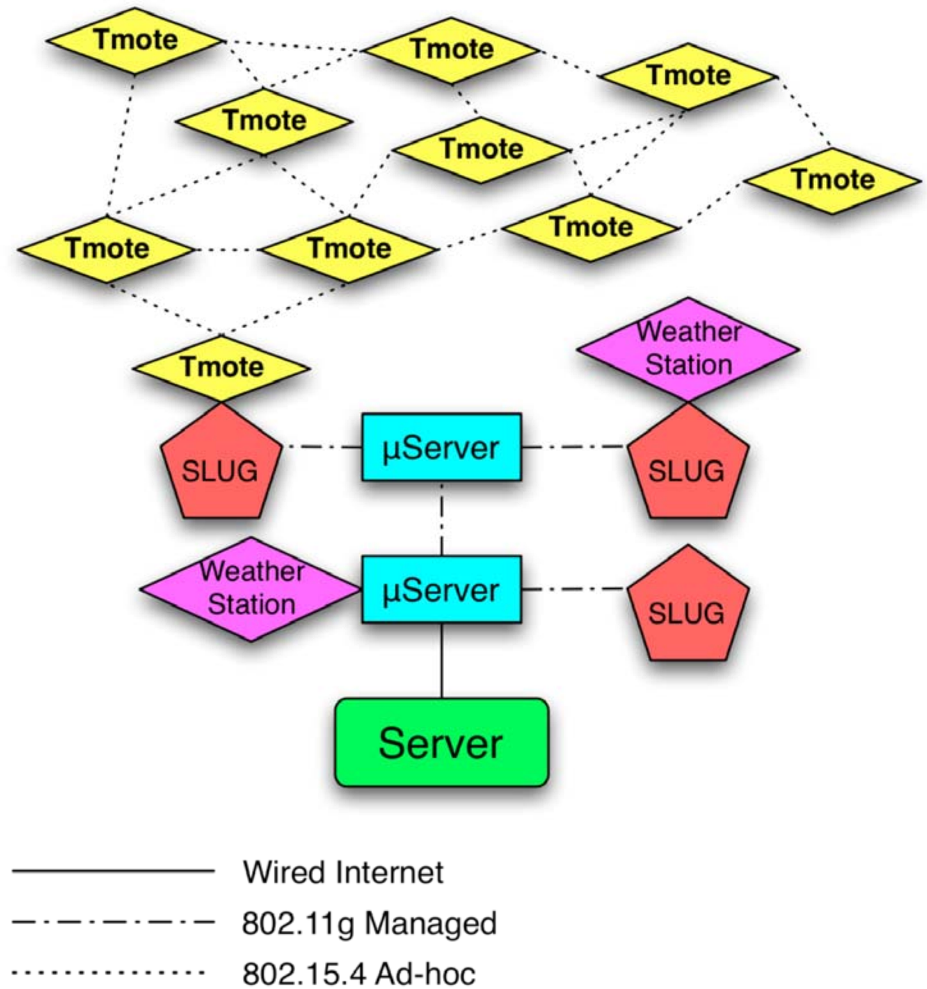
Testbed Topology w/ Physical Distribution

- Provides best fidelity to actual SEAMONSTER environment
- Most difficult in terms of connectivity
- Consists of at least three physical locations
  - Microserver with "weather station" & tMote network
  - Microserver which collates data from several SLUGS
    - Two of three SLUGS in different locations (with attached tMote networks)



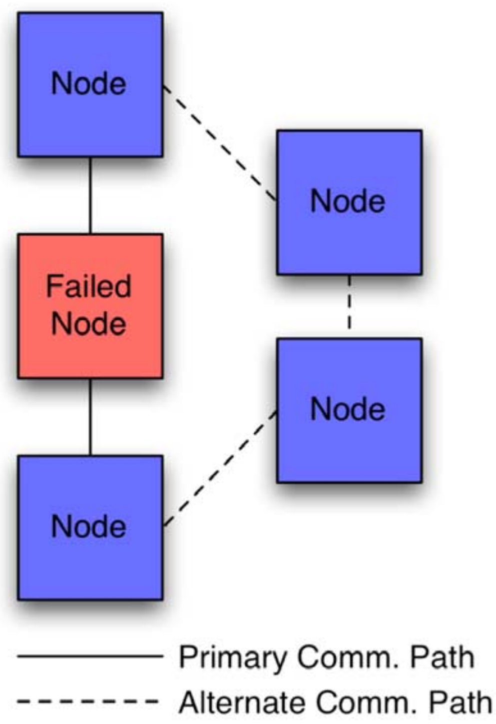
Testbed Topology w/o Physical Distribution

- Avoids potential firewall problems with physically separated layouts
- Single tMote network due to ZigBee ad-hoc network protocol
- µServer not directly connected to Server has a WAP (running in WDS mode)
- Second 'hop' through second µServer may present communication challenges for deployment & configuration



Middleware Integration Challenges (1/3)

- **Context**: Adapting to changing network topology
  - Sensor networks are often deployed in remote/inaccessible locations
  - Limited resources and/or damage may induce temporary loss of communication with nodes
- **Problem:** Failed links or nodes cause temporary or permanent loss of access to data stored on effected nodes
- **Solution Approach**
  - Introduce asynchronous publish/subscribe ports into agent components deployed onto nodes
  - Agents publish noteworthy data to these ports, and log data received
  - Data peers managed by deployment infrastructure

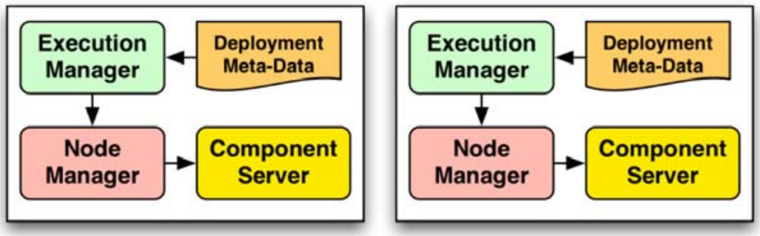


Middleware Integration Challenges (2/3)

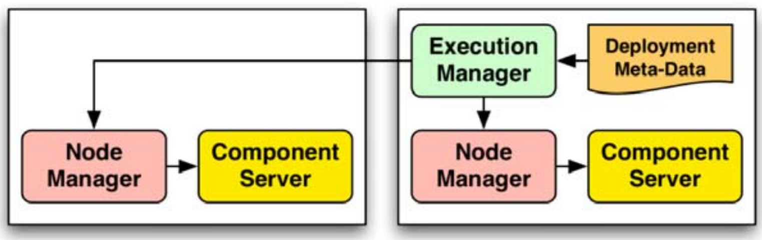
- **Context** –
  - Sensor nodes may be interested in large numbers of observable phenomena
  - Type, duration, and frequency of observation may change over time
- **Problem –** Limited resources (processor, bandwidth, storage) requires prioritization of observable phenomena
- **Solution Approach –**
  - Nodes contain components implementing agents capable of intelligent, autonomous planning
  - Agents may influence deployed applications through re-deployment interfaces and CCM component homes

Middleware Integration Challenges (3/3)

- **Context** –
  - Sensor nodes often have limited power, changing weather conditions may impede ability to re-charge batteries
  - Nodes may need to periodically power down to conserve battery life
- **Problem –**
  - Sleep/wake cycles causes the infrastructure and applications to lose state
  - Deployment infrastructure must preserve state to correctly re-deploy application
  - Application state must be preserved
- **Solution Approach –**
  - Describe all deployments as locality-constrained
  - Maintain entire deployment tool chains on each node
  - Periodically instruct agents to save state using CCM-defined `ccm_store` and `ccm_load` operations



Locality Constrained Deployment



Non-Locality Constrained Deployment

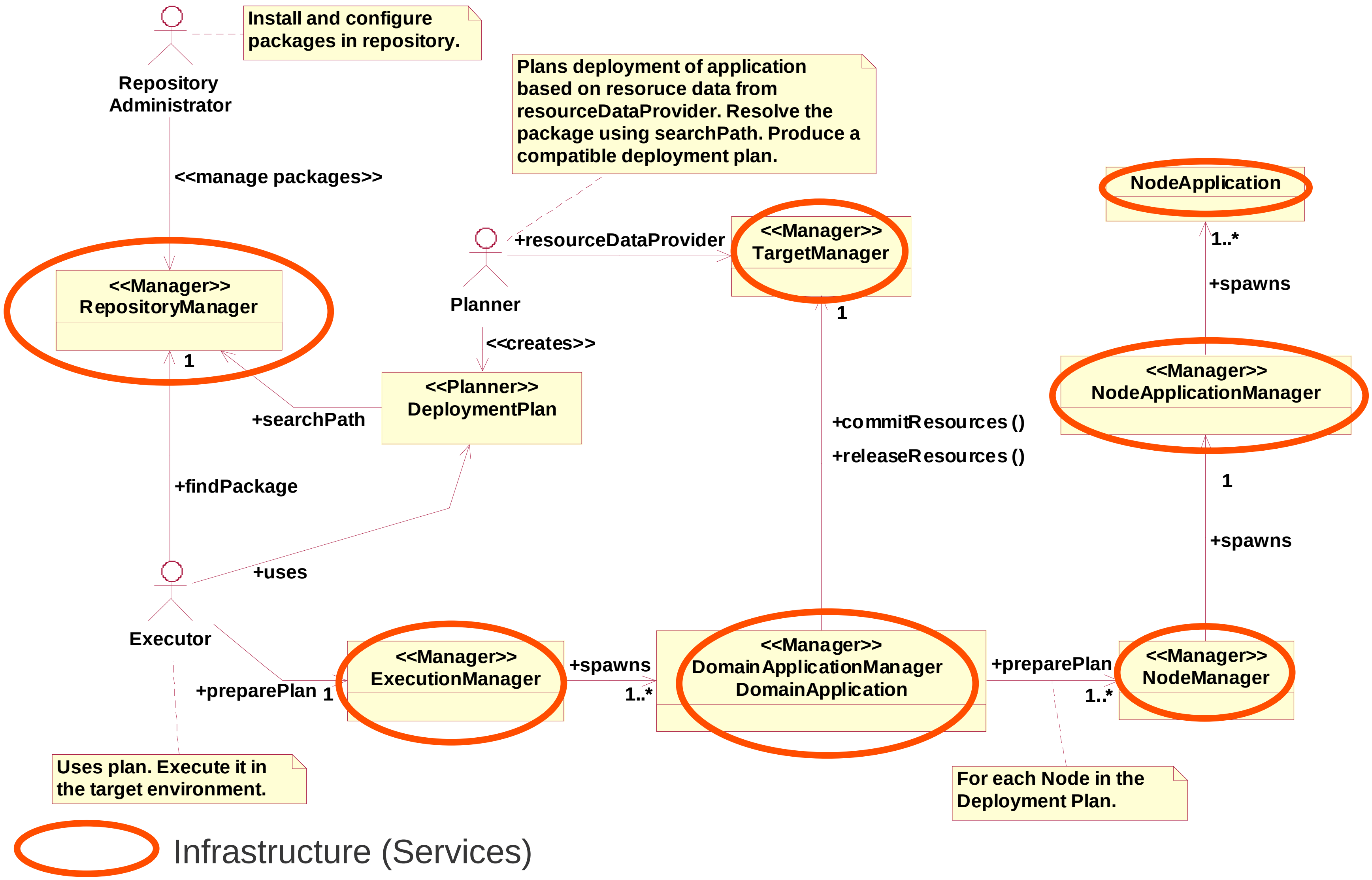
Future Integration Challenges

- Resource Constraints
  - Sensor nodes have limited processing and memory
  - Relatively large footprint of CCM limits number of components deployed to a single node
- Infrastructure Fault Tolerance
  - Uncertain and harsh nature of many sensor web environments presents substantial challenge to deployment infrastructure
  - Current solution unnecessarily coarse-grained and resource heavy
- Communication in Sparse Wireless Networks
  - Point-to-point communication is an implicit requirement of CORBA/CCM
  - Challenge currently avoided using infrastructure-based wireless networks
  - CORBA Wireless Access and Terminal Mobility specification may provide better solution

Questions and Discussion

Extra Slides

Deployment Infrastructure Overview (2/2)



SA-POP & RACE in MACRO

- SA-POP
  - Dynamic planning and scheduling under uncertainty
  - Replanning/rescheduling
  - Domain knowledge captured in TaskNetwork and TaskMap
- RACE
  - Dynamic resource allocation
  - Control algorithms for maintaining required QoS
  - Pluggable allocation and control algorithms