Evaluating Adaptive Resource Management for Distributed Real-Time & Embedded Systems

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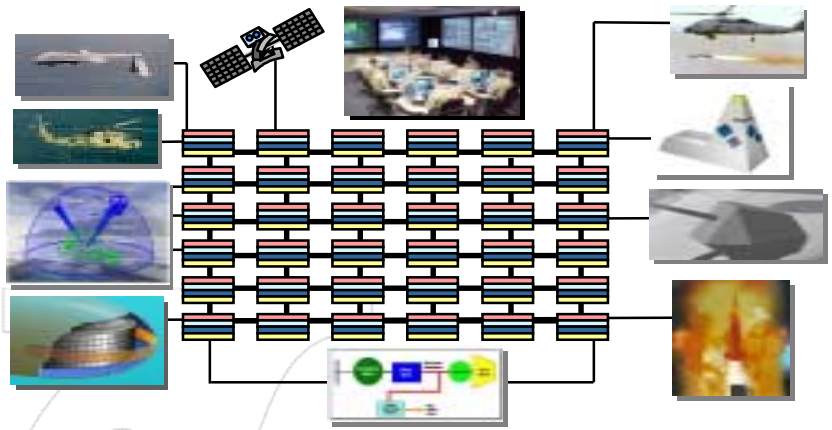
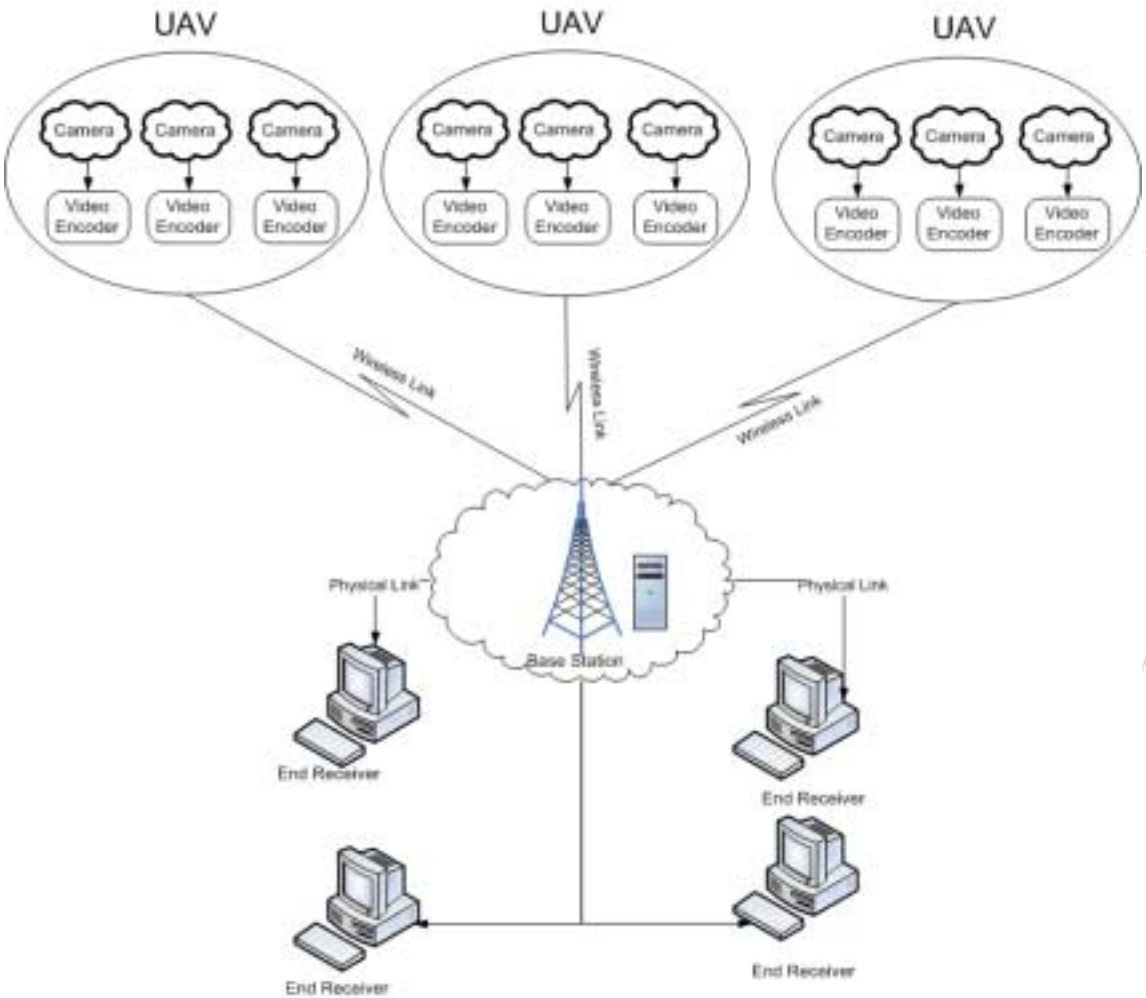
Motivation

- Context
  - End-to-end QoS requirements
  - Resources constraints
  - e.g., Total ship computing, autonomous air surveillance
- Problem
  - Operate in *open* & unpredictable environment
  - No accurate *apriori* knowledge of resource availability/demand
  - Need to avoid over-utilization & under-utilization
- Solution
  - *Adaptive resource management*

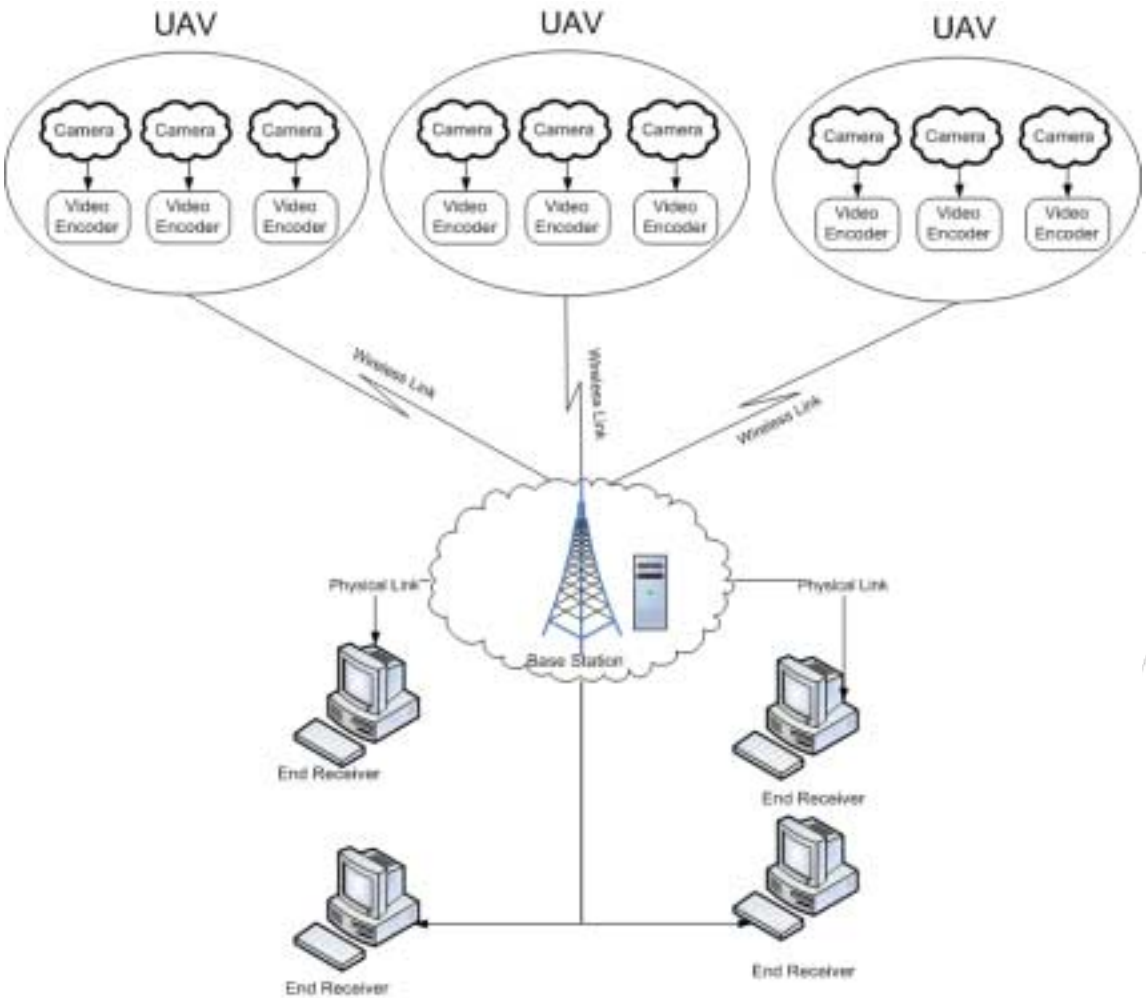


Case Study: DRE Multimedia System (1/2)



- System Architecture
  - Data Source
    - UAV
  - Data Distributor
    - Base Station
  - Data Sinks
    - End Receivers
- Application QoS
  - Latency
  - Inter-frame delay (jitter)
  - Frame rate
  - Picture resolution
- System Resources
  - UAV computing power
  - Network bandwidth

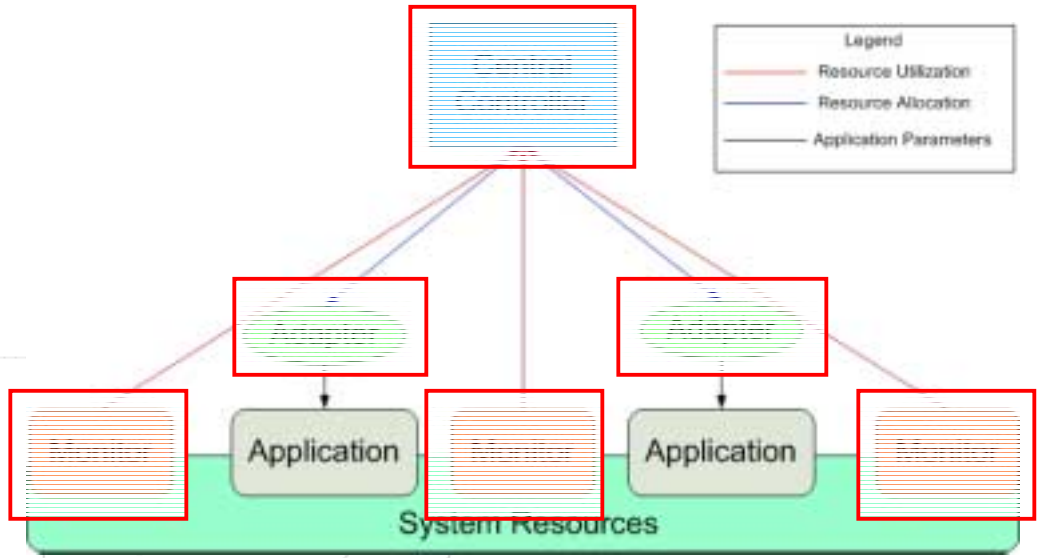
Case Study: DRE Multimedia System (2/2)



- Application Classes
  - Guaranteed & best-effort
- Application Parameters
  - Frame rate, picture resolution, & compression scheme
- System condition (current resource utilization)
  - Under-utilization
    - Large amount of residual resources
  - Over-utilization
    - Loss of resources & increase in resource demand
  - Effective utilization
    - Desired system condition

Hybrid Adaptive Resource Management Middleware (HyARM)

- Central Controller
  - Hybrid control theoretic techniques
  - Modify application input parameters via application adapters based on current resource utilization
- Application Adapters
  - Modify application input parameters based on inputs from central controller
- Resource Monitors
  - Observe resource utilization
    - Per application & net system resource utilization

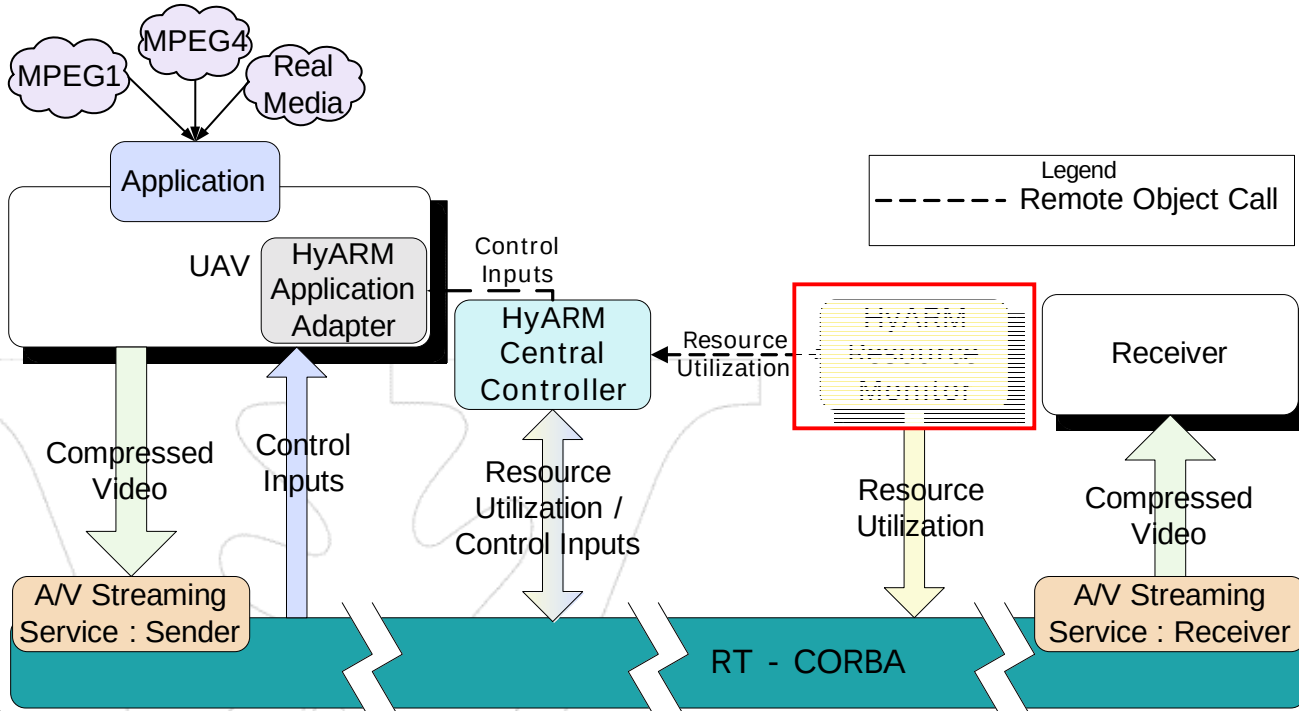


- HyARM performs
  - Online monitoring of resource utilization & application QoS
  - Dynamically modifies application input parameters
  - Manages
    - System resource utilization
    - Application performance (QoS)

HyARM features a *feedback control loop*

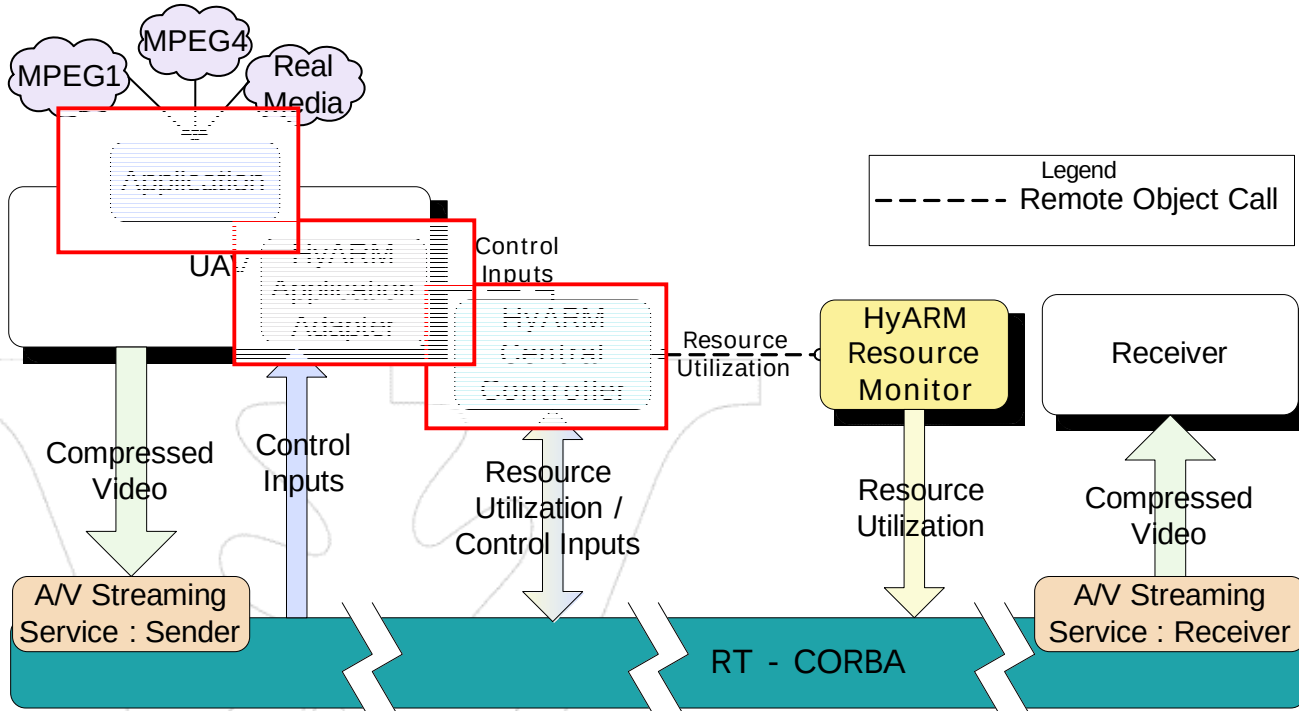
Implementing HyARM with Real-time CORBA (1/2)

- Software Infrastructure
  - Real-time CORBA
  - A/V Streaming Service
- CORBA Servants
  - Monitors
  - Controller
  - Application & Application Adapters
- Monitors
  - Implement the Observer Pattern
  - CPU Monitor
  - Network Monitor



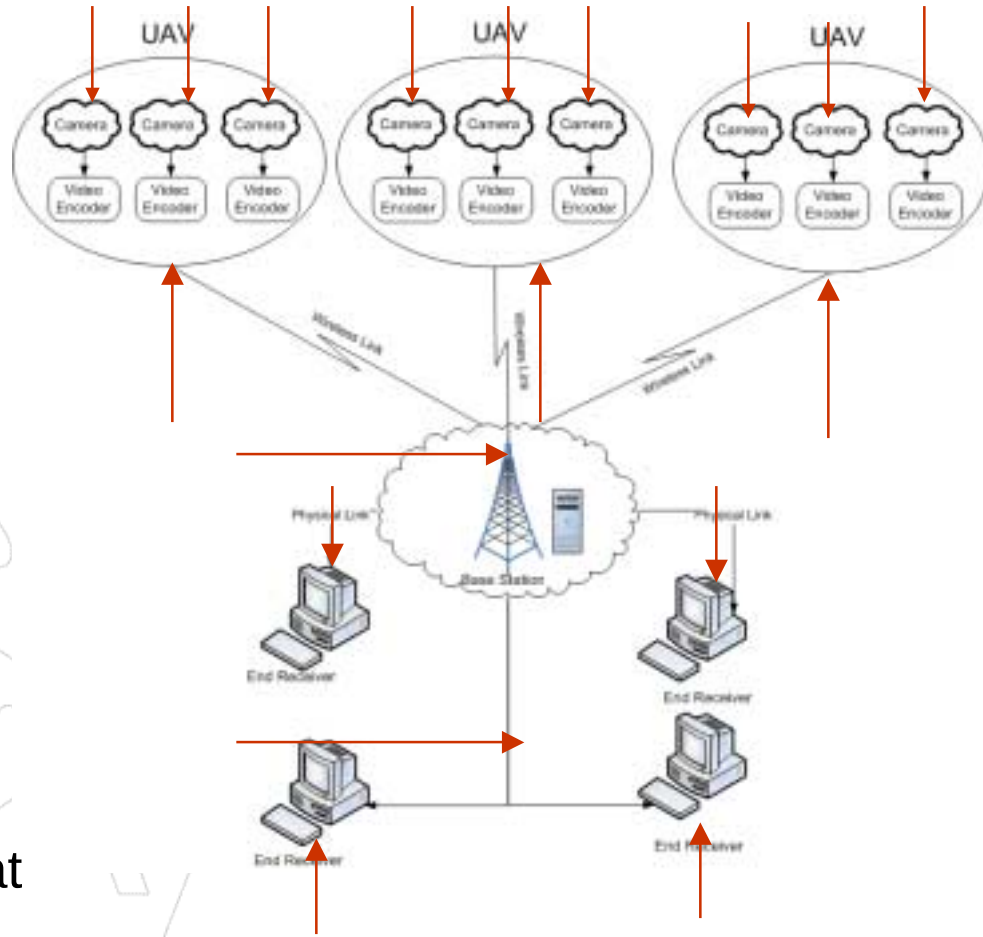
Implementing HyARM with Real-time CORBA (1/2)

- Application - Video Encoder
- Application Adapter
  - Modify input frame rate and/or resolution and/or compression scheme
- Controller
  - Compute application input frame rate & / or resolution & /or compression scheme



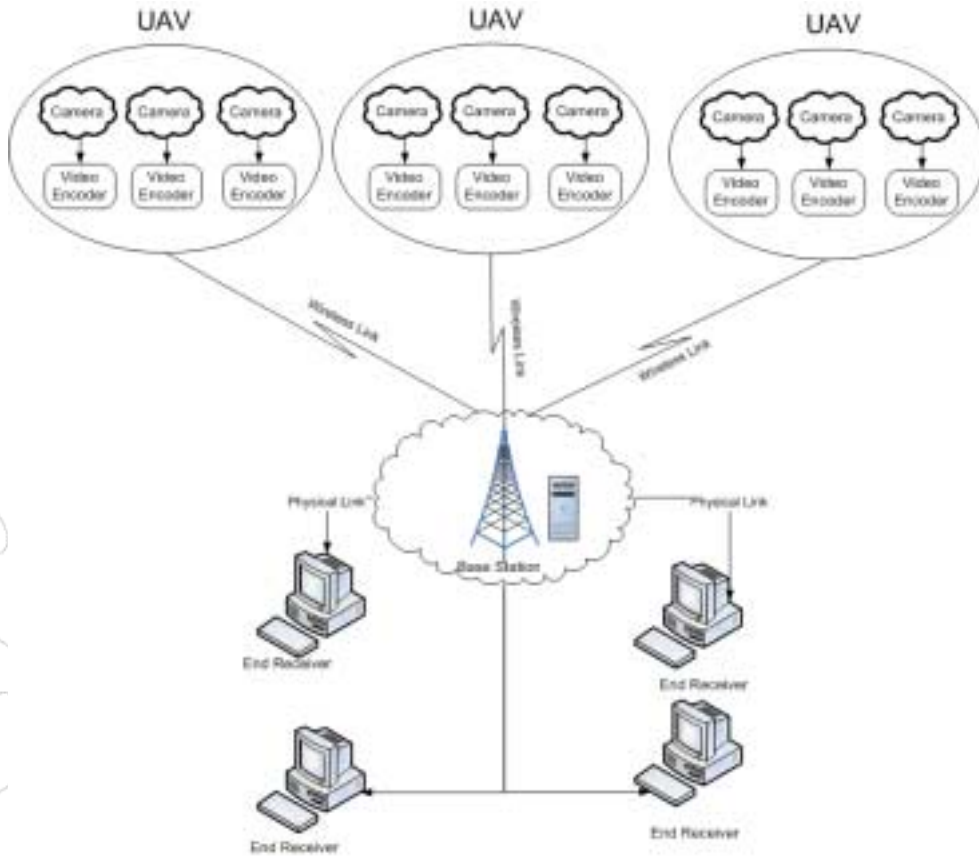
System Formal Model (1/2)

- *n* applications $\{Ti \mid 1 <= i <= n\}$
- *m* resources $\{R_j \mid 1 <= i <= m\}$
- Sampling period T_s
- $U(k)$: resources utilization at sampling period *k*
- $U_g(k)$: resource utilization of guaranteed applications
- $U_{be}(k)$: resource utilization of best-effort applications
- U^s : Desired utilization set-point
- U_g^s : Desired utilization set-point of guaranteed applications specified at system initialization



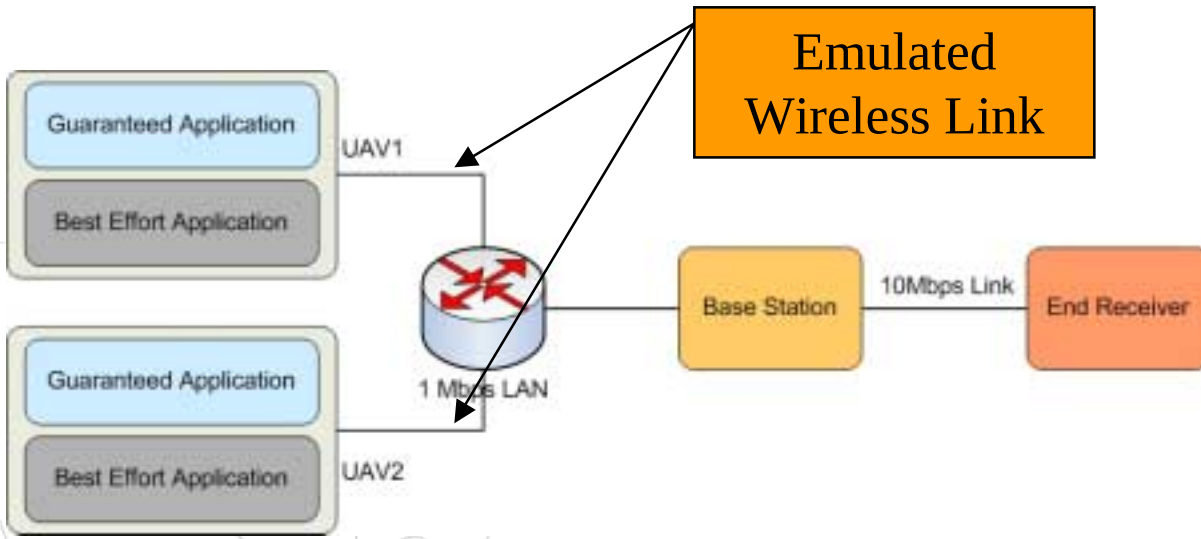
System Formal Model (2/2)

- $U_{be}^{s}(k)$: Desired utilization set-point of best-effort applications
  - $U_{be}^{s}(k) = max\{(U^{s} - U_{g}(k)), 0\}$
- Objective
  - $max(U(k))$ subject to $U_{j}(k) <= U_{j}^{s}\ \{R_{j} \mid 1 <= i <= m\}$
- Application parameters
  - *Continuous* variables
    - Resolution
  - *Discrete* variables
    - Frame rate
    - Compression scheme

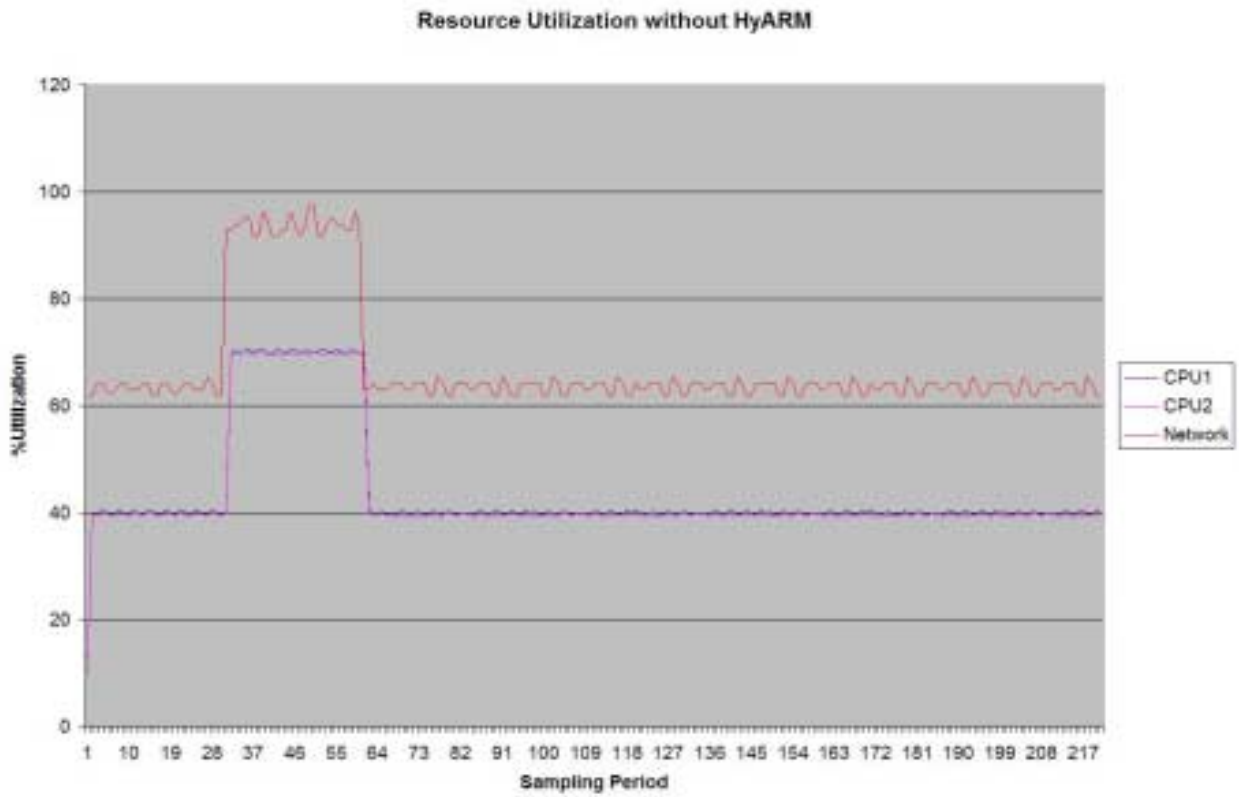


Hardware Testbed & QoS Requirements

- Processors
  - PIII 600 MHz
  - Memory 256 MB
  - RT Linux (Timesys)
- Software
  - Ffmpeg 0.4.9-pre1
  - Iftop 0.16
  - ACE 5.4.3 + TAO 1.4.3
- 1 Guaranteed & 1 best-effort application in each UAV
- Resource utilization set-point (each resource)
  - System utilization 0.69
  - Guaranteed 0.50

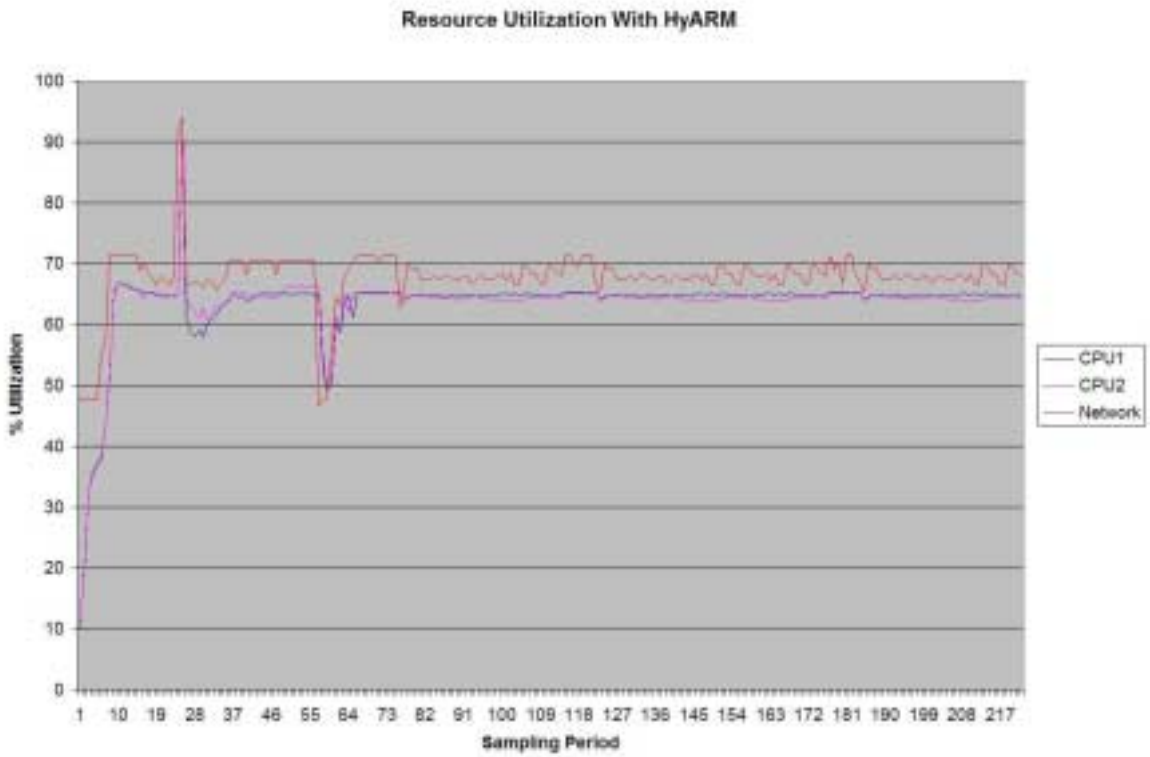


Empirical Results : Resource Utilization (1/2)



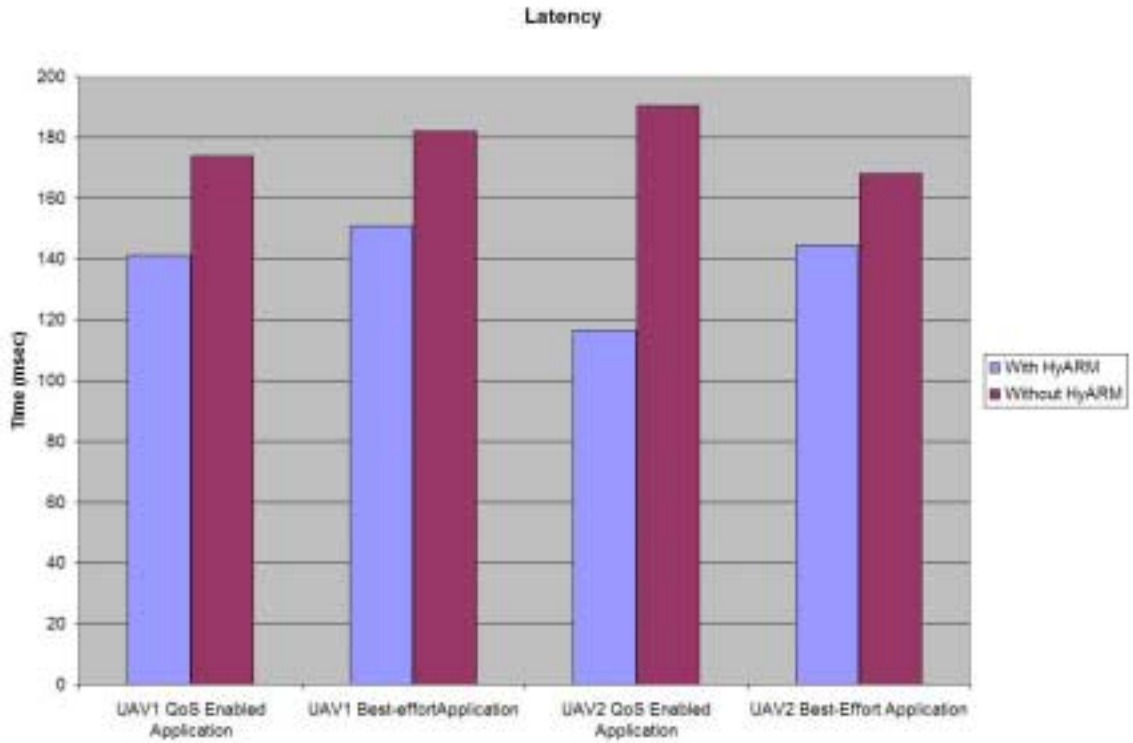
- Compared resource utilization of
  - CPU
    - UAV1
    - UAV2
  - Wireless Network (emulated)

Empirical Results : Resource Utilization (2/2)



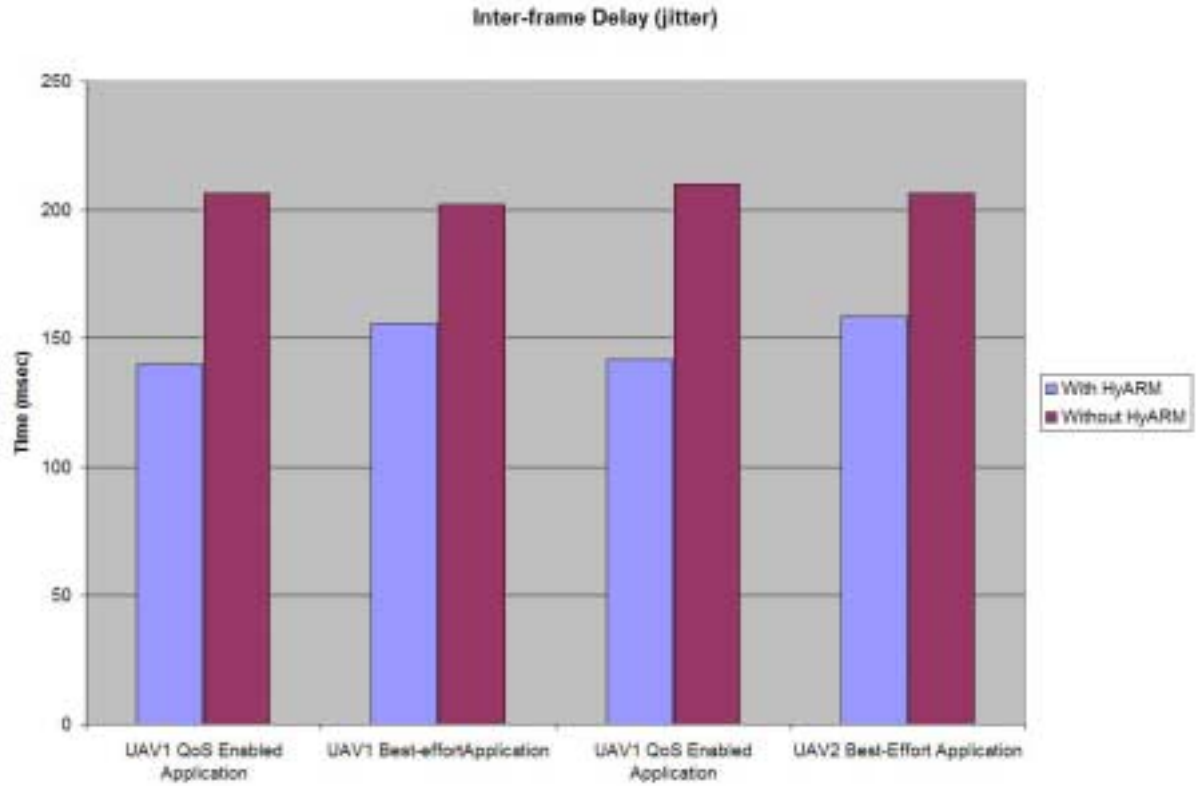
- Results indicates resource utilization is maintained within bounds
- HyARM
  - Adapts to resource availability & demand
  - Ensures effective & adaptive resource management for DRE systems

Empirical Results: Latency & Jitter (1/2)



- Compared real-time video properties
  - Latency
  - Jitter
- Results indicates HyARM enables better real-time performance
  - Lower latency & jitter for guaranteed applications

Empirical Results: Latency & Jitter (2/2)



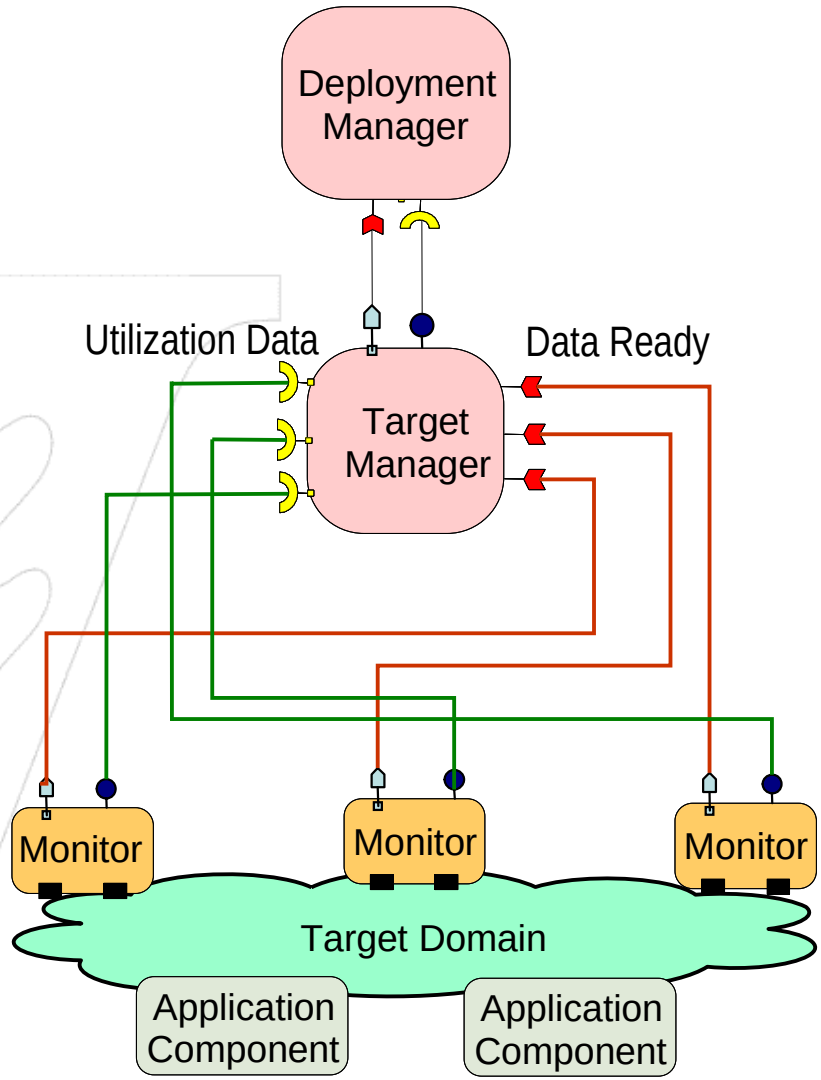
- HyARM
  - Improves overall system performance
  - Ensures QoS requirements of guaranteed applications are met

Related Work

- Feedback Control Scheduling (FCS)
  - Dynamically adjust resource allocation
  - Software feedback loop
  - Designed & implemented using control theoretic methodologies
  - Can operate only on continuous control variable
    - Not applicable to
      - Avionics
      - Total ship computing
- CAMRIT applied control theoretic techniques
  - TCP buffer used as indictor of network resource utilization
  - Performs resource management of network resource
  - All applications are of the same priority
- QuO
  - Bridge between application QoS requirements & QoS capabilities of network
  - Relies on underlying network to handle fluctuations in network resource availability / demand

Future work

- De-centralized controller
- Upgrade implementation of HyARM from CORBA to CCM
- Use MDD to model & develop adaptation algorithms
- Resource Allocation and Control Engine (RACE)
  - Pluggable framework for variety of resource allocation & adaptation algorithms
  - Resource allocation – bootstrapping
  - Runtime adaptation
  - Manages system resource utilization & application performance



Concluding Remarks

- HyARM ensures
  - Effective resource utilization
  - QoS requirements of guaranteed applications are met
- HyARM enables adaptive resource management for DRE systems
  - Improves
    - Resource utilization
    - Application Performance
    - Preserves application relative priority
- Source available for download at http://www.dre.vanderbilt.edu/~nshankar/HyARM