SYSTEMS ENGINEERING
Research Center
A US DoD University Affiliated Research Center

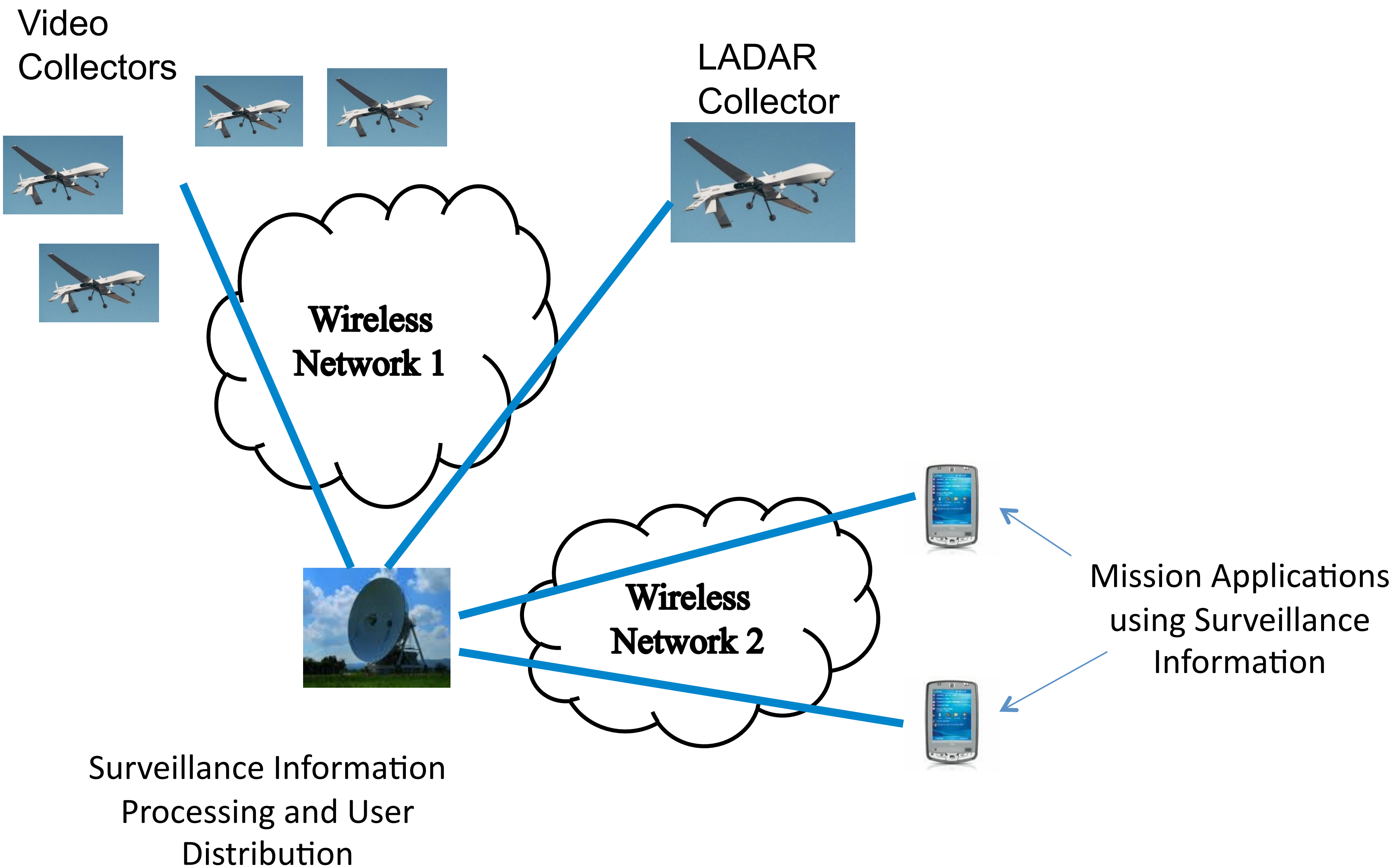
Architectures for Adaptive Multi-Scale Optimization "AMO"

Barry Horowitz
University of Virginia

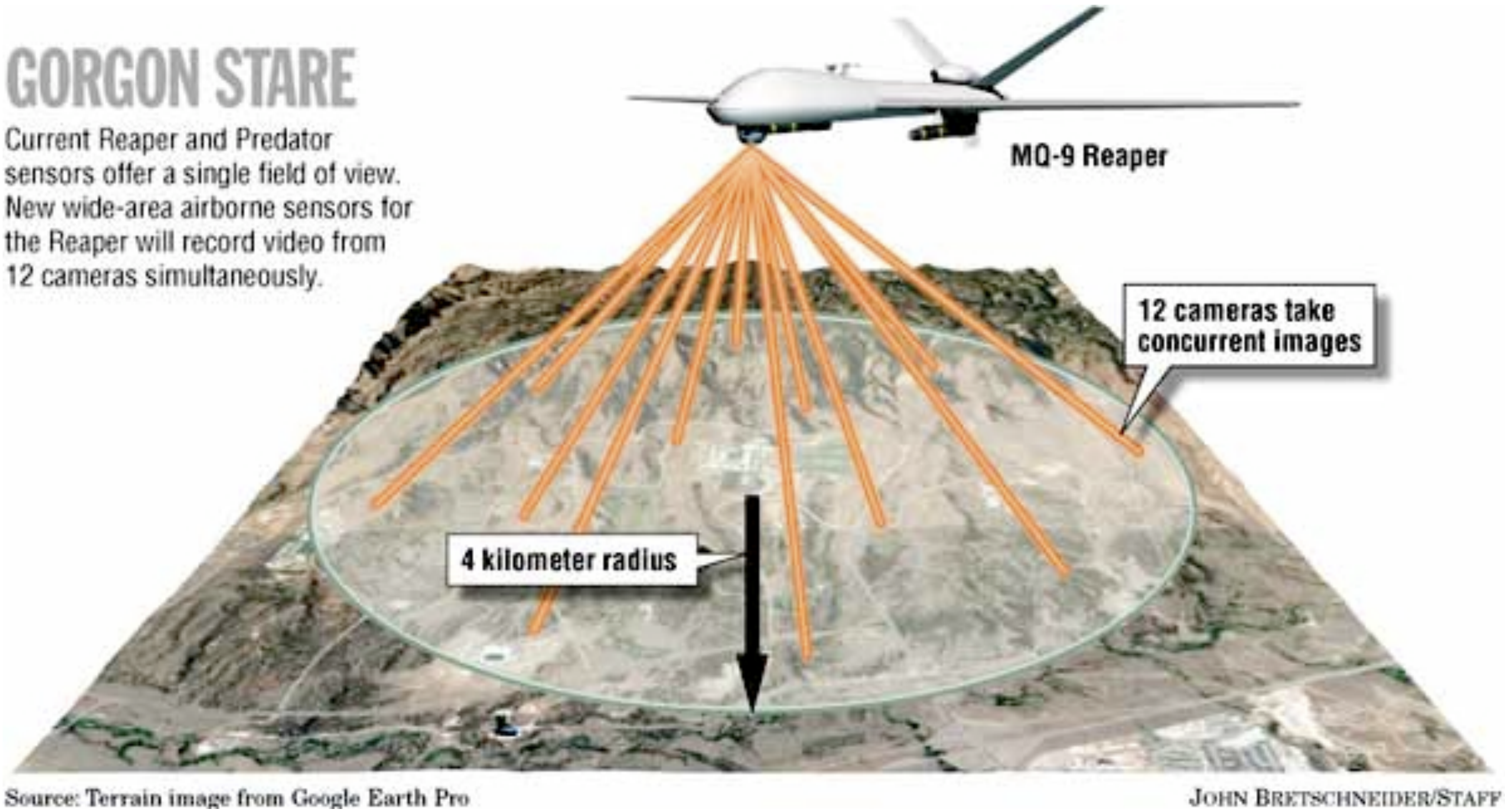
November 9-10, 2010

SYSTEMS ENGINEERING
Research Center

General System Problem Scenario



Video Collection



LADAR (Laser Detection and Ranging)

- LADAR utilizes a fine beam to generate high fidelity point measurements reflecting from observed surfaces
- Beam penetrates foliage and similar surfaces, revealing concealed object
- Provides 3D range point cloud data (~1mm point size), useful for object recognition

SYSTEMS ENGINEERING
Research Center

Context for Discussing AMO (1)

- Technology advances have provided the basis for utilizing “smart” components for significantly enhancing the performance of systems operating under extremely constrained circumstances
- Smart Component: A component (or sub-system) that is capable of measuring its surrounding environment and achieving improvements by adapting the way it performs based on the measurements
  - Cognitive radios –component level
  - Video-aware networks – sub-system level
  - Smart grid – emerging system concept to exploit smart components

SYSTEMS ENGINEERING Research Center

Context for Discussing AMO(2)

- However, smart components are really only “so-so smart” components
  - Limited measurements
  - Don’t necessarily know overall system objectives, especially when they are time varying
  - Only have a limited set of operating modes to switch between
- AMO provides a system-level basis for making smart components “smarter yet” components
  - Near real-time sharing of measurements among components and sub-systems
  - Near real-time distribution of changing objective functions
  - Adding additional modes of adaptive operation to smart components and subsystems that are objective function related
  - Deriving optimal, or more realistically near-optimal, system solutions for components sharing information and adapting to their integrated measurement sets

SYSTEMS ENGINEERING
Research Center

Adaptive Multi-Scale Optimization

Objective Functions Distributed to Smart Components

+

Smart Component Measurement and Coordination

+

Additional Objective Function Related Modes
of Smart Component Operation

+

Distributed Optimization

AMO

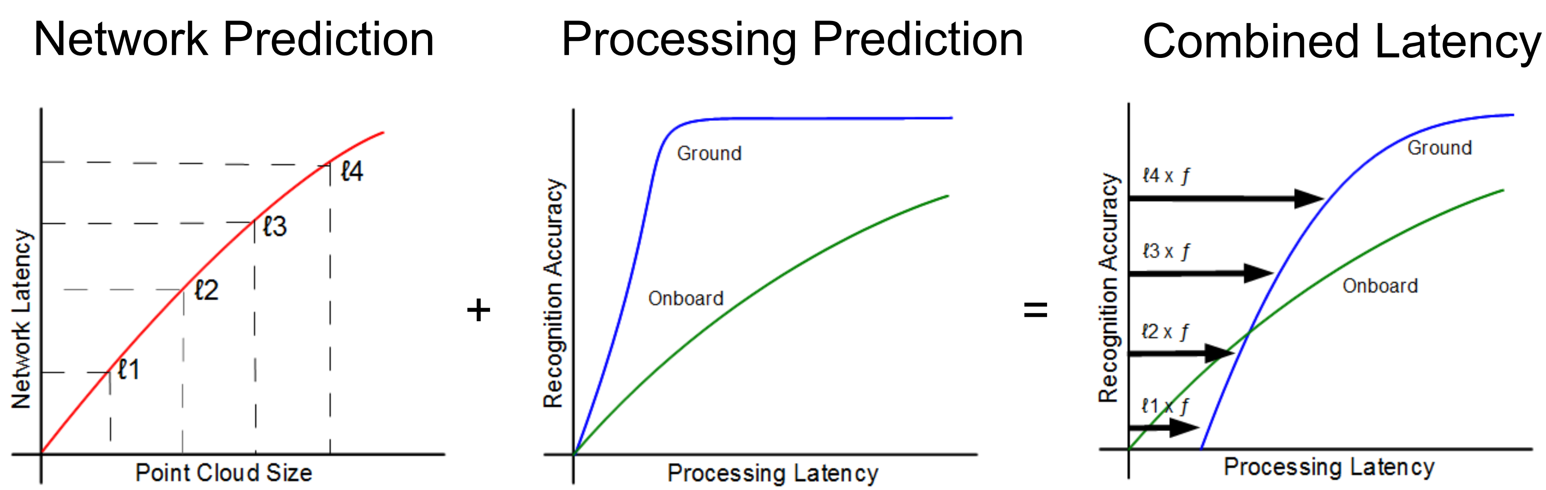
SYSTEMS ENGINEERING
Research Center

AMO-based Architectures

- Provides system framework for system design for highly constrained systems
- Achieves better results (as measured by system objective functions) through exploitation of:
  - enhanced information sharing
  - additional modes of individual component operation, with new modes tuned to the system objective functions and critical operating constraints
- Solutions inspired by techniques derived from such disciplines as:
  - Distributed Optimization
  - Linear and Non-Linear Programming
  - Game Theory
  - Utility Theory
  - Optimal Control Theory
- Provides solutions based upon distributed coordination rather than centralized optimization so as to:
  - Provide more scalable solutions
  - Avoid critical points of failure
  - Provide new approaches to system evolution

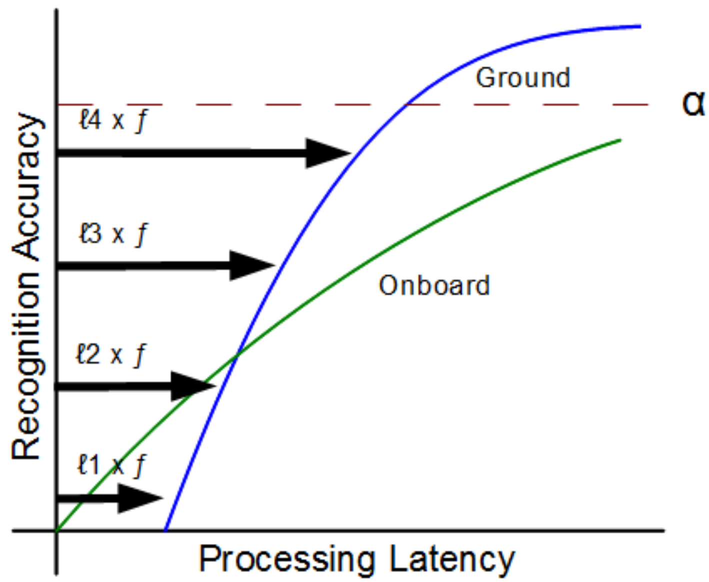
SYSTEMS ENGINEERING
Research Center

Accounting for Time-Varying Communication Network Latencies



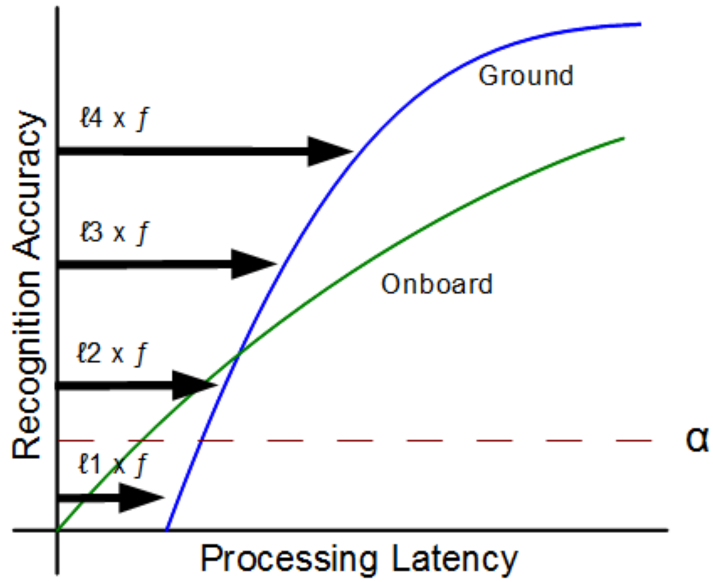
- The network reports the relationship between transmission latency and data file size
- The A/C can determine the expected accuracy for alternative point cloud file sizes
- To account for total latency when utilizing the ground site, the expected network latency, ℓ , for the observed data is added onto the processing latency

Minimizing Latency for a Specified Accuracy (1)



- The accuracy value α determines the amount of processing to perform on the data – more processing results in higher expected correct recognition rates
- In the above example, the ground station is estimated to reach a desired accuracy value with less total latency than the drone; thus, the drone will choose to incur the transmission costs and defer processing to the ground

Minimizing Latency for a Specified Accuracy (2)



- Varying the desired accuracy level may yield a different processing allocation decision
- In this example, a reduced specified accuracy level may be attained onboard with less total latency than on the ground
- The ground site can decide on the relative importance of latency and accuracy for the A/c to use in its processing allocation decision

AMO Benefits

- The LADAR processing allocation process offers potentially significant benefits on a situational basis in terms of
  - Important reductions in latency or
  - Important accuracy improvements

SYSTEMS ENGINEERING
Research Center

Design Patterns and Protocols to Make Reusable AMO Solutions

- While solutions may appear to be highly customized, the ***attributes of solutions are repeated***:
    - Smart Component Coordination Info (Input and Output):
        - identifying the multiple modes of smart component operation,
        - measurements,
        - relevant exogenous data
        - performance relationships and
        - objective functions
    - Smart Component Controls for selecting modes of operation based upon received values of coordination data
- ***Standardized AMO design pattern(s)*** can be developed to address specific classes of systems that need to aggressively apply "customized" AMO solutions
- To more efficiently support coordination needs, ***new communication protocols for AMO information exchanges*** can be developed

Suggested Research Effort

- Select system applications that involve high volume data operating in an overly constrained operating environment (processing/communications).
- Explore architectural structures for such system applications, with attention at multiple scales ranging from micro to macro.
- Start to formulate standards that would be needed to help user communities to more economically address the AMO type solutions, with reusable design patterns offering a potentially viable approach for supporting standardization