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

Nishanth Shankaran, Xenofon Koutsoukos, Douglas C. Schmidt, & Aniruddha Gokhale

Department of EECS, Vanderbilt University
Nashville, TN
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

Legend
- - - - - - Remote Object Call
n applications \( \{ T_i \mid 1 \leq i \leq n \} \)

m resources \( \{ R_j \mid 1 \leq i \leq m \} \)

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
\( U_{be}^s(k) \): Desired utilization set-point of best-effort applications

\[ U_{be}^s(k) = \max \{ (U^s - U_g(k)), 0 \} \]

Objective

\[ \max (U(k)) \text{ subject to } U_j(k) \leq U_j^s \{ R_j | 1 \leq i \leq m \} \]

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

Emulated Wireless Link
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