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Robust Control for Safety and Security

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New Technologies Enable New Operational Concepts

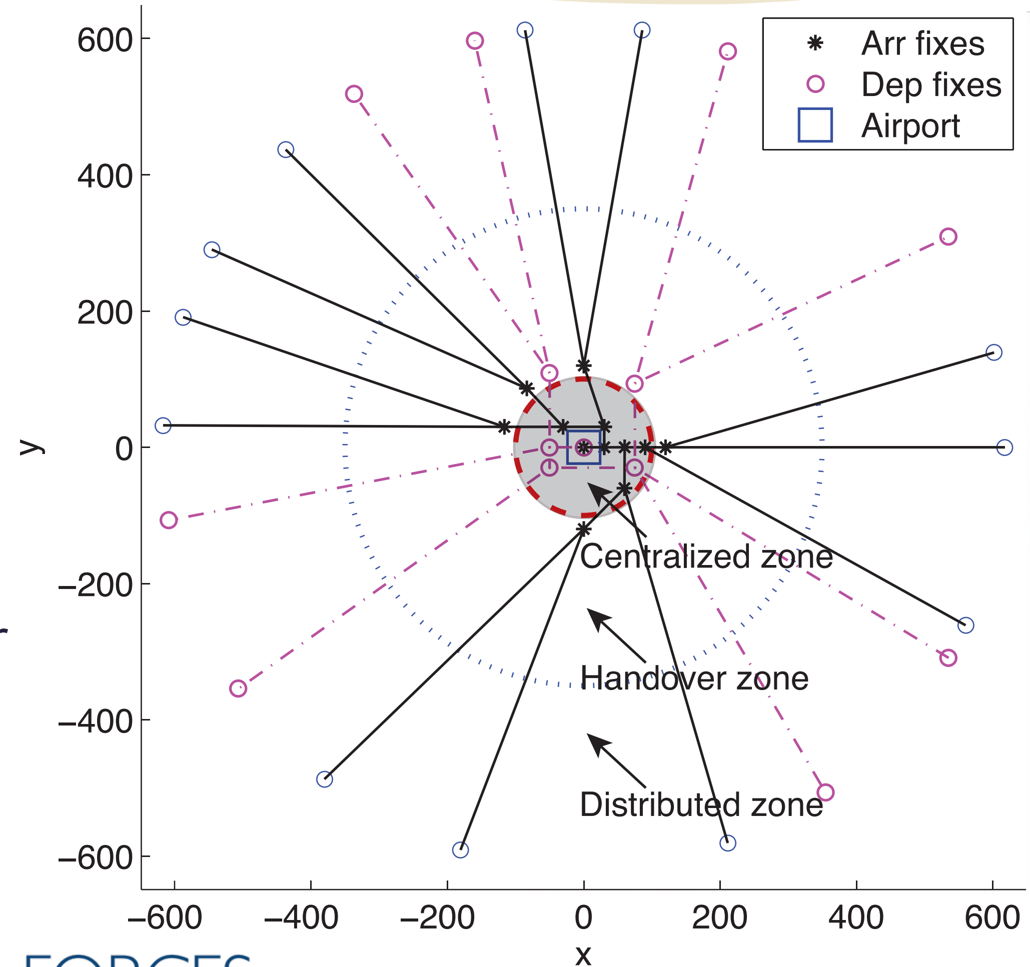
* Today's operations
  * Surveillance using ground-based radar systems
  * Primarily "procedural" approach to air traffic control
  * Manual handoffs between controllers with little prior coordination
  * Radio communications between pilots and controllers
* NextGen operational concepts
  * Satellite-based surveillance technologies: ADS-B
  * Increased potential for control and optimization algorithms
    * Increased availability of state information (onboard and ground)
    * Datalink capabilities

Opportunities and Challenges

* Increased potential for control and optimization algorithms
  * Enhancing system capacity
  * Improving operational efficiency
  * Maintaining/improving system safety
* New challenges
  * Interactions between new and legacy infrastructure
  * Information security
    * GPS jamming/spoofing
    * Detecting adversaries in the presence of uncertainties
  * Incentives for participation
    * Cost vs. potential benefit of collaboration
    * Risks associated with information-sharing

Hybrid Communication/Control Algorithms

* Objectives: Safety and efficiency
  * Conflict detection and resolution
  * Optimize State Update Interval
  * Minimize flight times
* Decentralized at longer range
  * Low traffic density
  * ADS-B surveillance
  * Max transmit power
* Handover zone
  * Decentralized control
  * Adaptively adjust transmit power
* Centralized close to the airport
  * High traffic density
  * Min transmit power
  * Ground radar surveillance
    * Augmented by ADS-B



Park et al., IEEE Trans. on Intelligent Transp. Sys. 2013

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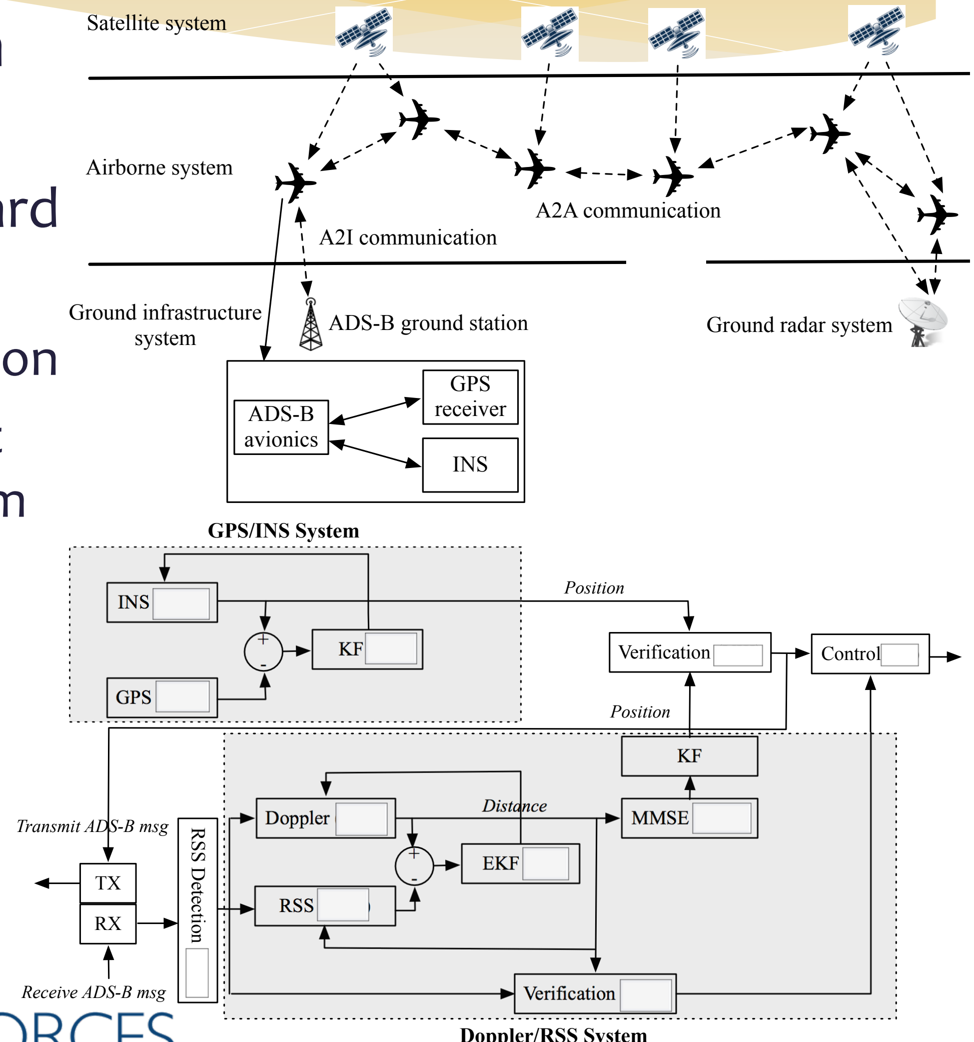
High Confidence Networked Control

- Secure, fault-tolerant control in the presence of adversaries
  - Distributed control using onboard threat detection
    - GPS and inertial sensor data fusion
    - Verification using Doppler effect and RSS of ADS-B messages from neighboring aircraft
    - Control objectives
      - Conflict avoidance, maintaining separation in the presence of uncertainty
      - Minimizing flight times
      - Fault detection



Park et al., under review, 2013

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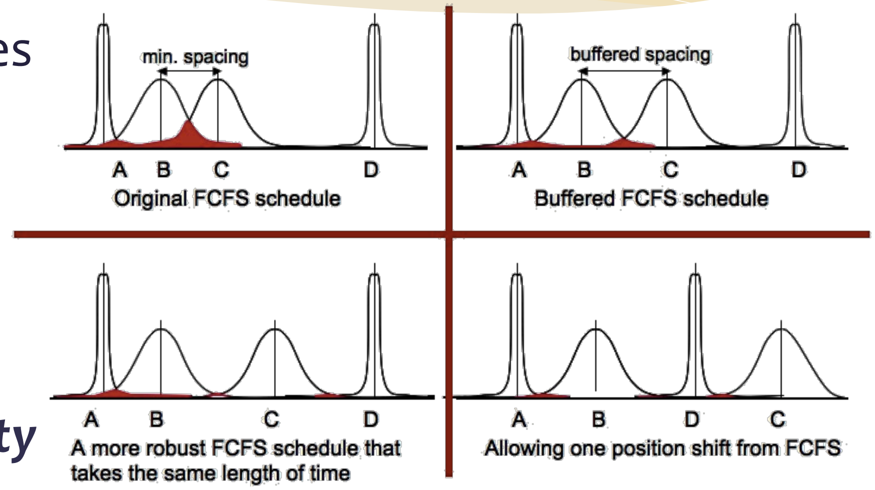
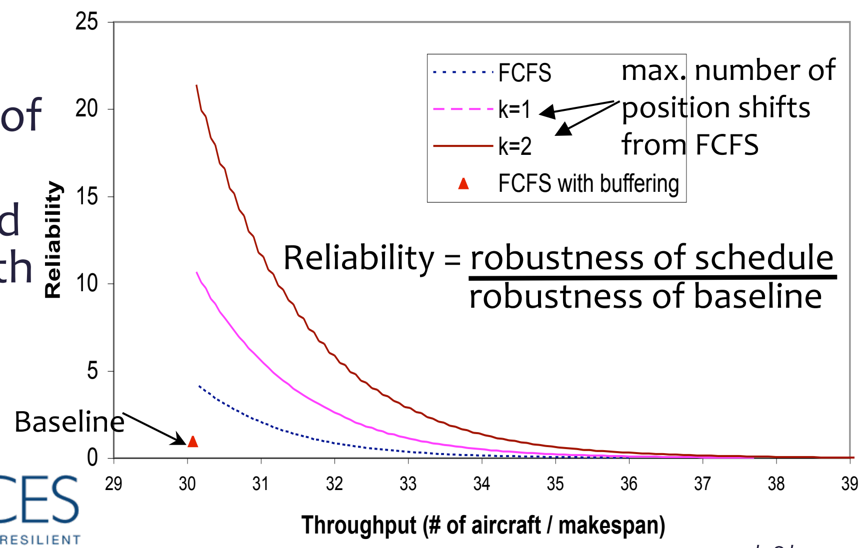
Safe, Efficient and Robust Scheduling

- Sequenced to land (takeoff) on a runway, and determine their landing (takeoff) times
  - Separation requirements (safety)
  - Limited flexibility afforded to air traffic controllers
  - Operational constraints (including arrival/departure time windows)
  - Precedence constraints
- **Objectives:** Throughput, robustness, ***equity***
- Results
  - Solution space can be represented as a network whose size is linear in the number of aircraft
  - Various interesting extensions can be solved in (pseudo-)polynomial time as shortest-path problems on variations of this network
  - Can evaluate tradeoffs between multiple objectives





Chandran & Balakrishnan, ACC 2008
Balakrishnan & Chandran, Oper. Res., 2010
Lee & Balakrishnan, Proc. of IEEE, 2008

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Resource Reallocation in the Presence of Uncertainty

* Initial allocation of resources typically adopt an optimistic view of capacity
* Algorithms for reallocating resources given stochastic capacity forecasts
  * Exchange mechanisms
    * Pareto-efficiency (no other allocation preferable to all airlines)
    * Voluntary participation (incentive to participate)
    * Incentive compatibility (incentive to report true preferences)
    * Core allocation (no incentive for airlines to deviate by forming coalitions)
  * Stochastic optimization algorithms given scenario-tree forecasts
    * Evaluation of incentives to participate, using realistic aircraft delay costs
    * Evaluation of tradeoffs between adaptability (extent of dynamic replanning) and flexibility available to airlines
  * Mechanisms that combine optimization with (monetary) transfers

Balakrishnan, CDC 2007
Ramanujam & Balakrishnan, under review, 2013

Summary

* New technologies present opportunities for robust control algorithms
* New challenges pertaining to
  * Safety
  * Security
  * Information-sharing
  * Interactions between new and legacy infrastructure systems
  * Integration and co-design of Economic Incentives (EI) and Robust Control (RC) algorithms for better system performance

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