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POSTGRADUATE
SCHOOL

An Integrated Command and Control Architecture for Unmanned Systems for 2030

Systems Engineering and Analysis

Cohort-16

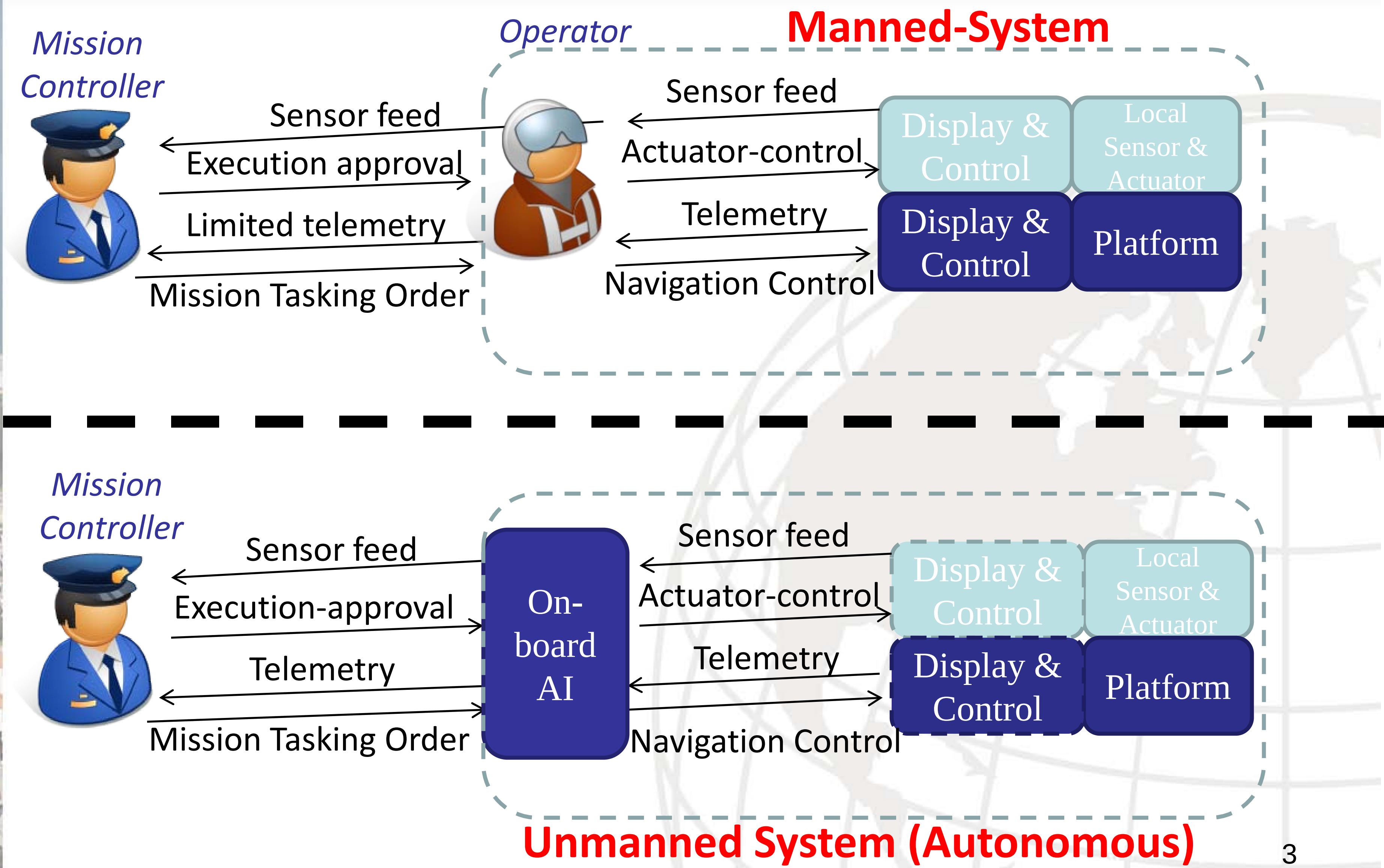
Monterey, California
WWW.NPS.EDU

Integrated Project Tasking

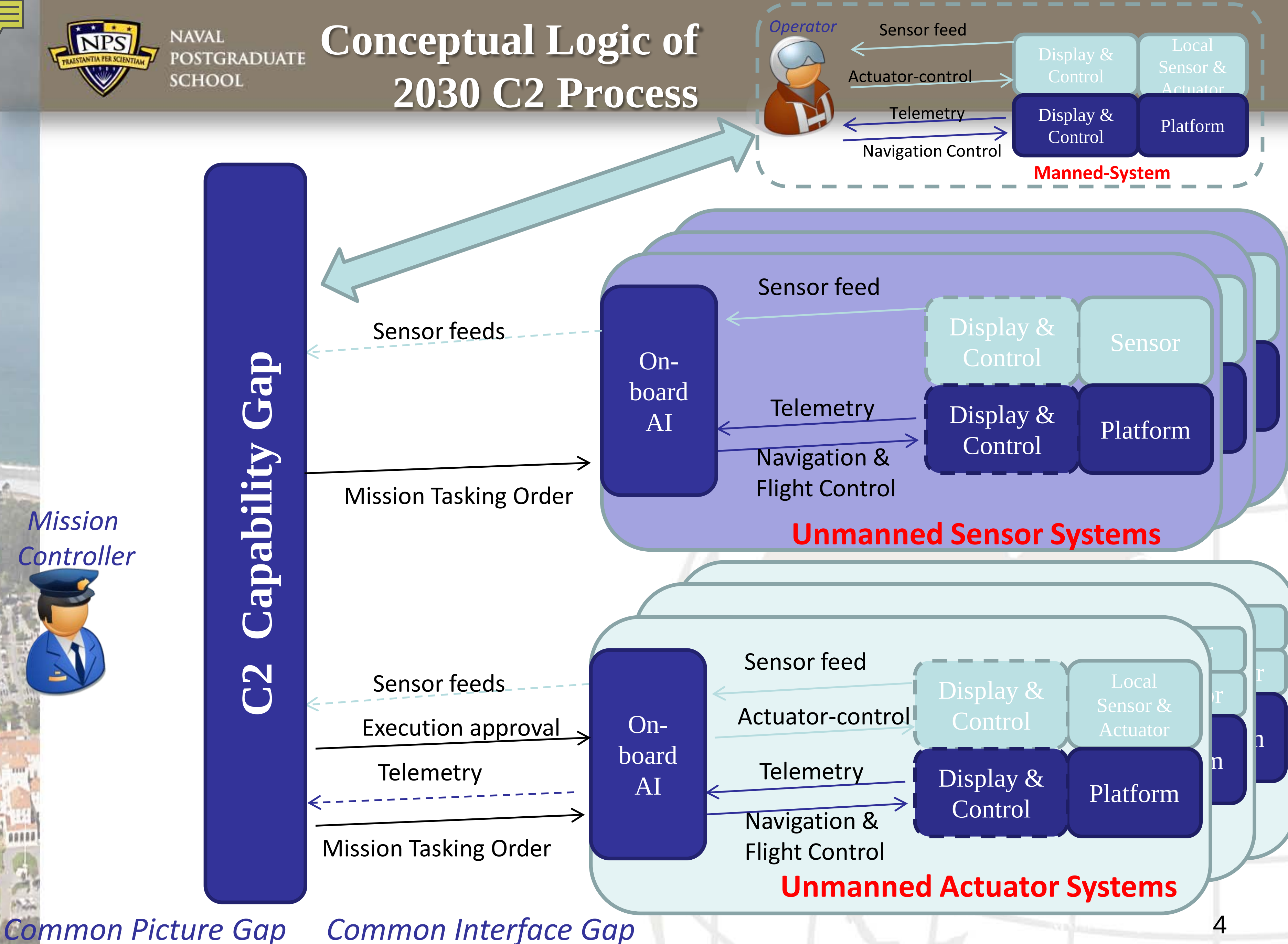
- Develop a Joint Systems concept to produce a coherent vision of unmanned vehicles

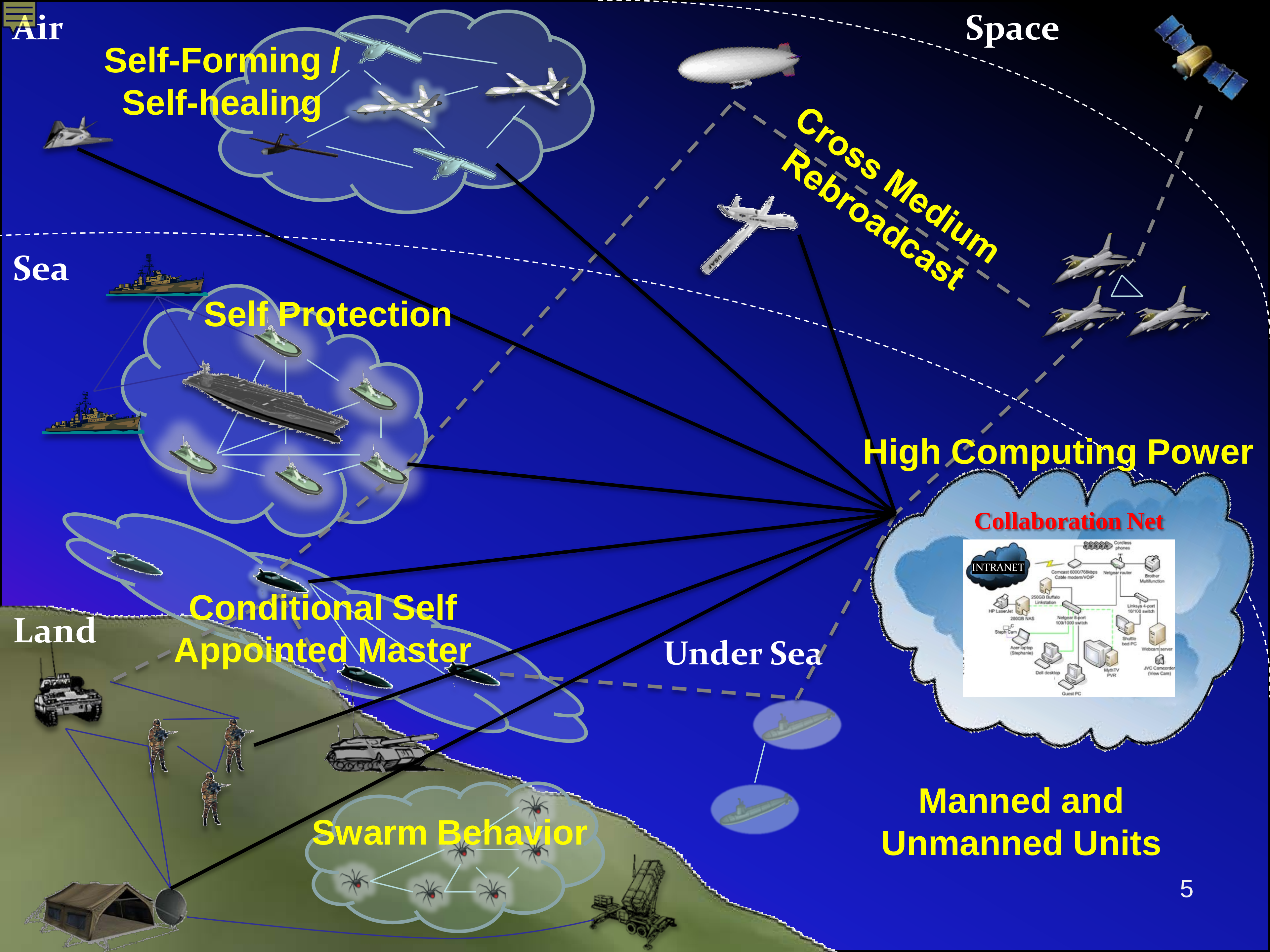
- Design a Command and Control (C2) architecture considering potential technology gaps and determine a more streamlined architecture with gap fillers

Current C2 Process



Conceptual Logic of 2030 C2 Process





Air
Self-Forming /
Self-healing
Space
Cross Medium
Rebroadcast
Sea
Self Protection
High Computing Power
Collaboration Net
INTRANET
Conditional Self
Appointed Master
Land
Under Sea
Manned and
Unmanned Units
Swarm Behavior

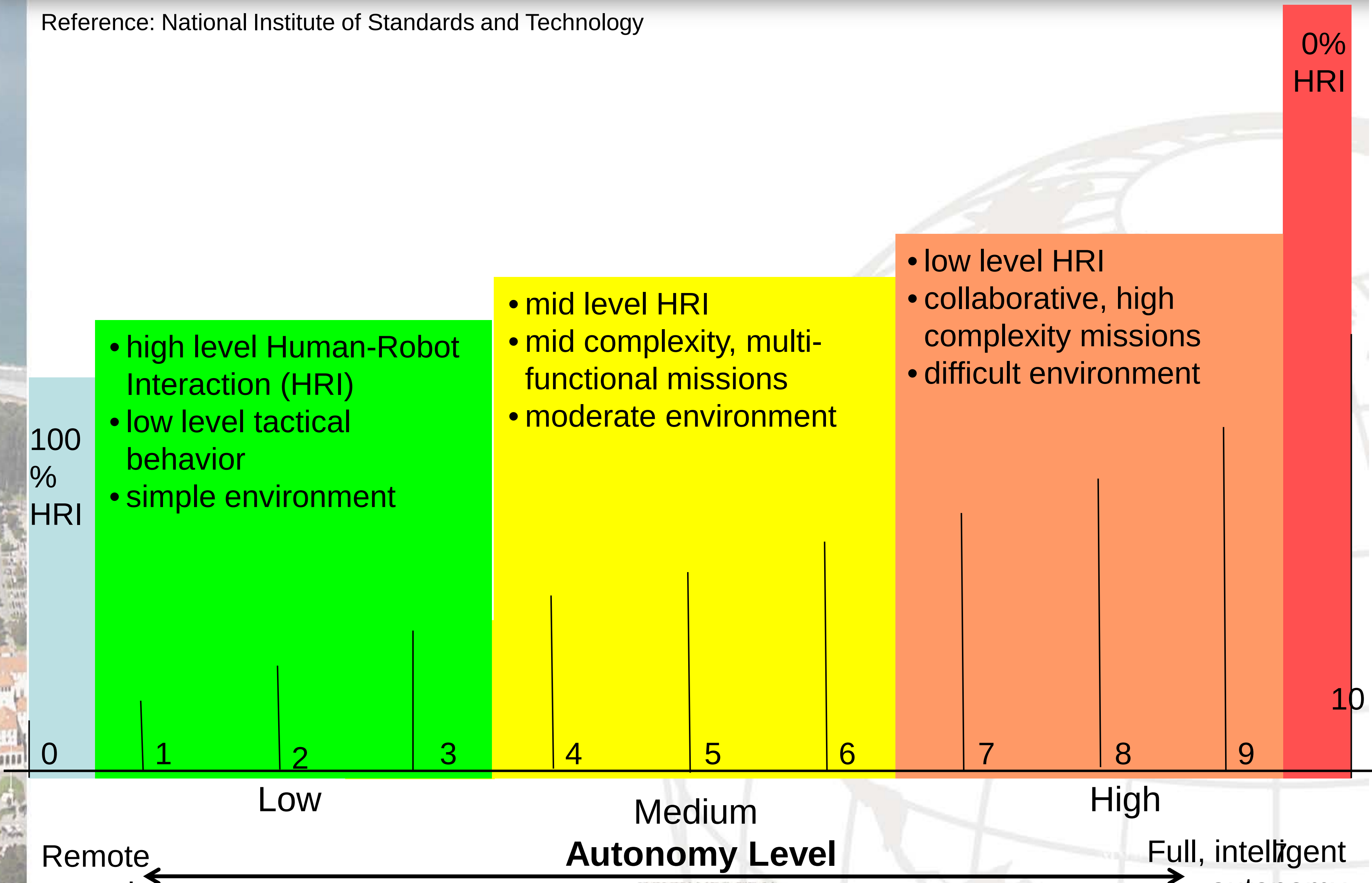
Human and Machine Comparison

HUMAN EXPERTISE	MACHINE EXPERTISE
The Good News:	*The Bad News:*
Creative	Uninspired
Adaptive	Needs to be Told
Sensory Experience	Symbolic Input
Broad Focus	Narrow Focus
Commonsense Knowledge	Technical Knowledge
The Bad News:	*The Good News:*
Perishable	Permanent
Difficult to Transfer	Easy to Transfer
Difficult to Document	Easy to Document
Unpredictable	Consistent
Expensive	Affordable

Source: Canning, John S. "A Definitive Work on Factors Impacting the Arming of Unmanned Vehicles" NSWC Dahlgren

Autonomous Levels for Unmanned Systems

Reference: National Institute of Standards and Technology



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Functional Architecture

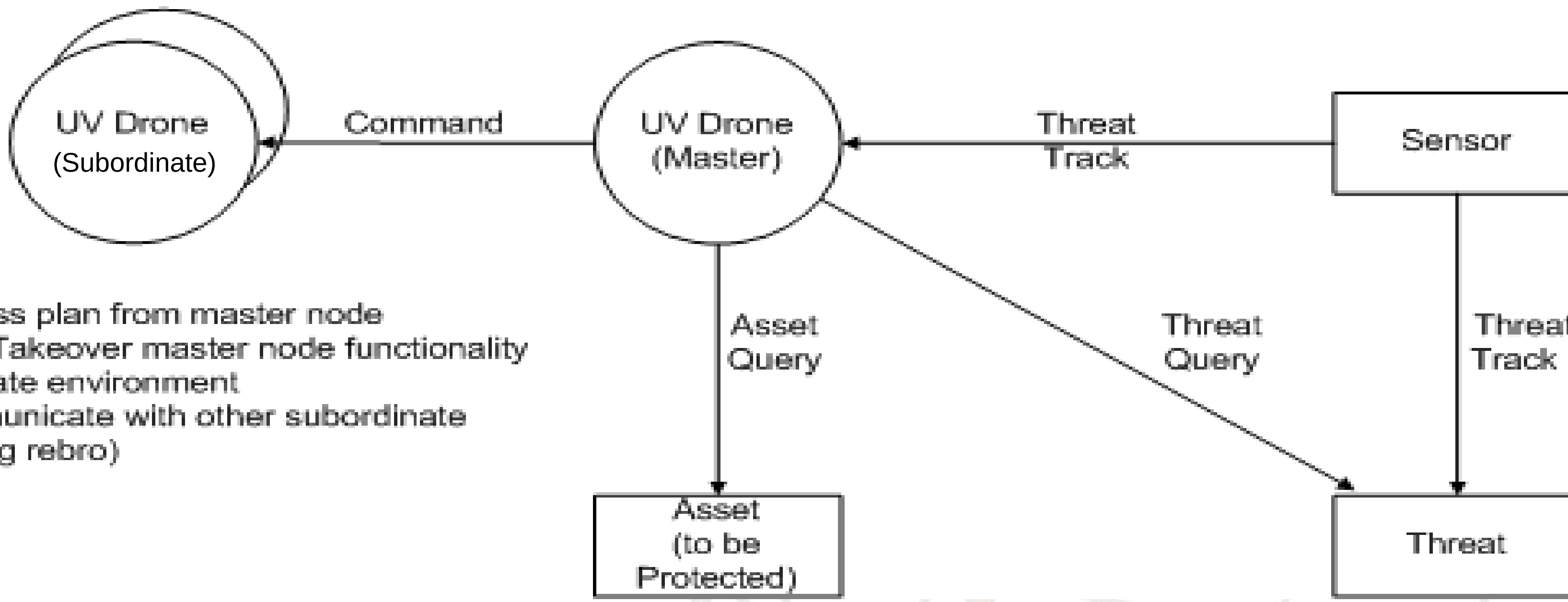
0 Manage UV Operations				
1 Provide C2	1.1 Observe	1.1.1 Monitor Situation	1.1.1.1 Monitor Internal Factors 1.1.1.2 Monitor External Factors	
	1.2 Orient	1.2.1 Understand Situation 1.2.2 Identify Mission Success Gap	1.2.1.1 Assess Friendly Capability 1.2.1.2 Assess Threat 1.2.1.3 Analyze Environment	
	1.3 Decide	1.3.1 Determine COA	1.3.1.1 Develop COA 1.3.1.2 Analyze COA	1.3.1.2.1 Assess Risk 1.3.1.2.2 Analyze timing 1.3.1.2.3 Select COA
	1.4 Act	1.4.1 Command Assets	1.4.1.1 Assign Mission 1.4.1.2 Direct UVs 1.4.1.3 Provide Resources	
	1.5 Share to Network			
2 Collaborate	2.1 Operate in Network	2.1.1 Establish Capability Interface		
	2.2 Manage Data	2.2.1 Organize Data 2.2.2 Share Data		
	2.3 Collect Data			
	2.4 Secure Network			
3 Conduct UV Operations	3.1 Operate Sensors	3.1.1 Sense Environment 3.1.2 Share Raw Sensor Data 3.1.3 Fuse Sensors 3.1.4 Share Sensor Picture		
	3.2 Operate UVs	3.2.1 Formulate Tactics 3.2.2 Schedule and Allocate Tasks 3.2.3 Navigate/Execute Task 3.2.4 Report Position/Status 3.2.5 Assess/Report Operational Availability		

Operational Node Connectivity

OV-2 Miniature Drones (Force Protection)
Self-synchronizing UV drones forming protective shield around asset to block kinetic attacks

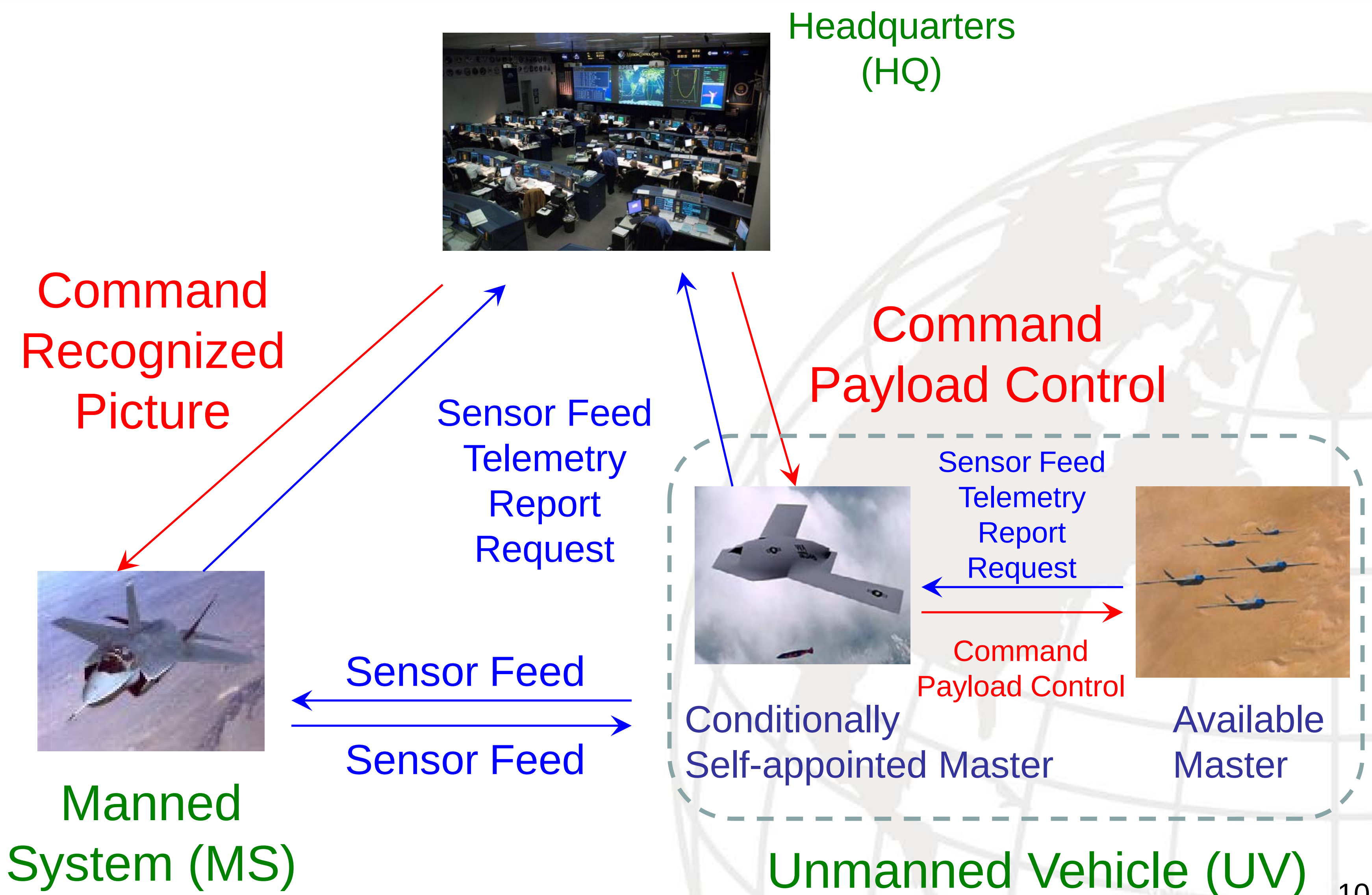
Note:
1. Self-forming: Must first determine who the Master is)
2. Could be MANET-style (Mobile Adhoc Networks)

Activity
1. Process threat track from external sensor node(s)
2. Query threat (when threat is in close proximity)
3. Formulate protection plan (how big or thick "wall" should be)
4. Broadcast plan to subordinate nodes
5. Navigate environment



Activity
1. Process plan from master node
2. Elect/Takeover master node functionality
3. Navigate environment
4. Communicate with other subordinate nodes (eg rebro)

C2 Information Exchange



Manned System/UV(Master) to HQ

Category	Info Type	Data Type	Band-width	Timeliness	Triggering Events	CIA
Sensor Feed	EO/Video Camera	Video (Live)	High	Milliseconds	- Algorithm - Operator - Time	IA Optional – C
	Radar	Data (Tracks)	Low	Seconds	As above	CIA
	SAR/ISAR	Image	Mid	Minutes	As above	IA Optional – C
	Gamma Radiation	Image	Mid	Minutes	As above	IA
	Terra-Hertz	Image	Mid	Minutes	As above	IA
	IFF	Data (Tracks)	Low	Seconds	As above	IA
	Sonar	Data (Tracks) Audio	Low Mid	Seconds Milliseconds	As above	IA
Telemetry	On-board Instrumentation	Data	Low	Variable	As above	IA
Report	BIT Status	Data	Low	Minutes	As above	A
	AI Decision Feedback	Data	Low	Minutes	As above	IA
Request	Execution	Data	Low	Seconds	- Algorithm	CIA

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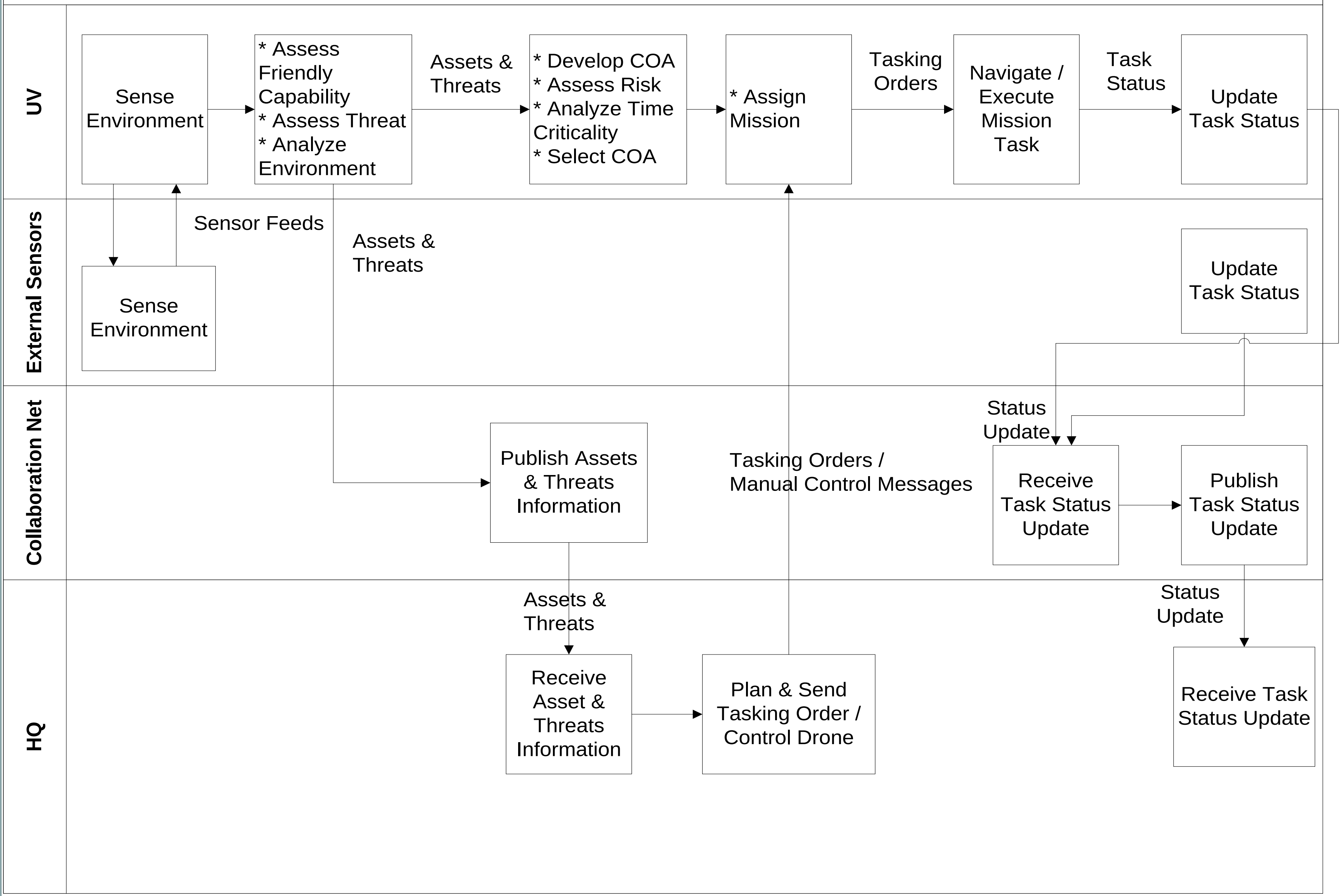
Operational Activity Model

OV-5 - Force Protection



Conceptual System View

Enterprise Applications

- Common Situation Pic
- ORBAT
- Campaign Management
- Space Management
- Target Management
- Operation Management
- Shooter Management
- BDA Management
- Frequency Management
- Resource Management
- Sensor Management

Data Services

- Data Fusion
- Time & Space Analysis
- GIS Services
- Identification Engine
- Time Management
- Medical
- Notification
- Intel Assessment
- Tracks
- Geographical Data
- Weather
- Imagery
- Logistics
- Manpower
- Knowledge Bases
- Replay Engine

Service Infrastructure

Process Engine
- Business Process Execution
- Process Monitoring

Enterprise Service Bus
- Message Delivery
- Message Transformation
- Message Mgmt

Connectors
- Platform Service Adapter
- Data Service Adapter
- Web Service

Directory
- Service Lookup
- Service Registration
- Service Directory

Security Infrastructure

- Authentication & Authorisation
- Confidentiality
- Integrity
- Non-Repudiation
- Security Administration

Operating Systems & COTS

- System Monitoring
- Business Process Engine
- Rules Engine
- Communication Package
- Collaboration Package
- Messaging Package
- Timer Function
- Backup and Recovery
- Data Storage Package

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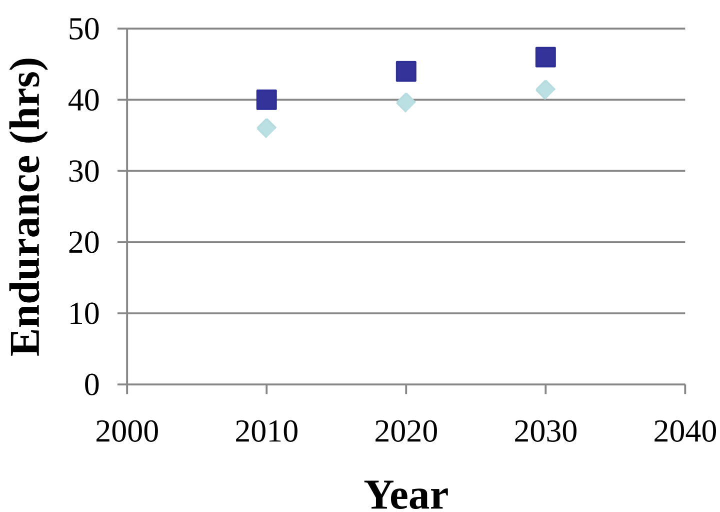
Global Hawk and Predator Analysis

	Combat Radius (nm)			Coverage Area (nm²)			Endurance (hr)		
	2010	***2020***	***2030***	***2010***	***2020***	***2030***	***2010***	***2020***	***2030***
RQ-4 Global Hawk	5400	5940	6210	9.16E+07	1.11E+08	1.21E+08	36	39.6	41.4
MQ-1 Predator	500	550	575	7.85E+05	9.50E+05	1.04E+06	40	44	46

Expected Endurance Increases Engine Cycle Only



◆ RQ-4 Global Hawk

■ MQ-1 Predator

Breguet Range Equation

$$Range = \frac{V}{g}\frac{1}{SFC}\frac{L}{D}\ln\frac{W_{initial}}{W_{final}}$$

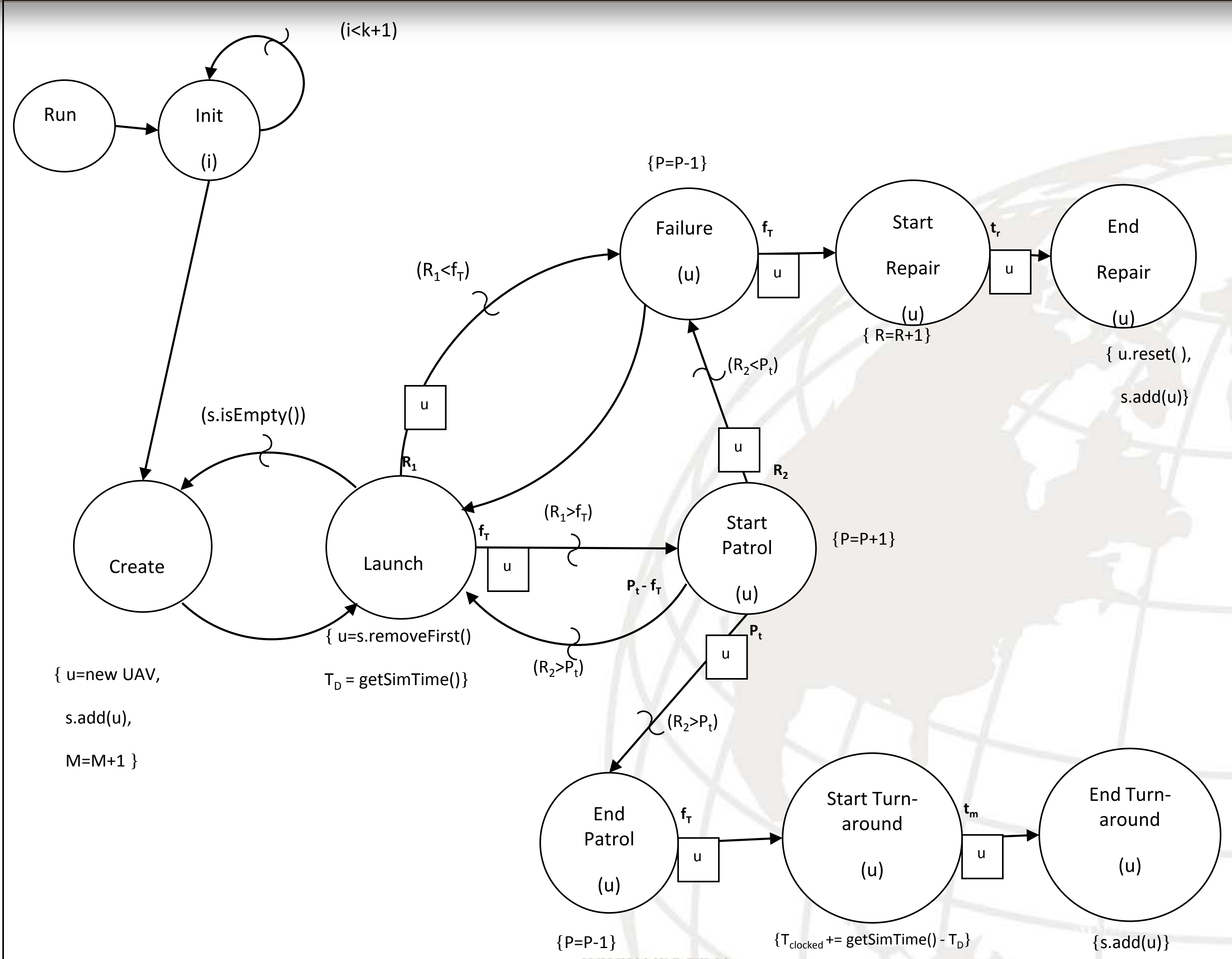
Fixed Platform Assumptions:

$$\left.\frac{L}{D}\right|_{constant} \equiv \text{constant } \alpha$$

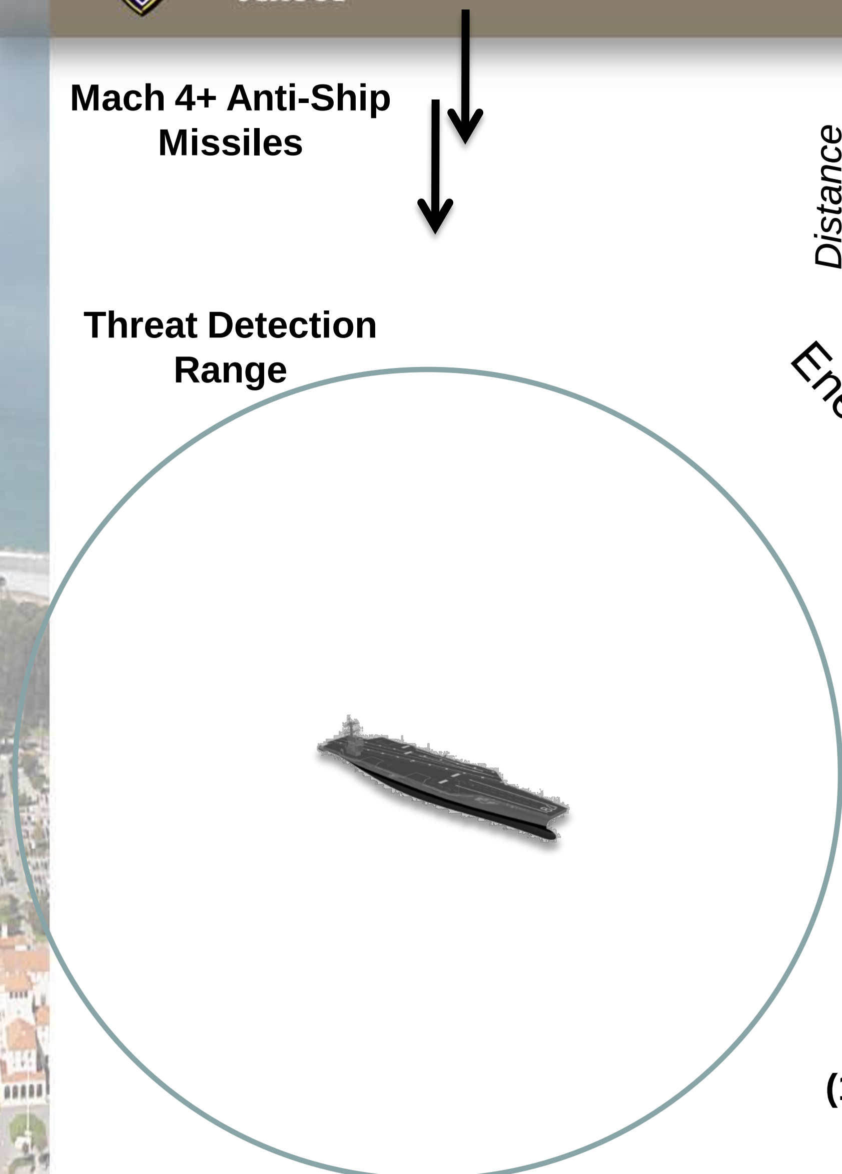
V , g = constant

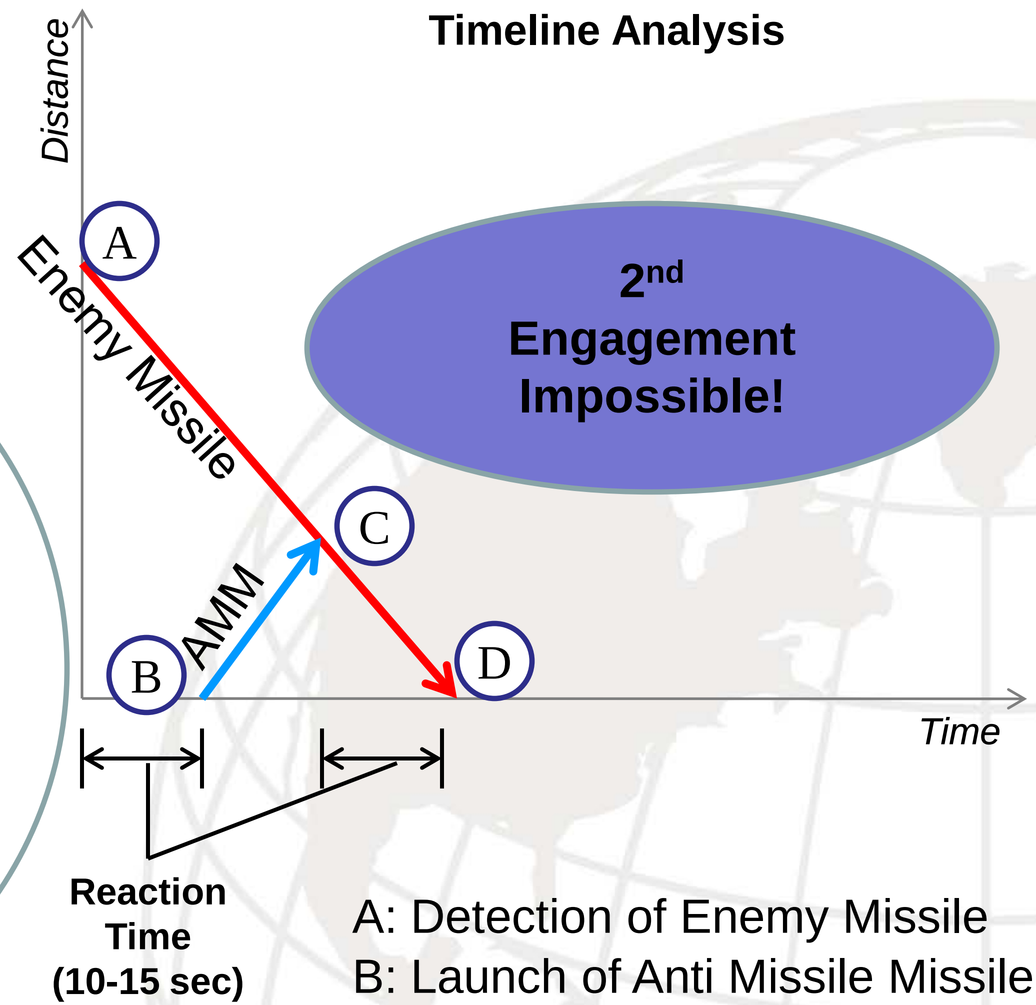
Structural/Tank mass = constant

Discrete Event Model



Scenario Analysis: Current Limits





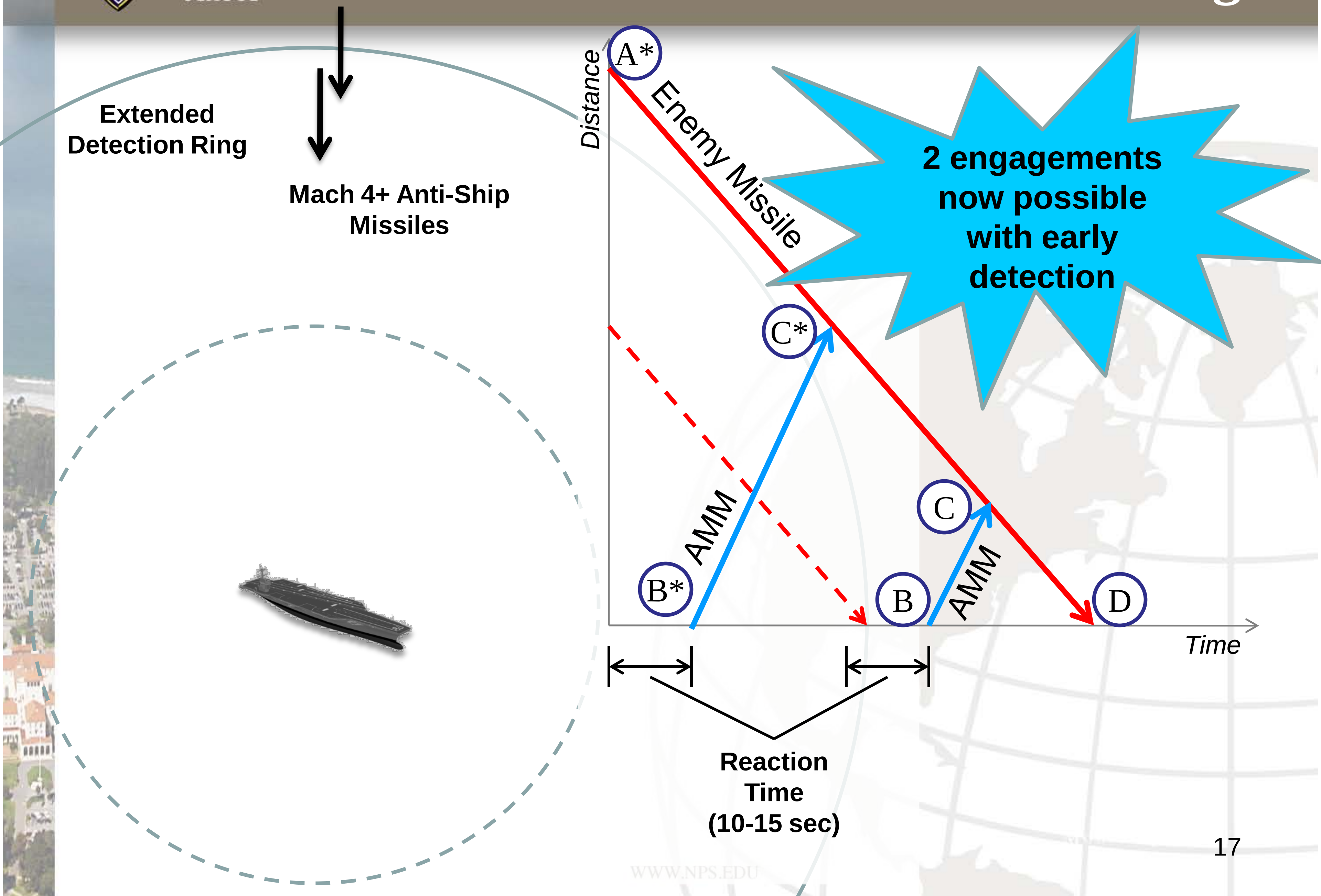
A: Detection of Enemy Missile

B: Launch of Anti Missile Missile

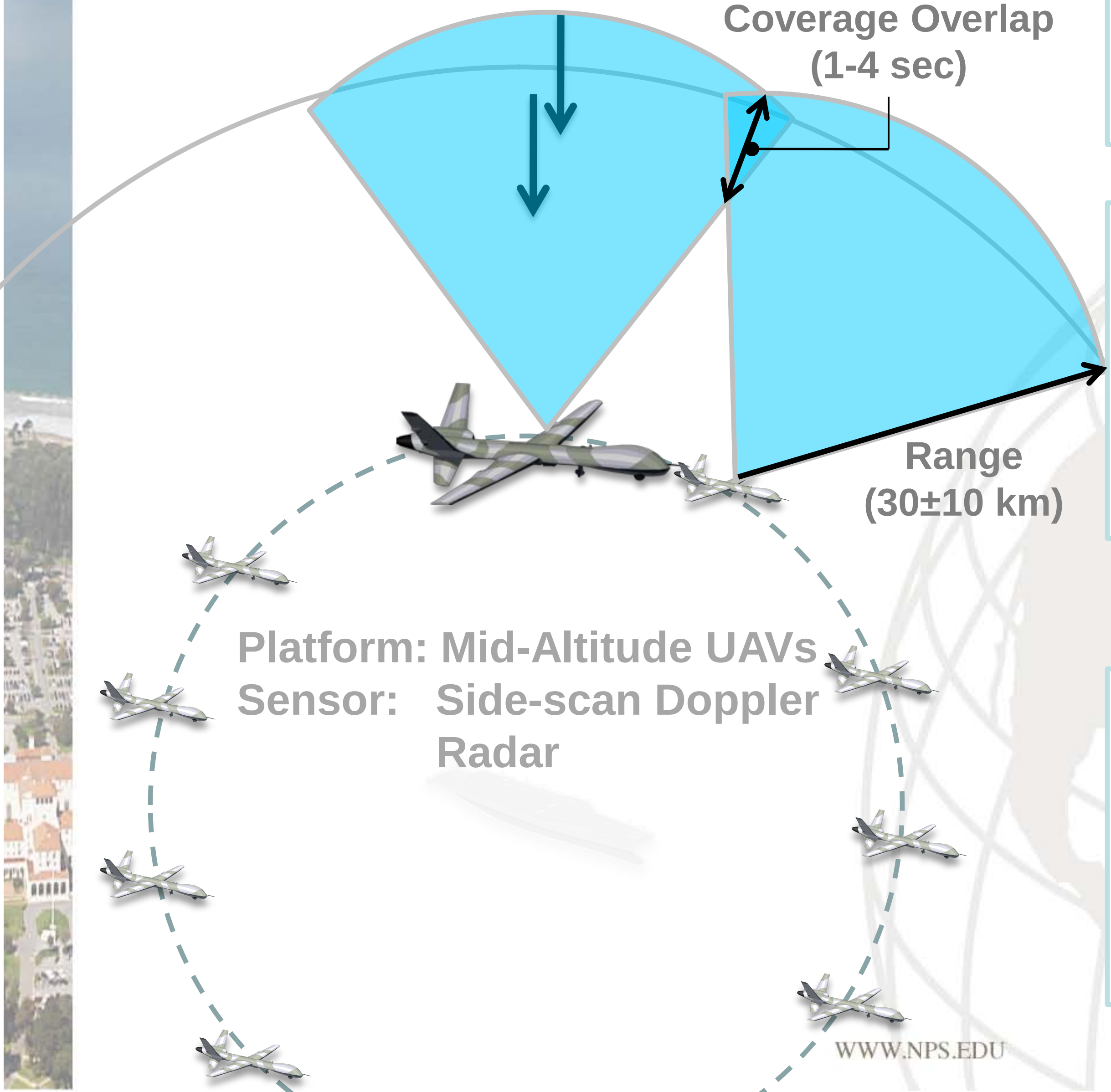
C: AMM intercepts Enemy Missile

D: Enemy Missile reaches target

Extended Detection Ring



Solution Analysis



C2 Architecture enables a group of UAVs to collaborate and fly together

Questions for Analysis:

1) What is the number of aerial picket stations required?

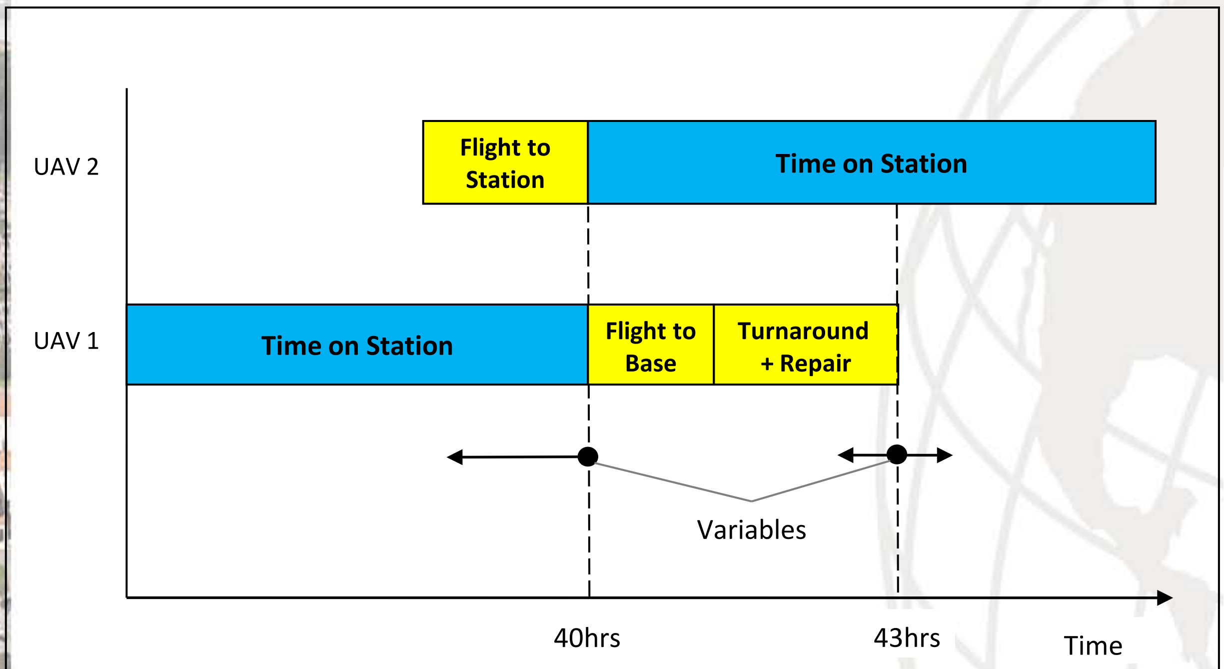
2) Size of UAV fleet required, given logistic constraints.

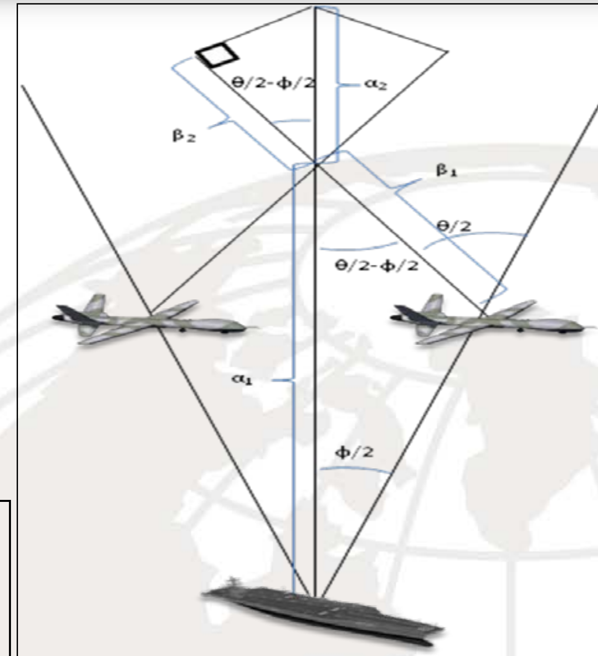
Primary Considerations:

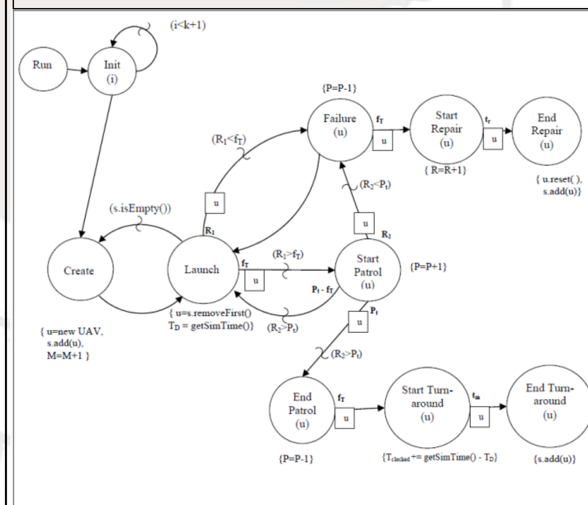
- Endurance
- Platform / Sensor mission critical failures
- Radar Range
- Coverage Overlap

Modeling and Results

- Number of Aerial Picket Stations modeled by geometry
- Determination of Fleet size modeled as a Scheduling problem with Discrete Event Simulation
- Monte Carlo simulation (1000 runs) using SimKit

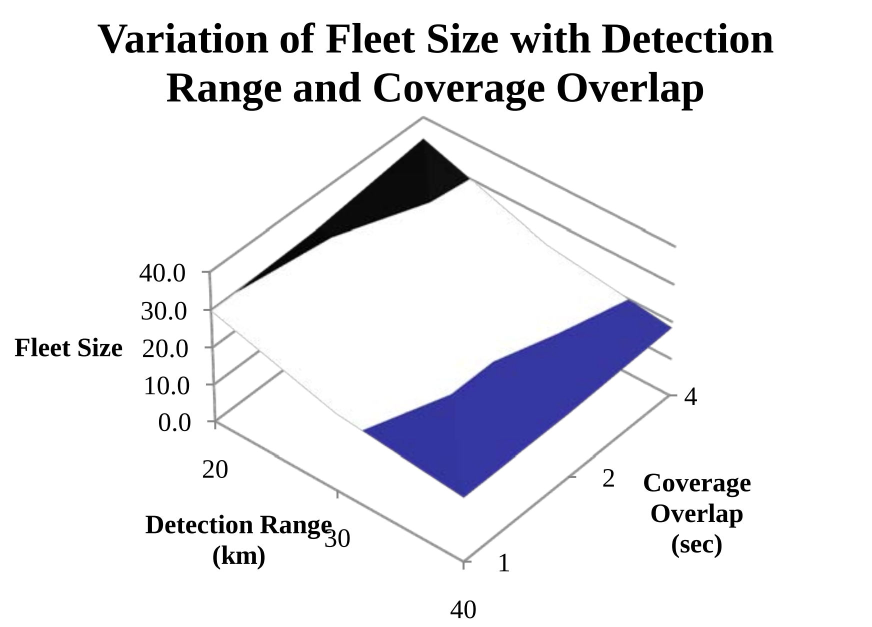






Modeling and Results

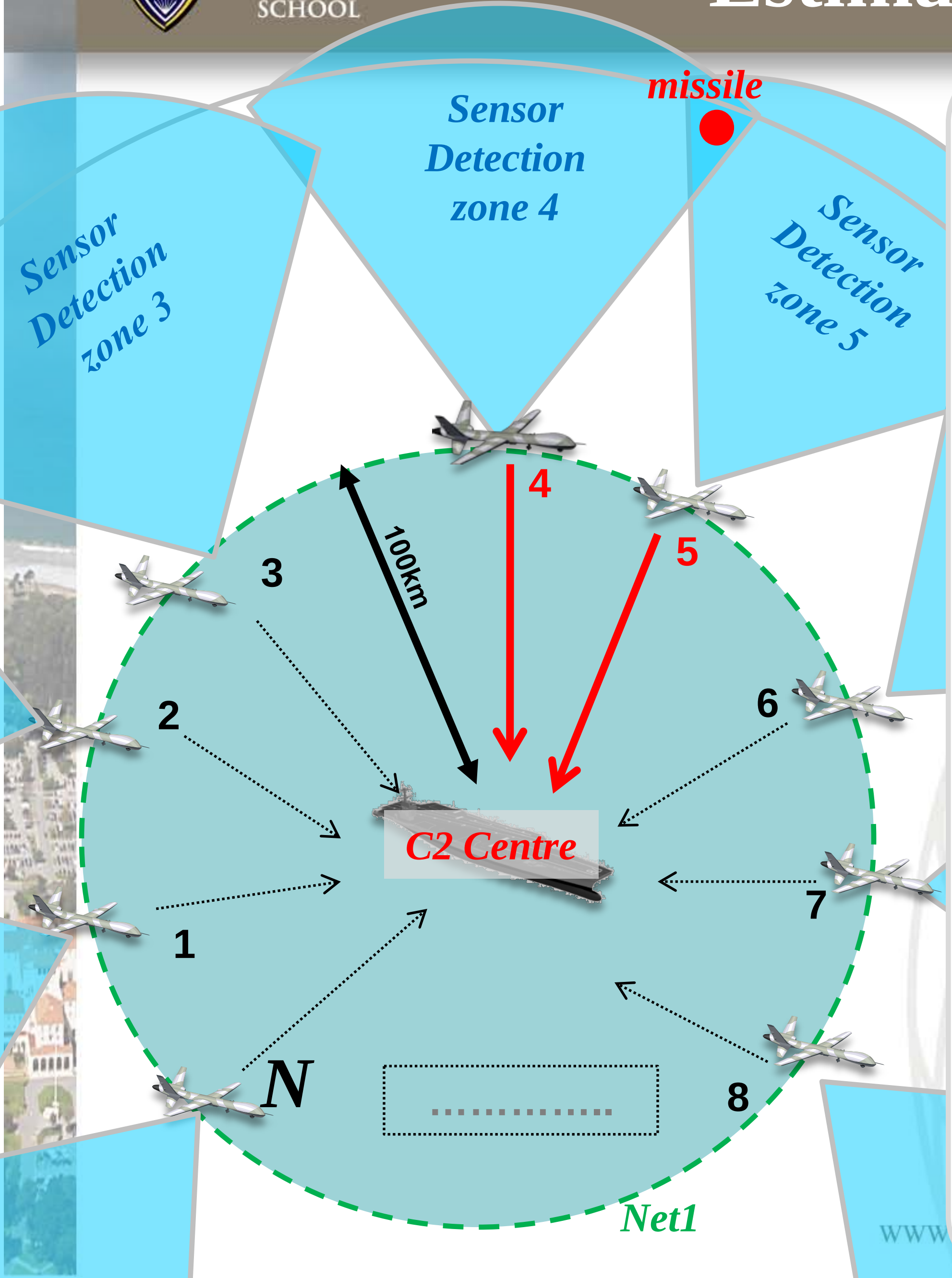
- A baseline fleet size of **21** UAVs is required
- A conservative estimate is **35** UAVs



Fleet Size

Coverage Overlap (sec)	Detection Range (km)		
	20	30	40
1	30	**21**	18
2	31	22	18
4	35	24	19

Estimation of BW requirement



- Estimated number of units supportable per datalink net:

$$n < \left(\frac{\text{Capacity reserved for sensor data transmission}}{2 \times \text{M} \times \text{Datarate demand per unit per track detected}} \right)$$

$$< \left(\frac{C_b(bit/s)}{2 \times M \times 8(bit/byte) \times D(byte/track) \times T(track/s)} \right)$$

•D: Average data size per track (bytes/track)
•T: Track update rate (tracks/second/target)
•C_b: System throughput capacity (coded) reserved for Link-16 sensor feed format (bits/sec)
•M: Max number of concurrent missile attacks expected

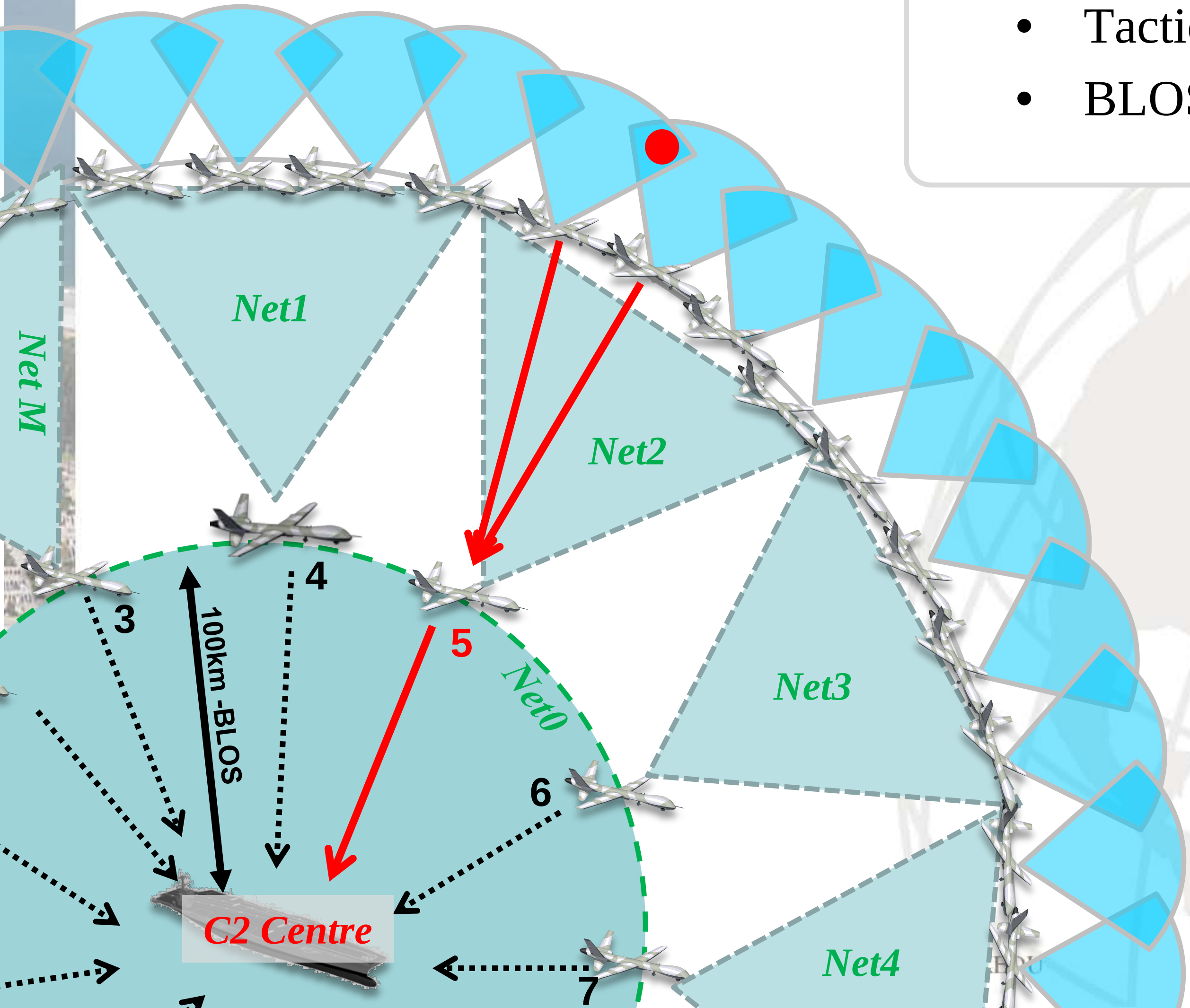
- Number of datalink nets required:

$$f \approx \left\lceil \frac{N}{n} \right\rceil$$

Range Extension

Two-tier relay network

- *NET0*
    - Tactical Datalink; or
    - BLOS Comms (e.g. SATCOM)

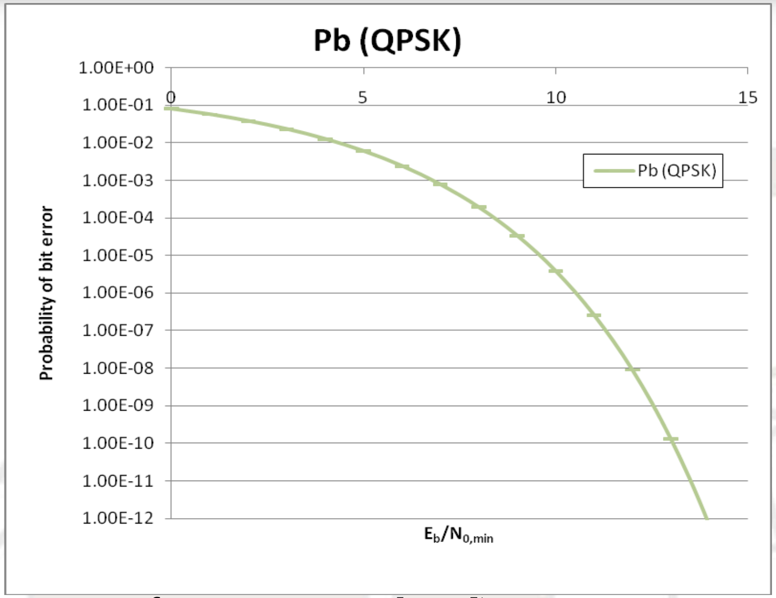


Link Budget: Link-16 (UHF-LOS)

$$\text{Fade Margin} = \left(\frac{E_b}{N_0}\right)_{received} - \left(\frac{E_b}{N_0}\right)_{\min}$$

$$\left(\frac{E_b}{N_0}\right)_{received} = S\left(\frac{R_b}{kT_{sys}}\right) = \frac{P_t.G_t.G_r}{L_{channel}.L_{sys}}\left(\frac{R_b}{kT_{sys}}\right)$$

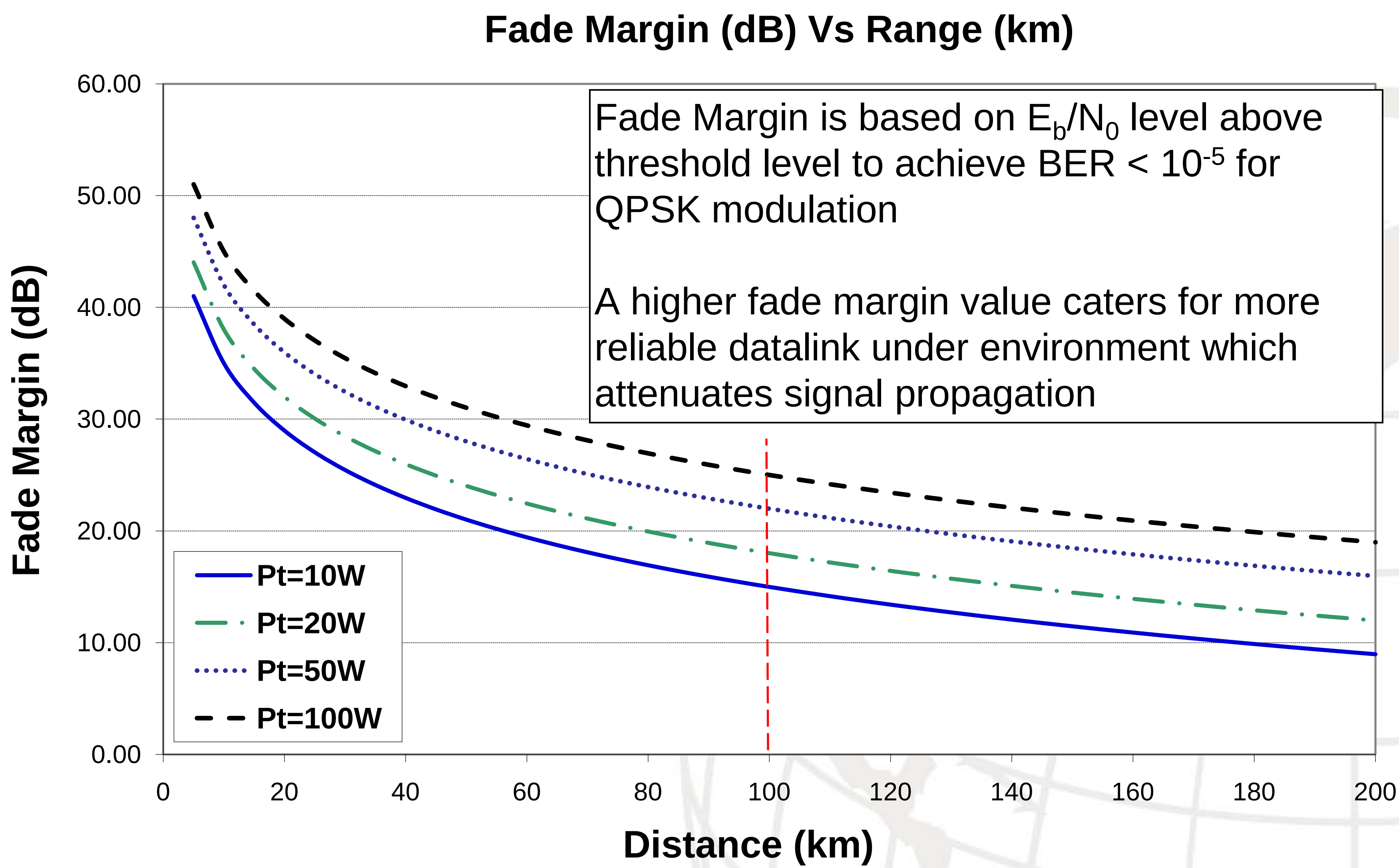
$$L_{channel} = \left(\frac{4\pi f_c R}{c}\right)^2$$



Assumptions

- RF carrier frequency, f_c = 1215MHz. (Link-16 Max frequency for UHF-LOS band)
- Receiver system noise temperature of, T_{sys} = 410K;
- Channel Bit-rate, R_b = 2400bps;
- Omni directional antennas with gain, G_t, G_r = 1dBi;
- Transmitter Power, P_t = 10W, 20W, 50W, 100W
- Digital Signal-to-Noise ratio (assume QPSK @ BER <10^{-5}), $E_b/N_{0,\min} \approx$ 10dB (See Figure 2);
- Other system losses, L_{sys} = 3dB;
- Channel Loss Model: Free space path loss model;
- Boltzmann Constant, $k = 1.38\text{x}10^{-23}$Joules
- Speed of Light, $c = 3\text{x}10^8$m/s

Range Assessment



Fade Margin is based on E_b/N_0 level above threshold level to achieve BER < 10^{-5} for QPSK modulation

A higher fade margin value caters for more reliable datalink under environment which attenuates signal propagation