



Ground Systems Introduction

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Meet your instructors

Donald Sather, Technical Fellow

Aerospace career:

37 years full-time



- **D.G. Sather:**
- Technical Fellow, The Aerospace Corporation
- 10 years experience radiation hardened parts & microprocessor design, satellite component/system design and test
 - Satellite operator experience
- 27 years experience design, construction, acquisition & test of ground systems and stations for a wide variety of USG customers
 - 2 years as the AF Chief Engineer for AFSCN and Launch Ranges



Class expectations

- Class is planned to be 2 hours
- There will be a break after about an hour
- Participants should ask questions throughout the presentations
- Please be as active as possible within the constraints of this virtual experience



Learning Objectives



Example of Ground System Operations

- *NOAA Satellite Operations**

Ground Systems Overview

- *Increased awareness and understanding of:*
 - Satellites ground systems in a system engineering context as they relate to:
 - *Other ground systems*
 - *Space missions*
 - Obtain an appreciation for how ground segment capabilities are determined
 - Understand the totality of functions which satellite ground segments must perform
 - Provide a context for how ground segment architectures are changing

* Reference: <https://www.youtube.com/watch?v=TWSua5ysuag>

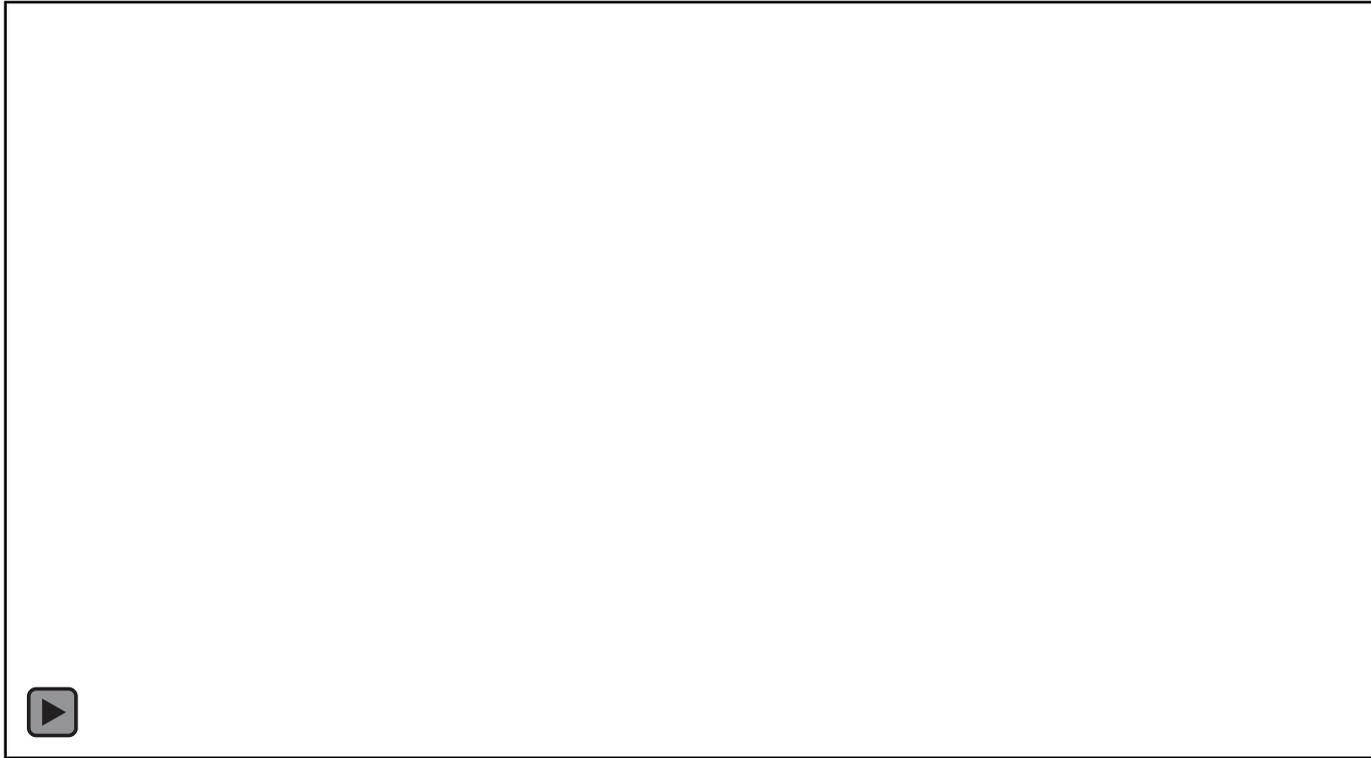


Ground Systems Overview

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The Aerospace Corporation



NOAA Satellite Operations





Learning Objectives

- *Understand satellite ground systems in a system engineering context as they relate to*
 - *Other ground systems*
 - *Space mission execution*
- *Obtain an appreciation for how ground segment capabilities are determined*
- *Understand the totality of functions which satellite ground segments must perform*
- *Provide a context for how ground segment architectures are changing*



- Scope
 - *Definitions*
 - *Within space missions*
 - *Within ground systems*
- **Functionality**
- **Modes of operation**
- **Allocation of functions to achieve the required capabilities**
- **Final Thoughts and Summary**



Definitions



- System
 - *An integrated set of elements, segments and/or subsystems that accomplish a defined objective, such as an air transportation system*
- Segment
 - *A major product, service, or facility of the system*
- Ground Segment
 - *That part of a space system for which all elements reside on the ground. It is a sub-system within the overall system*
- Ground System
 - *Used synonymously with Ground Segment*
- Ground Site
 - *A particular geographical location which contains one or more Ground System Elements or Subsystems*
- Ground Station
 - *An element of a Ground System the function of which is to provide a communications link between the ground segment and space segment. Usually provides both up/down communications links.*



Definitions (cont.)

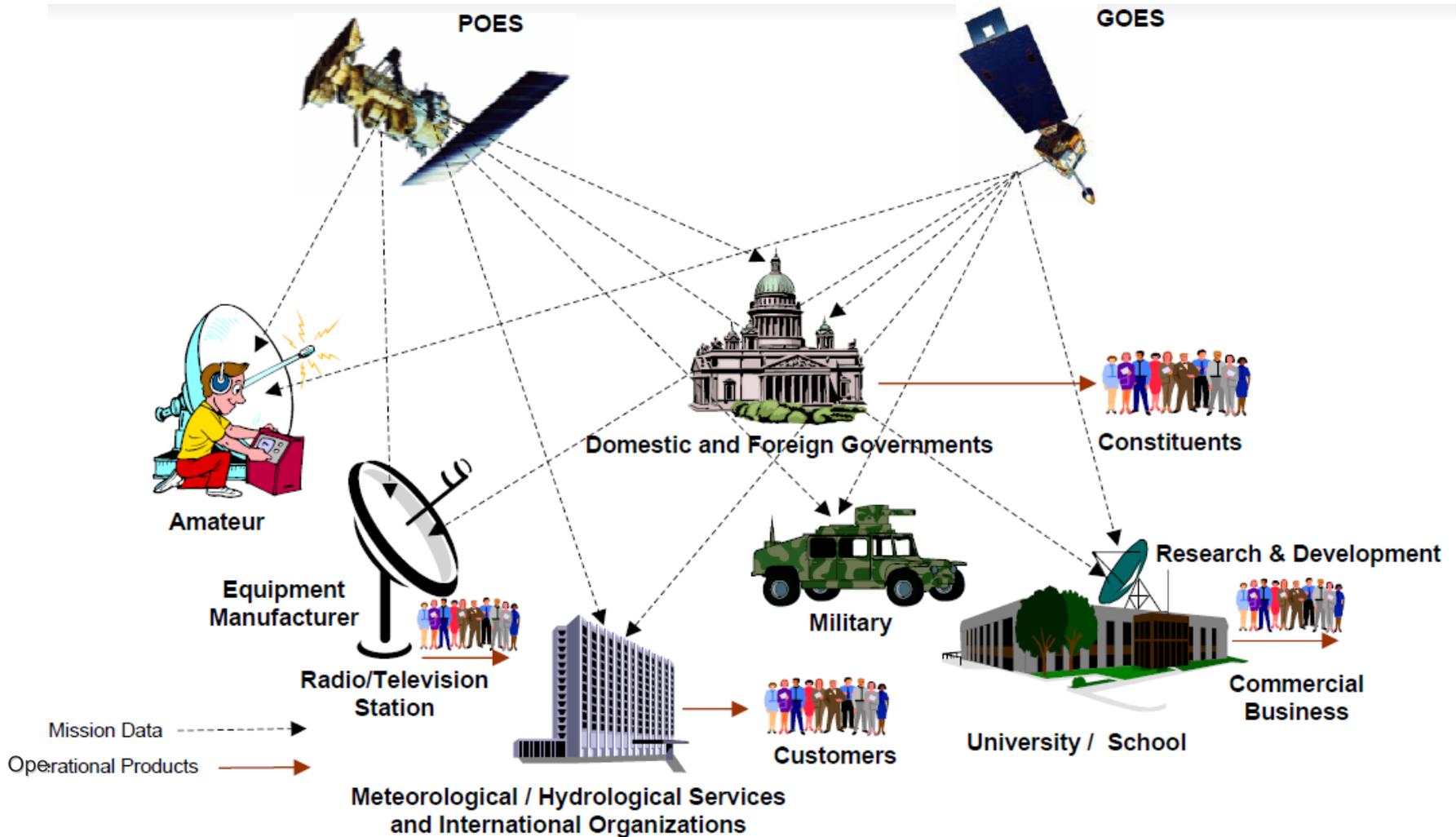


- Ground, Field or User Terminal
 - *Generally refers to a program/mission specific element that may have any or all of the following capabilities: send/receive data, data processing and display. In many cases, these terms refer to mobile units deployed in the field*
- Facility
 - *A structure, or set of structures, used to house specific ground system elements or subsystems.*
- Transportable
 - *Capable of being deployed and redeployed*
 - *Requires hours to days of setup*
- Mobile
 - *Self-propelled*
 - *Capable of mission operations while in motion or, more commonly capable of mission ops shortly after vehicle stops*

Definitions/terminology are unique to each program/development

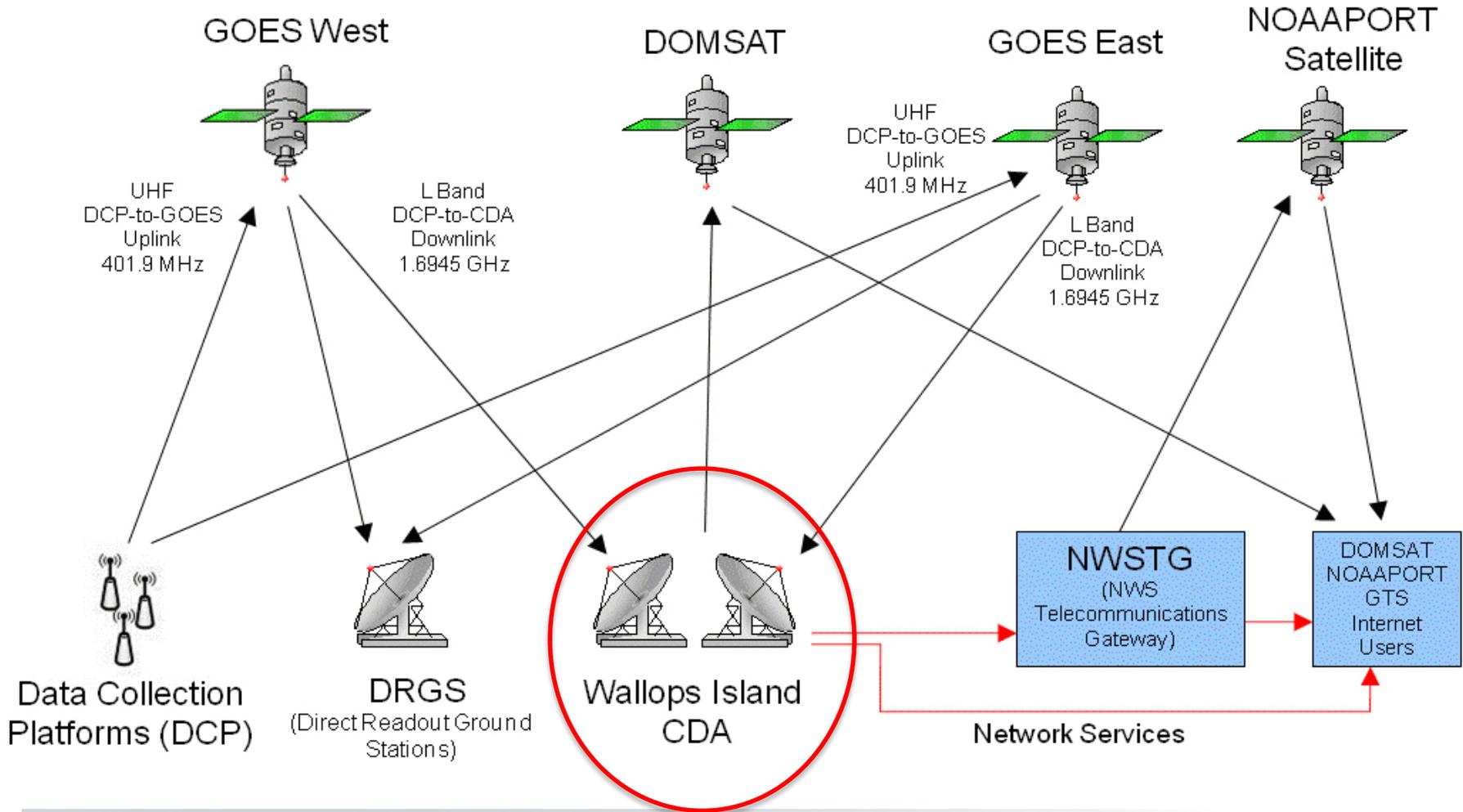


Basic Satellite Data Flow Overview [NOAA]

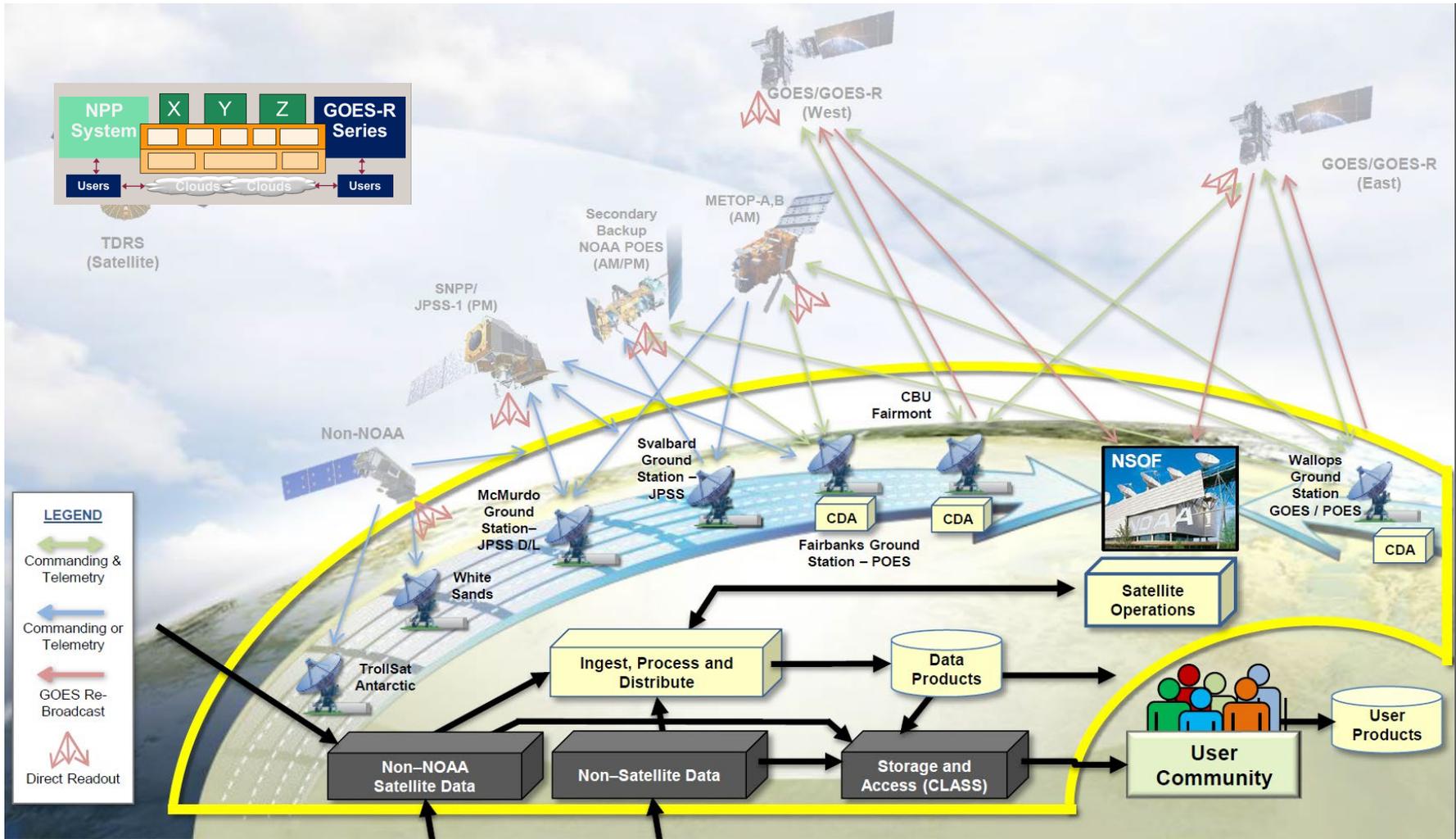




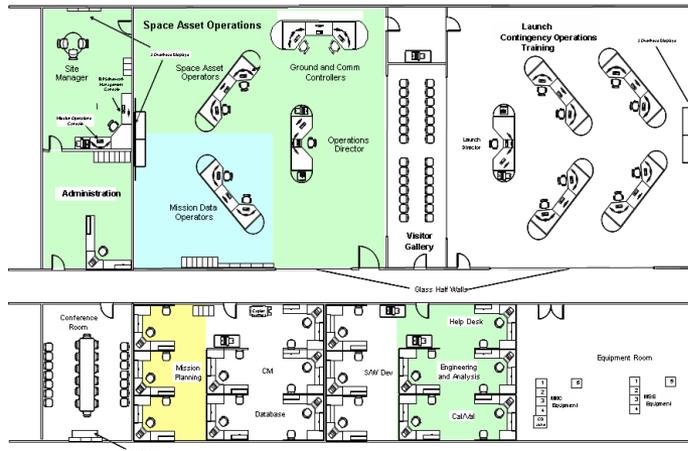
Data Collection System (DCS) Data Flows



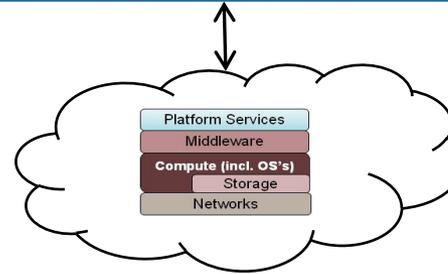
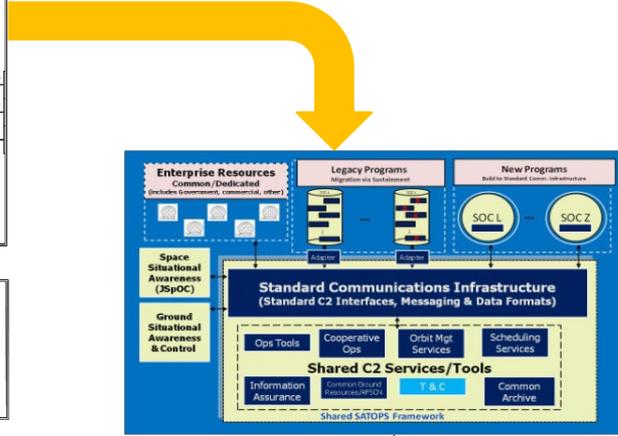
NOAA/NESDIS Integrated Ground Enterprise



Setting the Stage



1960 – 1999



2000 – 2015



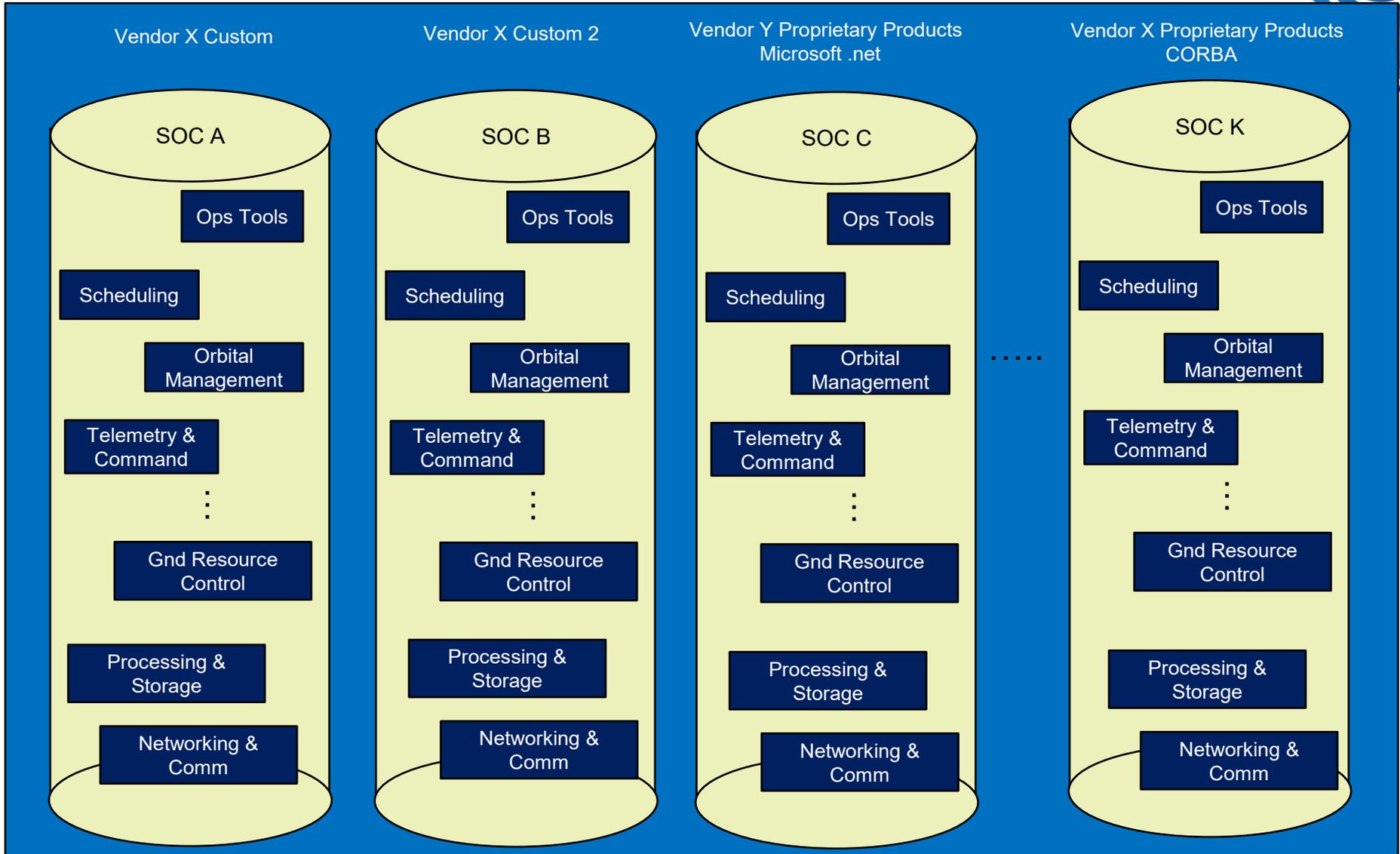
Current

- Functionality is the same across all time periods
- Implementation of functionality has evolved
- And, continues to radically change/evolve



Current Ground Environment

Legacy Situation – Mission “Stovepipes”



***Systems individually procured to fulfill a specific mission -
each having their own infrastructure***



What Drives Change in Ground Systems?

- 1. New Requirements***
- 2. Anticipated Cost Savings***
- 3. Neat New Technology Available***

-5

***Technology itself is not a driver!
(But it may enable capabilities for new requirements)***



The Pace of Change

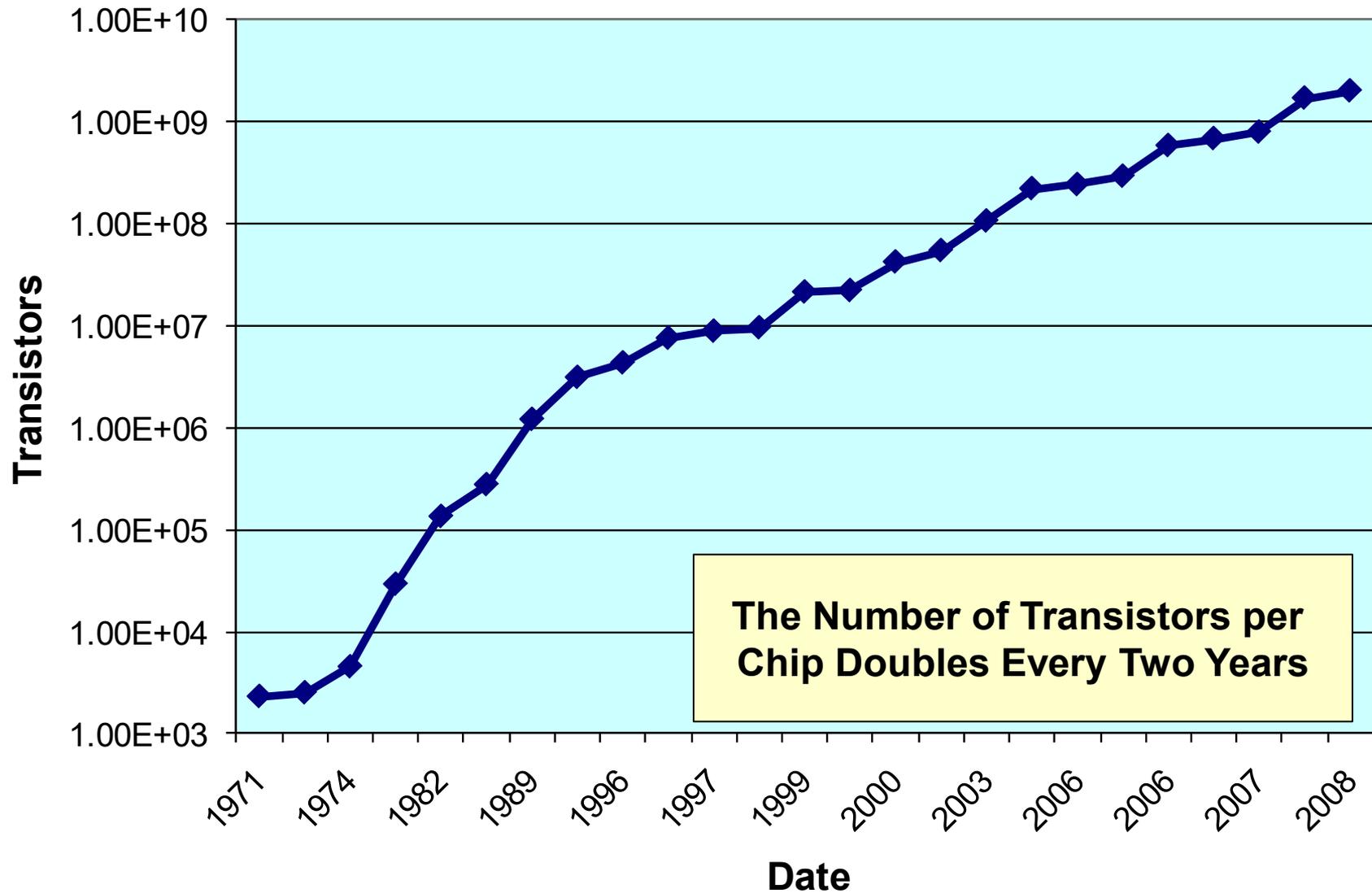


- **How much opportunity is there for innovation?**
 - *How many satellites are launched per year?*
 - 91 launches / 207 satellites worldwide in 2017¹
 - *Most for established programs*
 - 33 GEO satellites / 30 were COMSATs in 2017¹
 - *How many devices that use GPS are sold in a year?*
 - 10's of Millions possibly 100's of Millions with “Smart” technology
- **Pace of innovation depends upon opportunity in the current model**
 - New Technologies and Architectures are available
 - Allow for rapid rate of change without redesigning
 - Pace of technology exceeding our ability to update current architectures

1: Wikipedia – 2017 in Spaceflight page

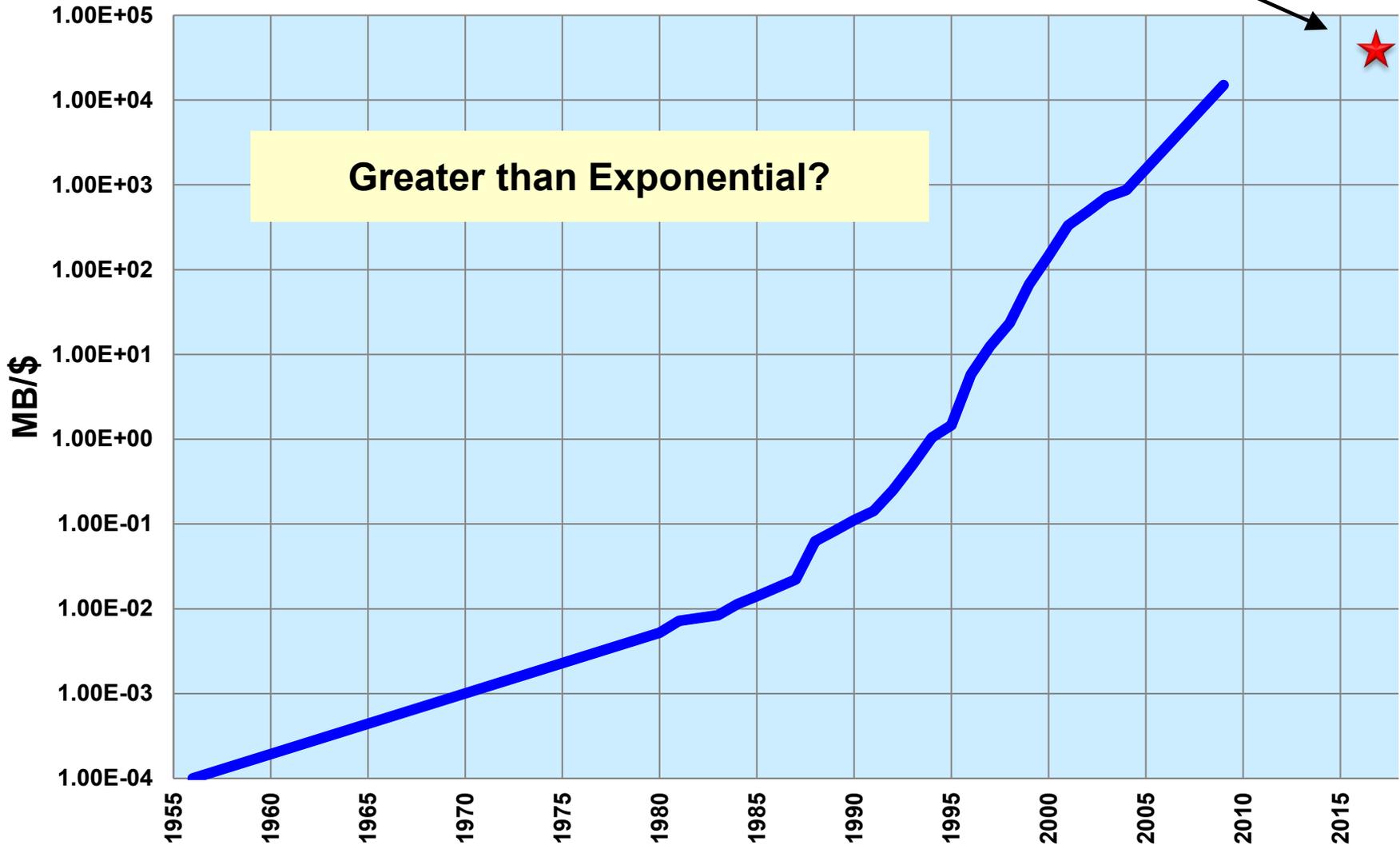
Pace of change in satellite ground systems is slow

Moore's Law



Hard Drive Costs

Latest Data Point:
12/13/2019 12TB=\$167



12/8/2017 Amazon 8 TB=\$144 / 12/8/2018 10TB = \$149

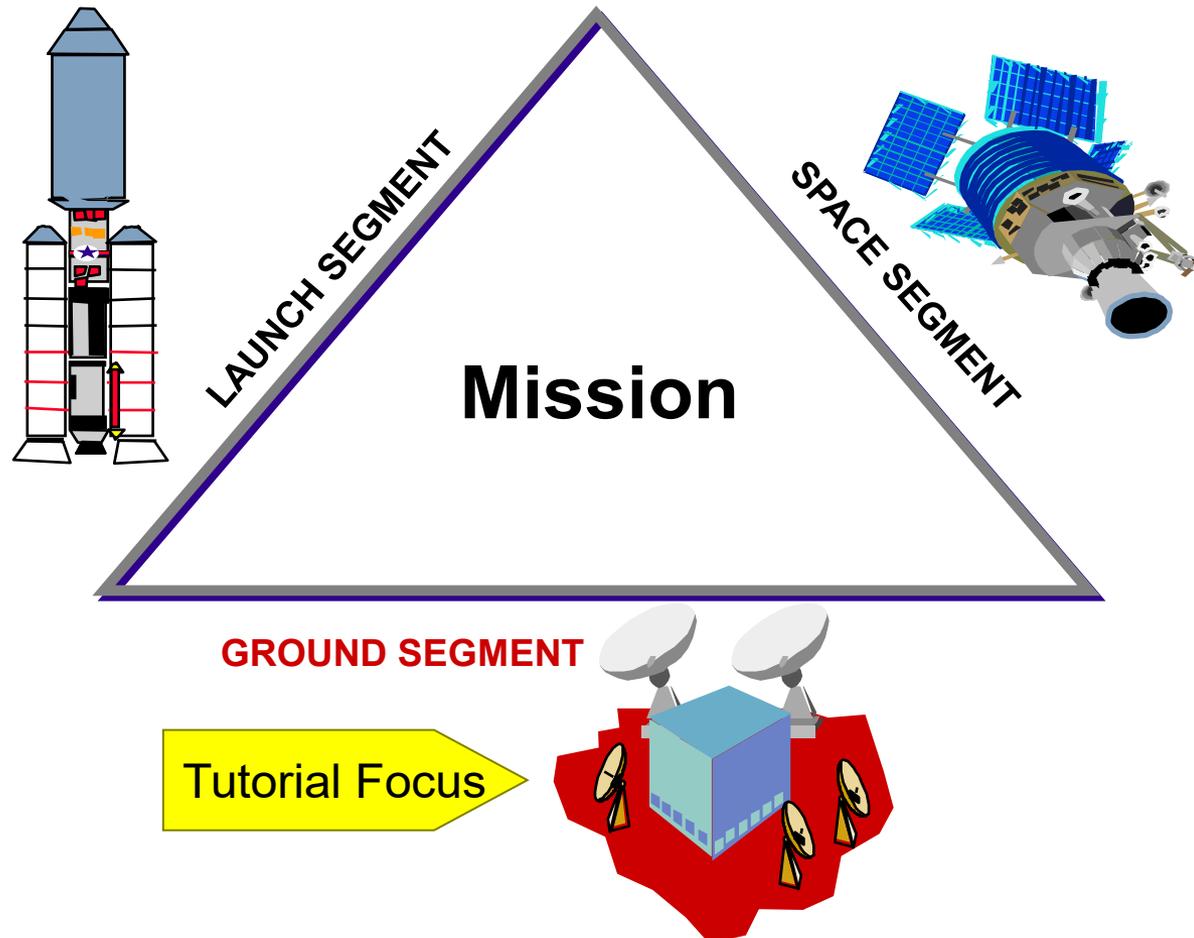


Challenges

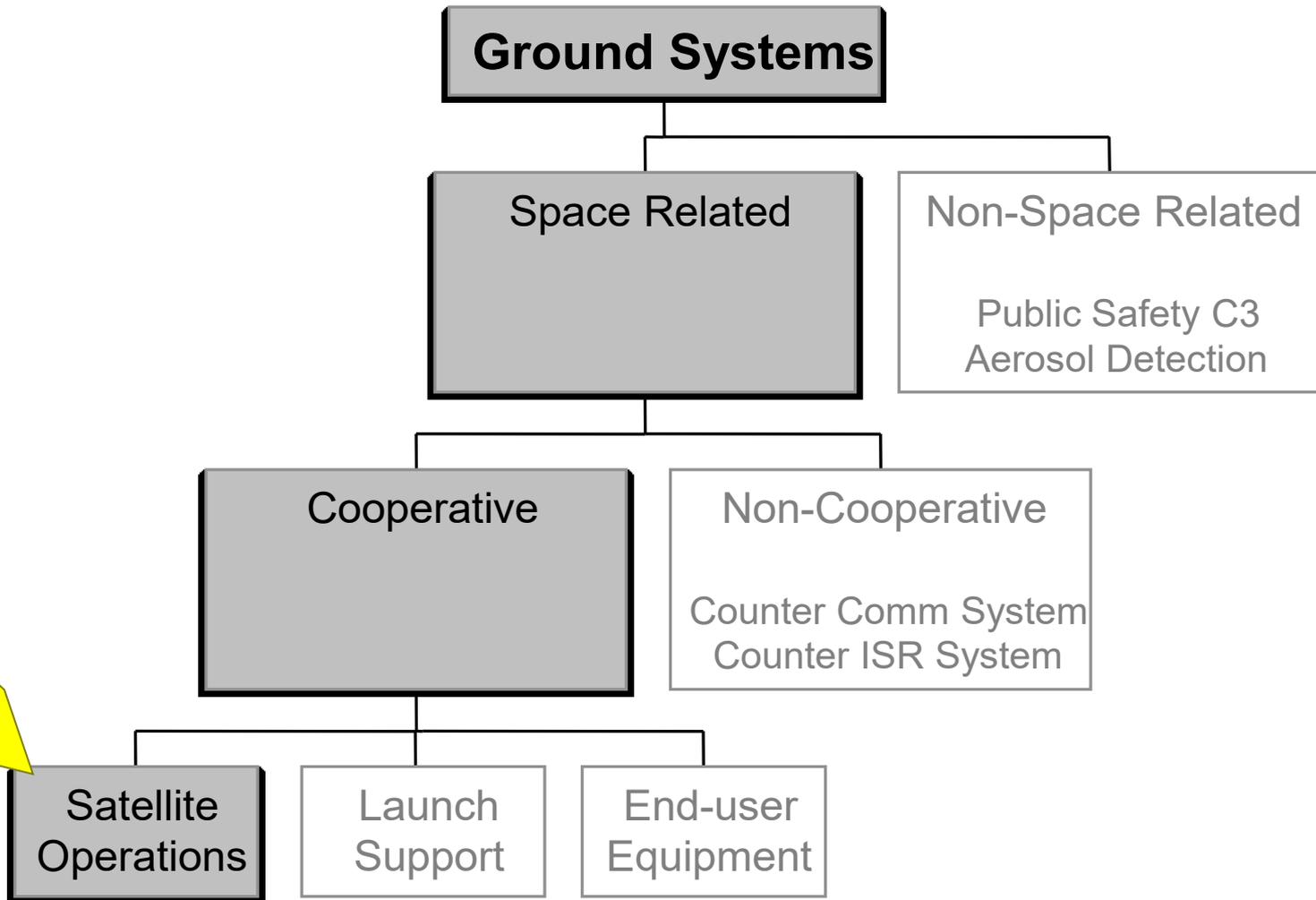
- Startup through initial delivery of systems too long a duration
 - System **obsolete, antiquated, and/or non-responsive** by time of delivery
 - Maybe even more so with software due to Information Assurance and Risk Management
 - Equipment **refresh necessary immediately** after IOC
 - *True operational needs not addressed*
 - CONOPS has changed
 - Mission focus has changed
- End goal is to provide an operationally suitable system in a “short” time span that can address current operational needs
- Drives the use of new architectural concepts
 - *SOA, Event-Driven and Data-Driven architectures*
 - *Agile SW, DevOps, CI/CD, ...*

Space Mission Architecture

- Space mission architecture includes all elements required to conduct a space mission



Ground Systems Taxonomy



Tutorial Focus



An Antiquated (?) Systems View (pre-2016)

Most systems were viewed as having three fundamental segments for implementation

OPERATIONAL ENVIRONMENT (examples)					
undersea	sea surface	subterranean	terrestrial	atmospheric	space
PLATFORM (examples)					
submarine	destroyer	missile silo	tank	bomber	satellite
MISSION ASSETS (examples)					
torpedo	missile	ICBM	gun	bomb	ir sensor



A Simple Systems View

Applied to Satellite Ground Systems

- **Operational Environment** – Terrestrial (usually)



Cosmonaut Yuri Gagarin

Courtesy US Air Force

A Simple Systems View (Old Paradigm)

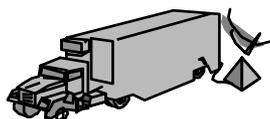
Applied to Satellite Ground Systems



- **Operational Environment – Terrestrial (usually)**
- **Platform – Facilities (fixed and mobile)**



Buildings



Shelters & Vans



Antenna Facilities

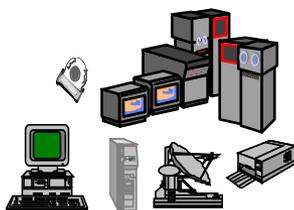


Infrastructure

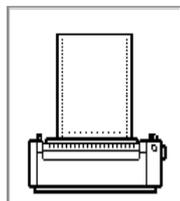
• Mission Assets



People



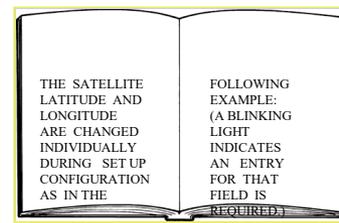
Hardware



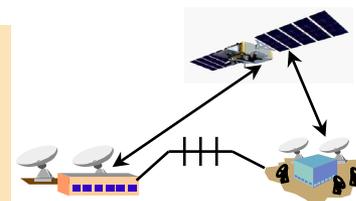
Computer programs



Cloud



Procedures



Communications Links

A Simple Systems View (New Paradigm)

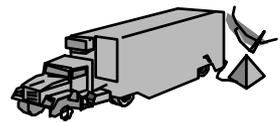
Applied to Satellite Ground Systems



- **Operational Environment – Air, Land and Sea**
- **Platform – Facilities (fixed and mobile)**



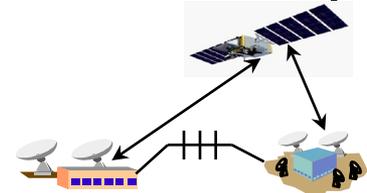
Buildings



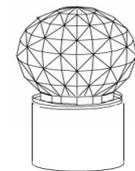
Shelters & Vans



Cloud



**Communications
Up/Down/XLinks**



Antennas

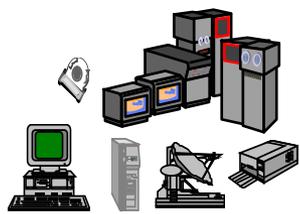


Infrastructure

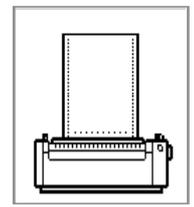
- **Mission Assets**



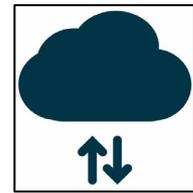
People



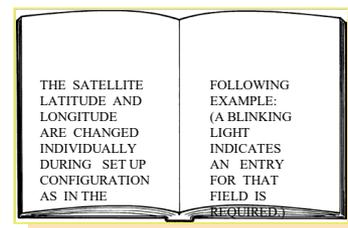
Hardware



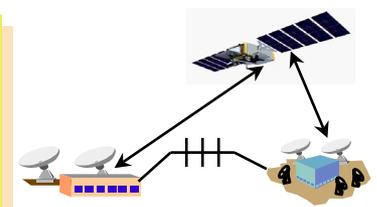
**Computer
programs**



Cloud



Procedures



**Communications
Up/Down/XLinks**



Operational Environment

How are the number and locations of ground assets determined?

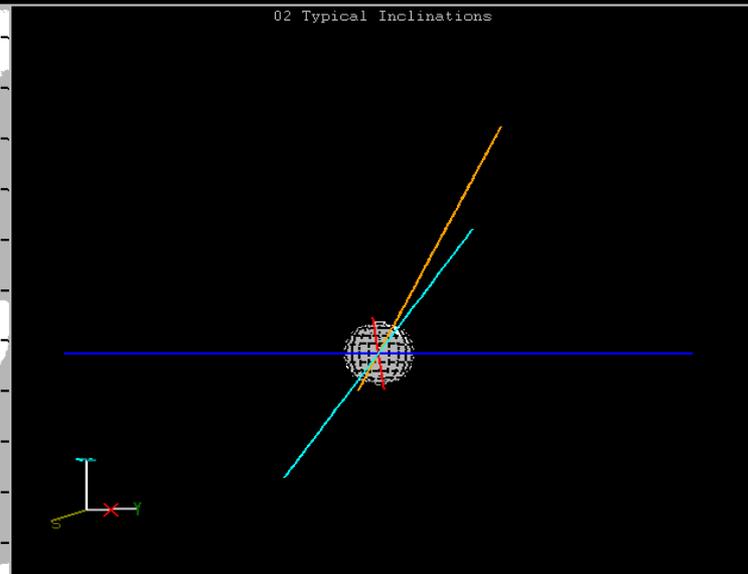
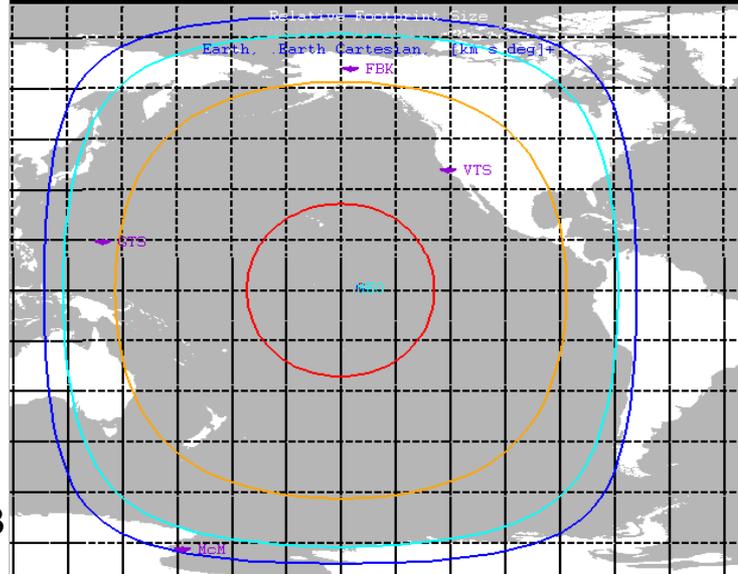


Drivers for Number & Location of Ground Assets



- Primary Considerations (Mission)
 - *Orbital Regime (HEO, LEO, MEO, GEO)*
 - *Ephemerides (altitude, inclination, period, etc.)*
 - *Views to / from satellites*
 - *Number of satellites to be contacted*
 - *Required contact duration*
 - *Number of contacts per satellite*
 - *Availability of inter-satellite links*

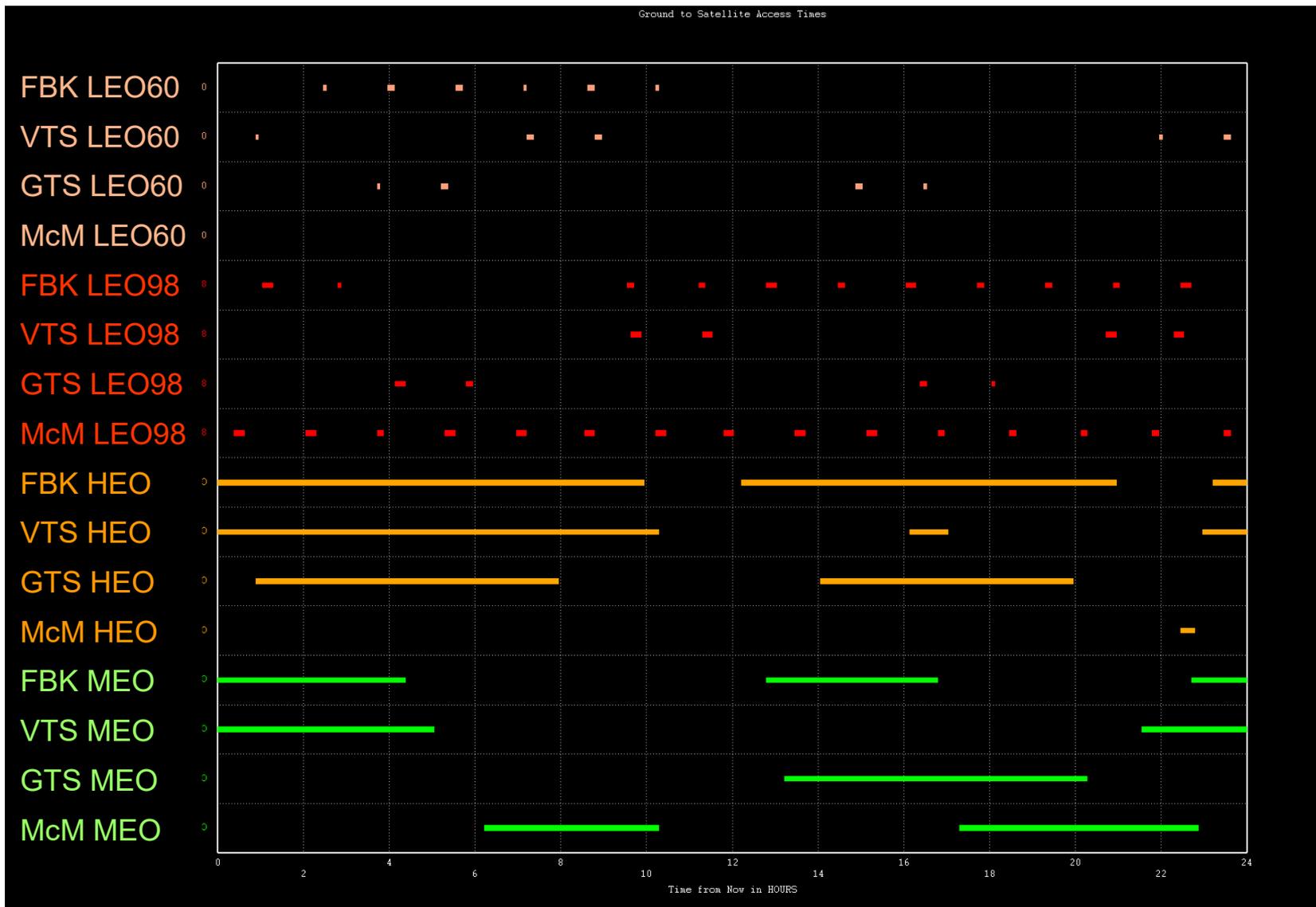
Satellite Orbit Regimes Compared



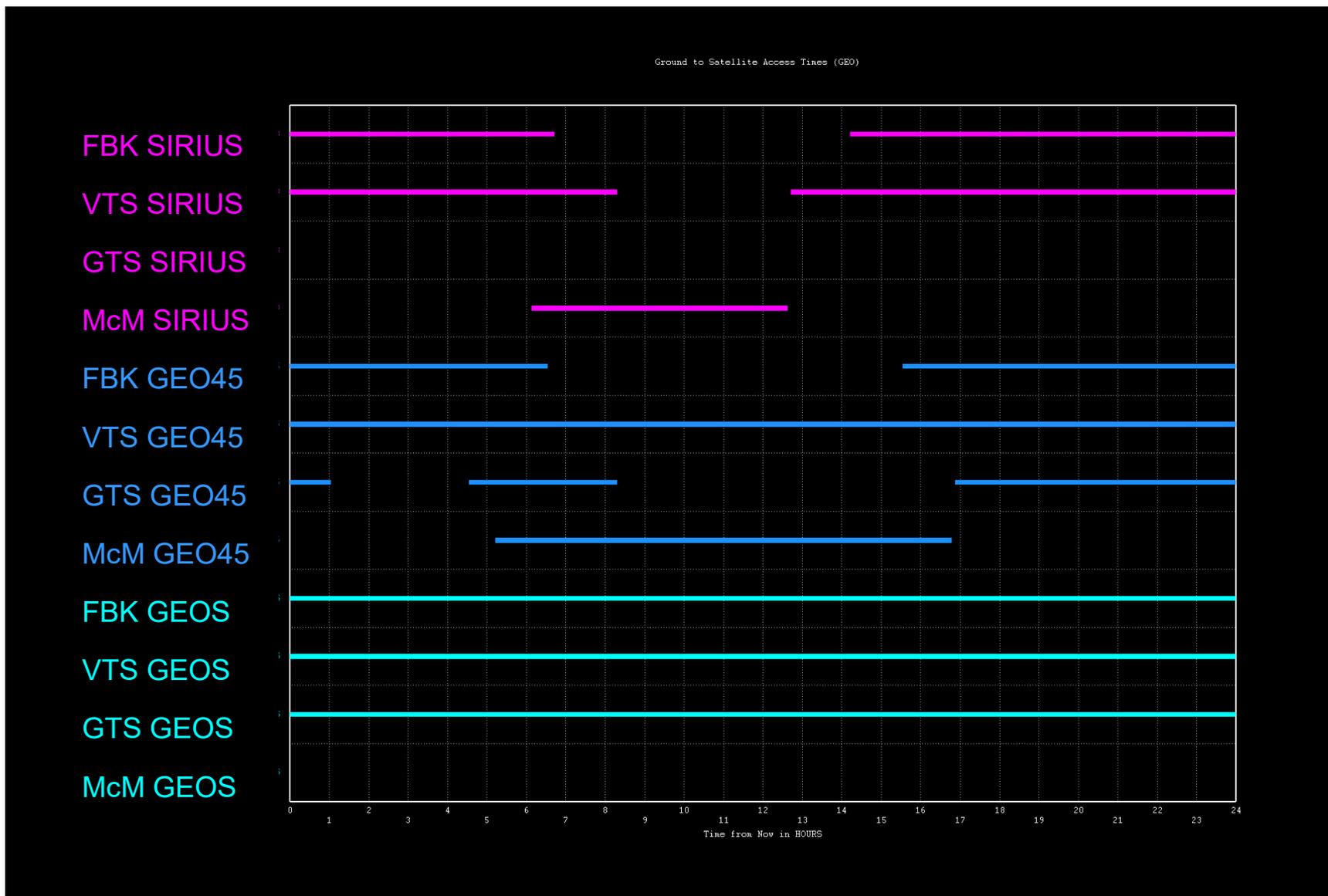
FBK: Fairbanks, AK
 VTS: Vandenberg AFB
 GTS: Guam
 McM: McMurdo Sound

LEO MEO HEO GEO

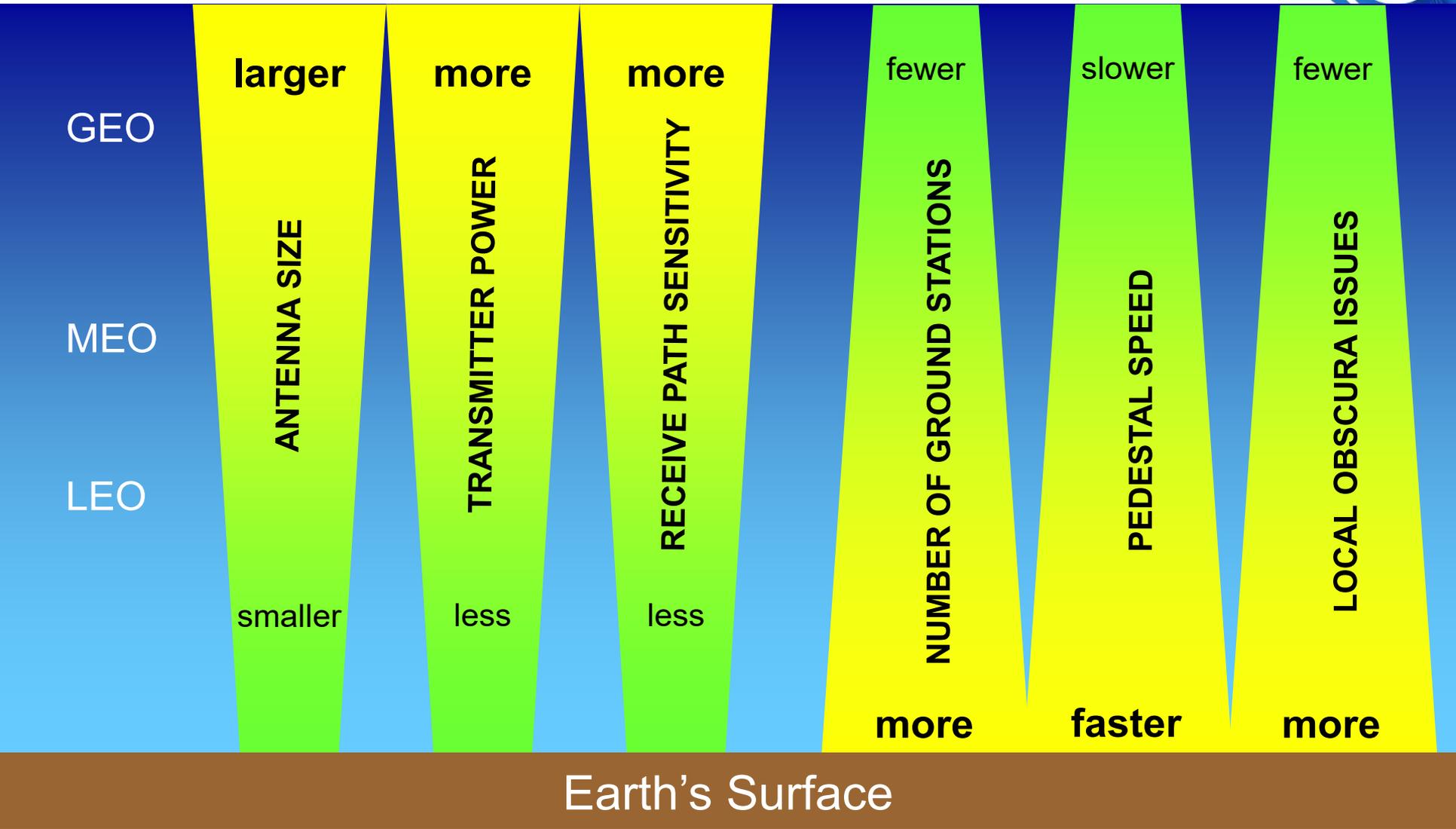
Comparison of Contact Times



Comparison of Contact Times (cont.)

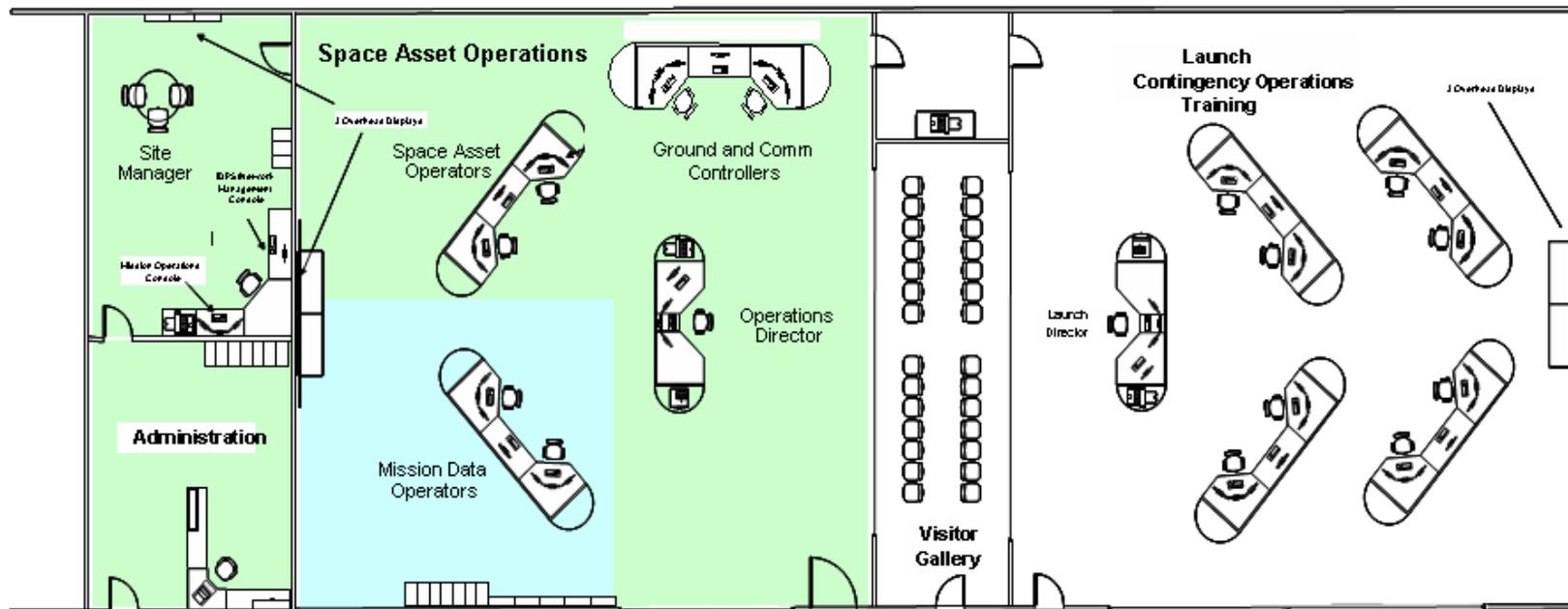


Effects of Orbit Regime on Site Design

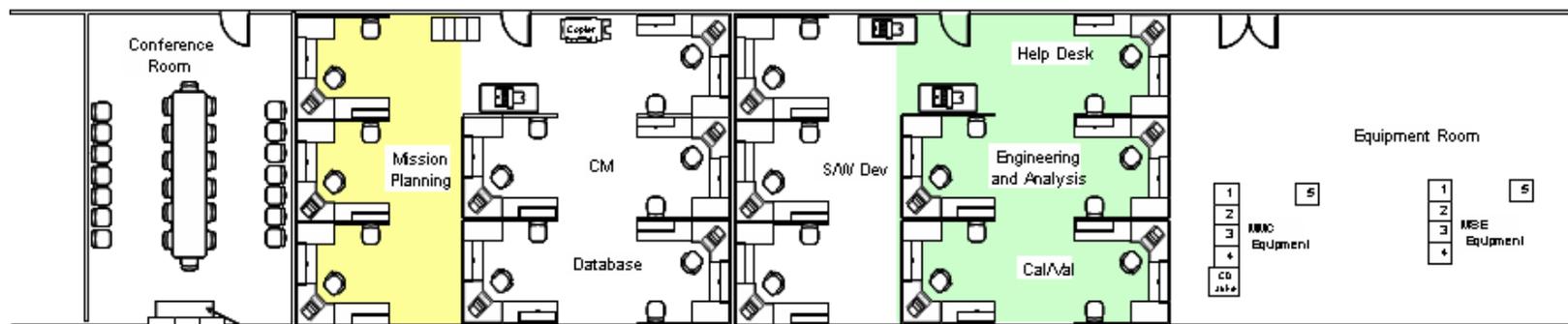


Number of ground stations may change with the availability of inter-satellite links

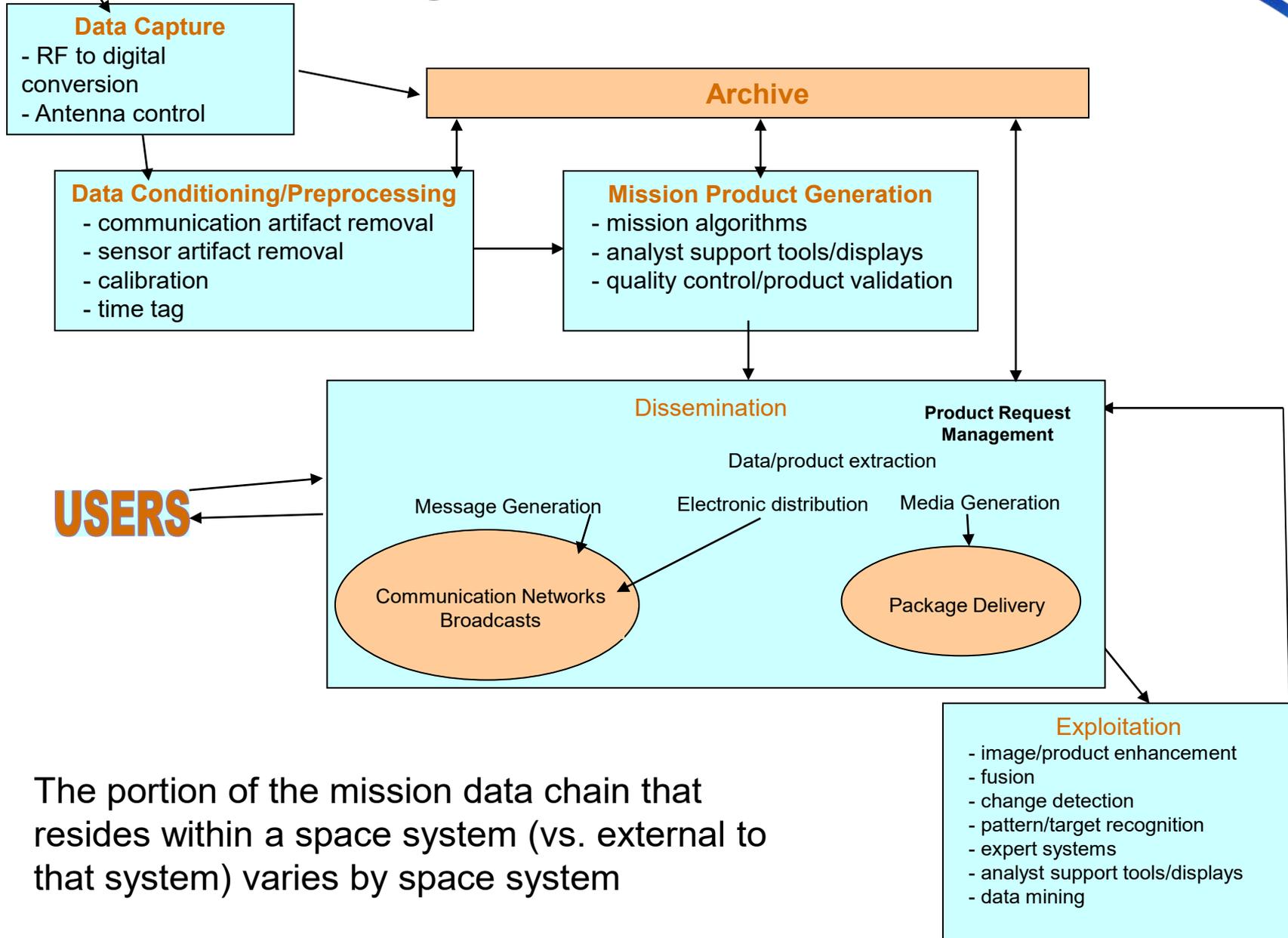
Old Paradigm Mission Control Center



Glass Half Walls



Old Paradigm Mission Data Chain



The portion of the mission data chain that resides within a space system (vs. external to that system) varies by space system

New Paradigm Mission Control Center





Architectures

SOA

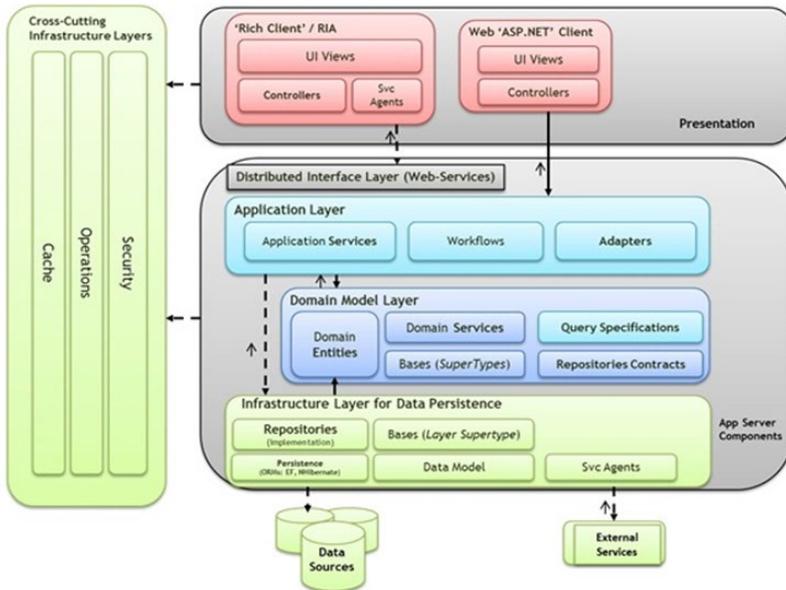
Event Driven

Data Driven

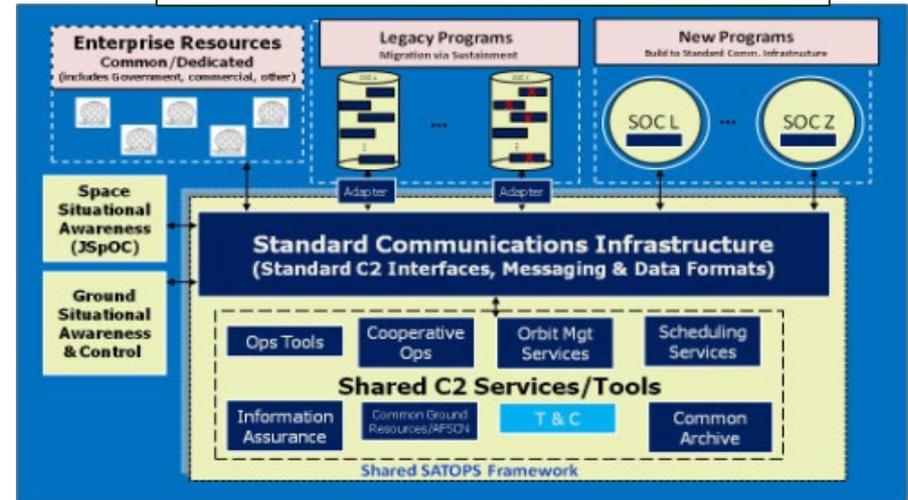
Potential Architectures



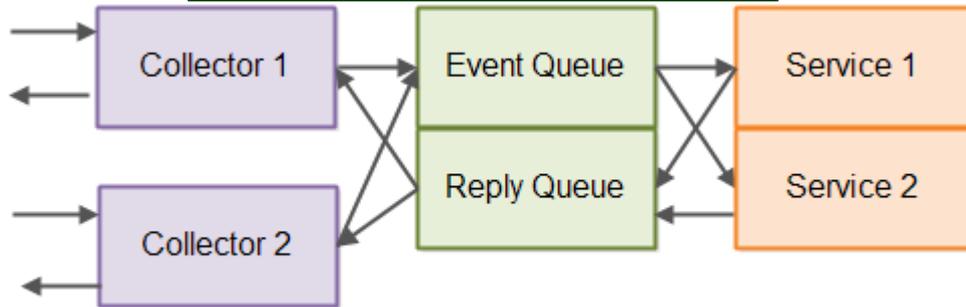
Data Driven Layered Architecture



Service Oriented Architecture

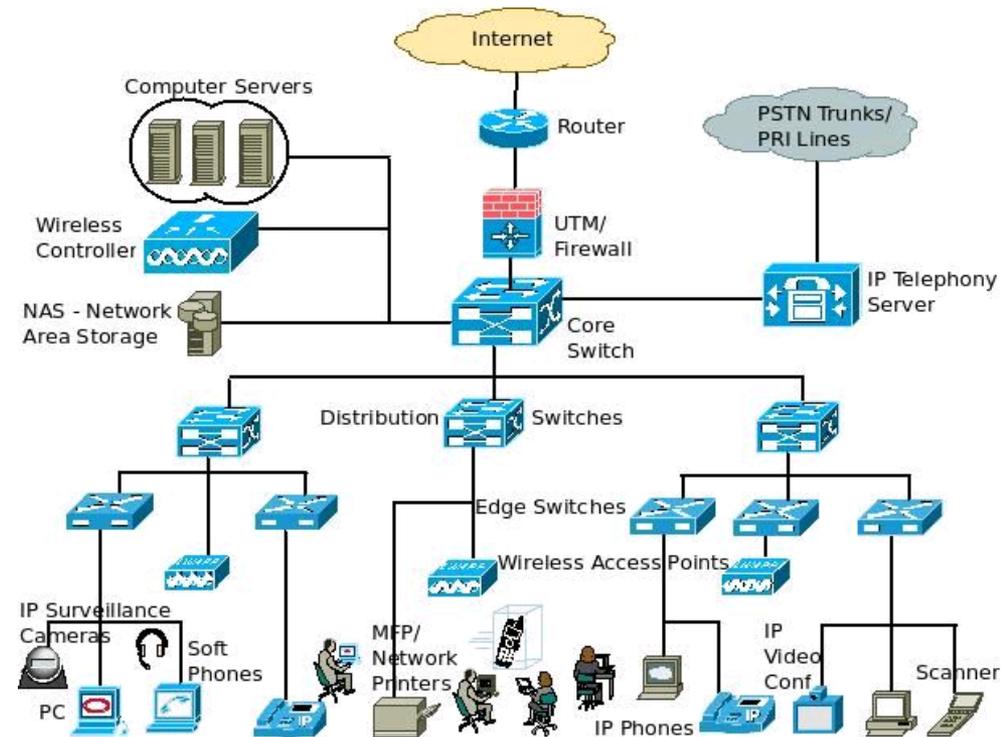


Event Driven Architecture



Network Architecture

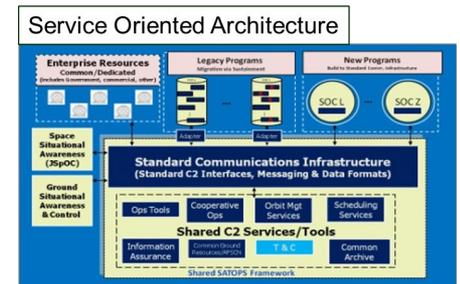
- The design of the network architecture includes:
 - *Physical components*
 - *Functional organization*
 - *Configuration*
 - *Operational principles and procedures*
 - *Communications protocols*
 - *Description of products and services*



Service-Oriented Architecture (SOA)

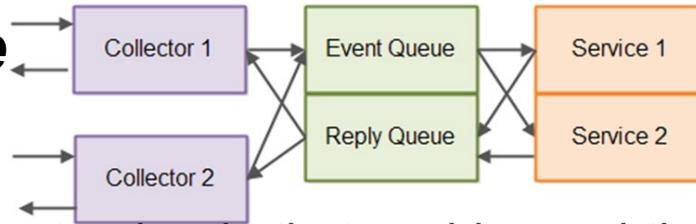
Current Path for Many

- SOA is an architectural style for developing and integrating enterprise applications as services across the enterprise
- Many variations, but standard principals are:
 - Provide services over the network through a communications protocol
 - Separates functions into services
 - Different services can be combined to functionally represent a large software application
 - Services are shared across the network (remote or local)
 - Can quickly add or remove services
 - Services Properties:
 - Represent an activity with a specified outcome
 - Is self-contained
 - Is transparent to consumers of the service (machine or human)
 - Separately deployed and maintained
- Example:
 - What was a “mission” is now separate services to point antennas, tune receivers



Move away from application centric architecture models

Event Driven Architecture



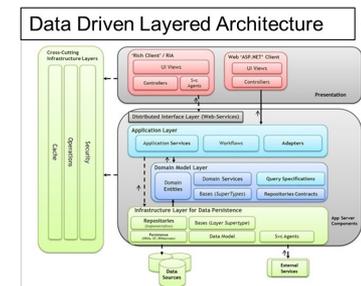
- Event Driven Architecture is an architectural style that enables real-time enterprise operations through detection processing, and consumption of events to identify and react to threats and anomalies
- This architecture has four parts
 - *Generate events through sensing a state change and sending a notification*
 - Message has a header identifying the event (metadata)
 - A message body that contains details of the state change that was detected
 - *Propagate the message through a communications protocol*
 - Can be either a broadcast or direct notification
 - *Detection of the event message and starting an appropriate response*
 - Response can be a display on a screen or a email/text message
 - *Notification of the consequences to the event*
 - This step is not required in all cases
- Being used by the Commercial SATCOM industry
 - *i.e. detect a telemetry parameter change and sent a text message to a technician*

An event driven architecture can be overlaid on a SOA (SOA 2.0)

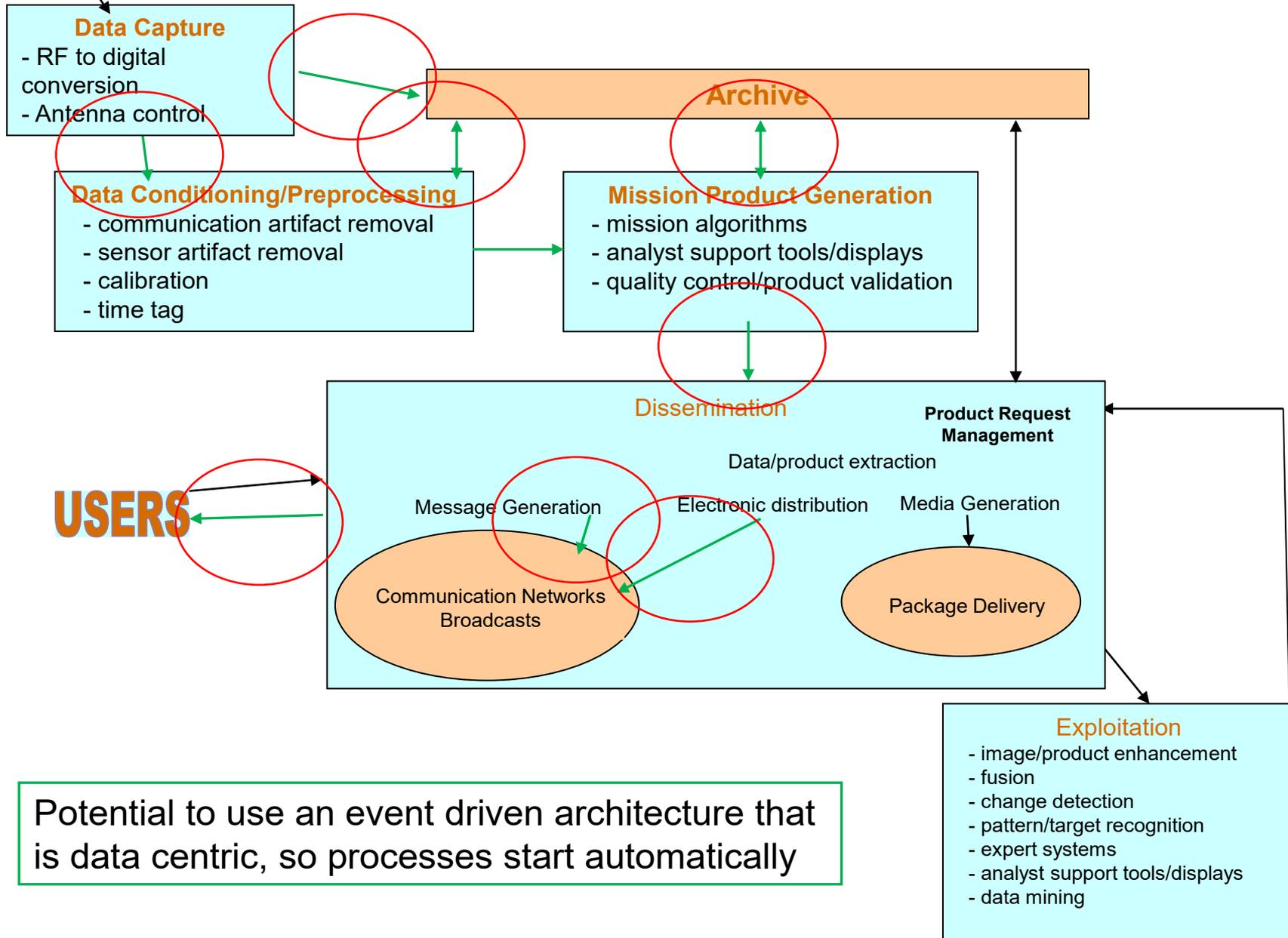
Data Driven Architecture

- Three basic rules
 - *Virtualize the Data*
 - Leave large data sets where they are
 - Bring data computation to the data to maximize the performance
 - *Information Quality*
 - Turn data into information
 - Deliver high quality information to the users as rapidly as possible
 - *Idea is to use the analysis for more effective decisions*
 - Input new data
 - Process the data consistent with older data
 - Make the data available across the enterprise
 - *Interpret the data for action*
 - *Let the data speak for itself*
 - Do not try and fit the data into preconceived notions
 - *Do not analyze to fit past patterns*
 - Be able to scale with demand

Think data first, not processes



Processes Start Automatically



Potential to use an event driven architecture that is data centric, so processes start automatically



- Scope
 - *Definitions*
 - *Within space missions*
 - *Within ground systems*
- **Functionality**
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Mission Assets

What functions are required?

What operational modes need be supported?

How are functions allocated?

Ground System Functional View



Primary Functions

Mission Management

Planning and scheduling what the space system will do

Asset Command and Control

Commanding the space asset to perform its mission and monitoring what it does. Controlling and monitoring ground assets.

Mission Data Chain

Doing something with what the space asset produces

Supporting Functions

Enabling the execution of the primary functions

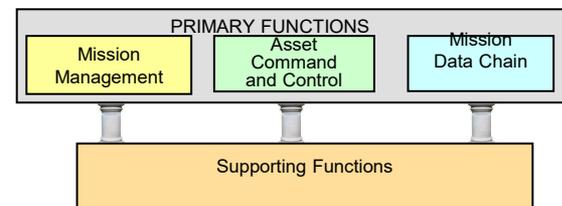
Archive
Simulation
Test
Training
Communications

Maintenance
Facility Management
Administrative Services
User Services
Security

Information Infrastructure

Mission Management Functions

- System planning
- Constellation management
- Payload planning, tasking, and scheduling
- Housekeeping planning and scheduling
- External resource scheduling
- Maintenance planning and scheduling
- Processing and distribution planning and scheduling
- Ground resource planning and scheduling
- Schedule dissemination
- Performance evaluation/reporting
- Performance assessment
- Report generation
- Tasking feedback





What is Planned/Scheduled When

System Planning [years to months]

- constellation management
- infrastructure modifications

Near Term Plan [weeks]

- external resources
- space and ground resources
- ground maintenance
- satellite maneuvers

Future Daily Planning [days]

- SOH activities
- payload operations
- PED activities
- ground operations

Daily Schedule [hours]

- "final" baseline schedule for space and ground

Near Real Time Replan [hours to minutes]

- anomaly response
- ad hoc tasking

Real Time Replan [minutes to seconds]

- anomaly response
- tip/cue response

E
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years ... months

... weeks

... days

... hours

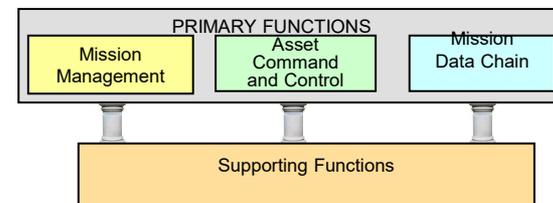
...minutes

...seconds

Space Asset Command and Control Functions



- Satellite Command and Control
 - *Telemetry processing*
 - *State of Health Telemetry Analysis*
 - *Telemetry Display and Distribution*
 - *Command Generation and Verification*
 - *Anomaly Detection, Isolation, Resolution*
 - *Commanding*
 - *Space System Situation Awareness*
 - *Ground System Status*
 - *Ground System Configuration*
- Ephemeris and Attitude
 - *Tracking*
 - *Ephemeris Determination*
 - *Ephemeris Prediction*
 - *Attitude Estimation*
 - *Attitude Maneuver Support*
 - *Station keeping*
 - *Maneuver Planning*
- System Control and Status
 - *System Situation Awareness*
 - *Ground Resource Management*
- Space to Ground Communications
 - *A/D Conversion*
 - *Encoding*
 - *Encryption/Decryption*
 - *Modulation/Demodulation*
 - *Upconversion*
 - *Amplification*
 - *Antenna Control*
- Sustaining Engineering and Anomaly Response
 - *Sustaining Engineering*
 - Subsystem experts
 - Short and Long Term Trending
 - Calibration Support
 - Factory Support
 - Anomaly Support
 - Manage Consumables
 - Space HW Testbeds
 - *Anomaly Response*
 - Define Contingency Workarounds
 - Isolate Cause
 - Define and Checkout Response





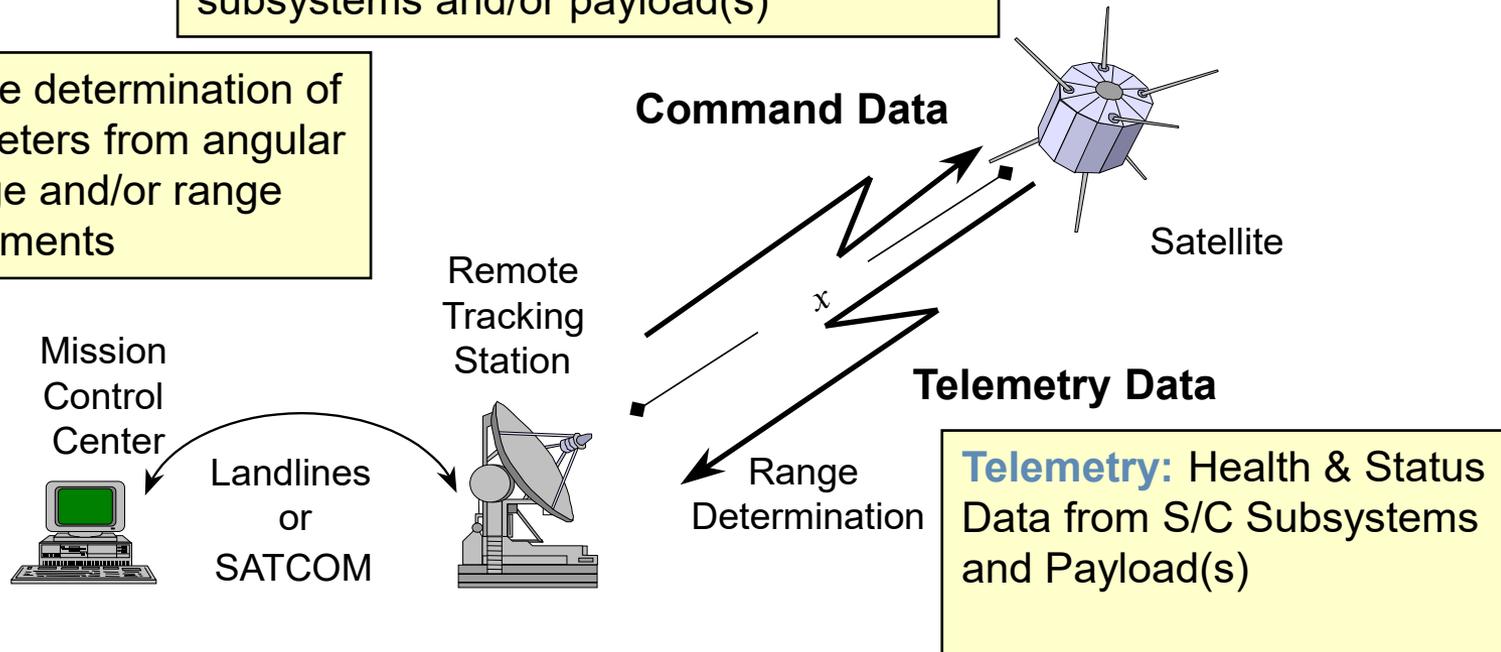
(Generic) Telemetry, Tracking and Command Subsystem

- **Why have a TT&C Subsystem? All satellite systems must have means of collecting satellite health and status and the means to control various subsystems and payloads**

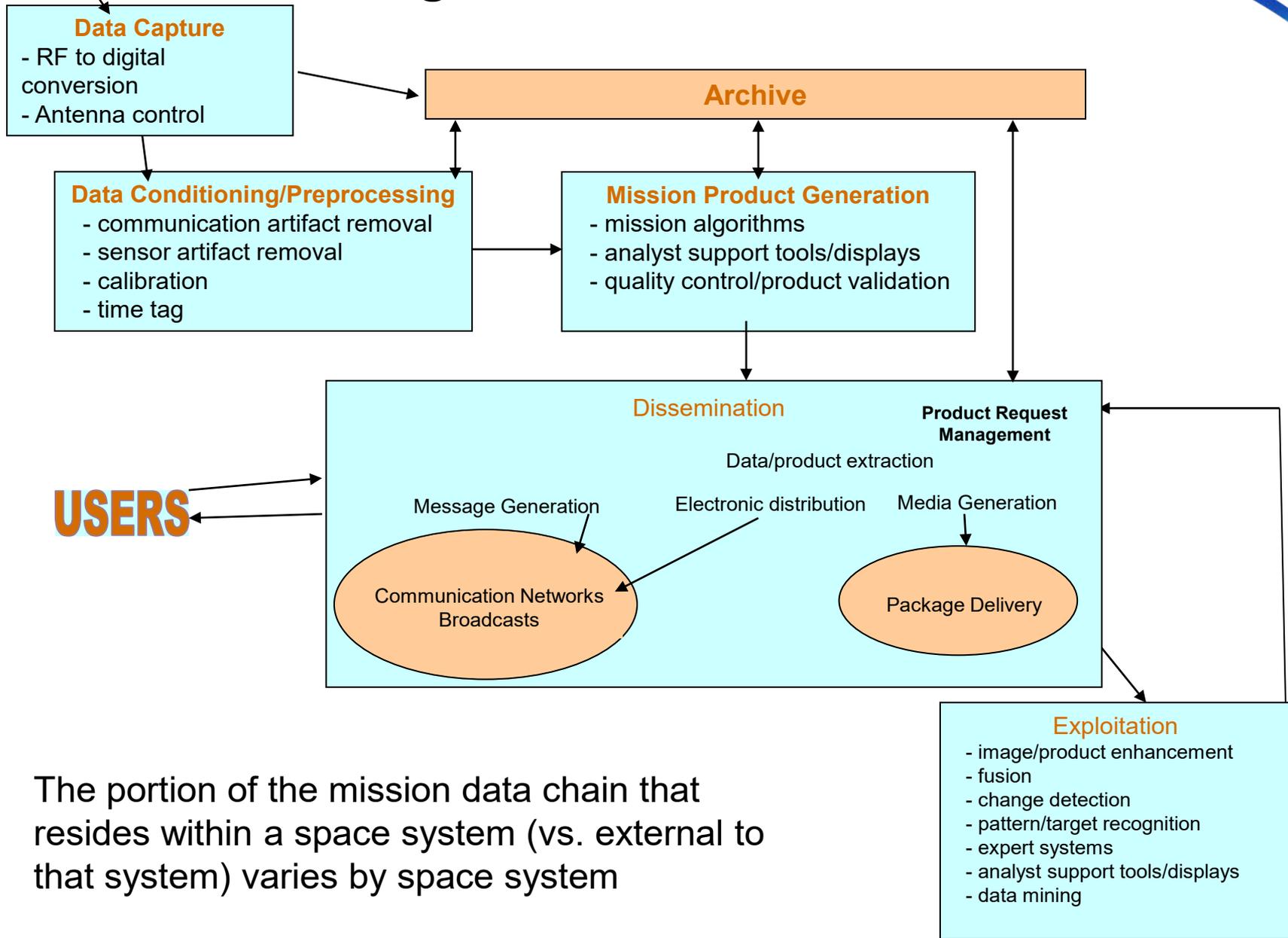
What's involved in TT&C?

Command: Signals to effect operation of and configure changes to S/C subsystems and/or payload(s)

Tracking: The determination of orbital parameters from angular position, range and/or range rate measurements



Old Paradigm Mission Data Chain

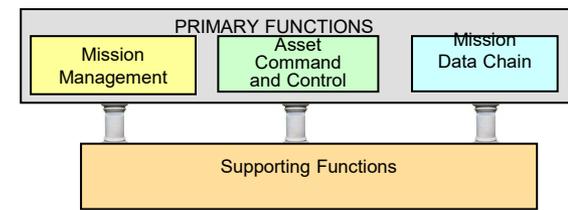


The portion of the mission data chain that resides within a space system (vs. external to that system) varies by space system

Mission Data Chain Functions

- Mission Processing
 - *Data Capture*
 - *Data Conditioning/Preprocessing*
 - *Mission Algorithms*
 - *Message Generation*
 - *Analyst Support*
 - *Situation Awareness*
 - *Quality Control/Product Validation*
- Data Product Distribution
 - *Data/Product Extraction*
 - *Exploitation*
 - *Electronic Dissemination*
 - *Media Generation*

- User Element
 - *Data Reception*
 - *Data Processing*
 - *Data Analysis*
 - *Data Exploitation*
 - *Help Desk*





Supporting Functions

Enabling the execution of the primary functions

Simulation

- Satellite
- On-board Processors
- Payload
- Ground
- External Interfaces

Test

- Maintenance Testing
- "Certification Testing"
- External Interface Testing

Training

- Training Courseware
- Launch Rehearsal
- System Orientation
- Exercise Support
- Operator
- Maintenance Personnel
- Technical Instructions

Maintenance

- HW
- Flight SW
- Ground SW

Archive

- Command and Telemetry
- Mission Data/Product
- System Logs
- Databases

Ground Communication

- Satellite Links
- Communication Control
- Commercial Land Links
- DISA Resources
- Networks (LAN,WAN,VPN,...)
- Voice Nets, VTC
- Web Connections

Facility Management

- Land and Structures
- Power
- Environment Control
- Physical Security Systems
- Fire Protection

Information Infrastructure

- Process Control
- Data Management
- Network Management
- Logging and Reporting
- Internal Interface Management
- Message Handling
- Common Support Applications
- User Interfaces
- Information Security
- Operating System Services
- Middleware
- General Utilities

Administrative Services

- Business Management
- Secretarial Support
- Personnel
- Office Automation

Security Services

- Information Security
- Physical Security
- Crypto Management
- Cyber Security



Amazon Ground Station (AGS)

Ground Station as a Service

Note: used as an example not an endorsement of AGS



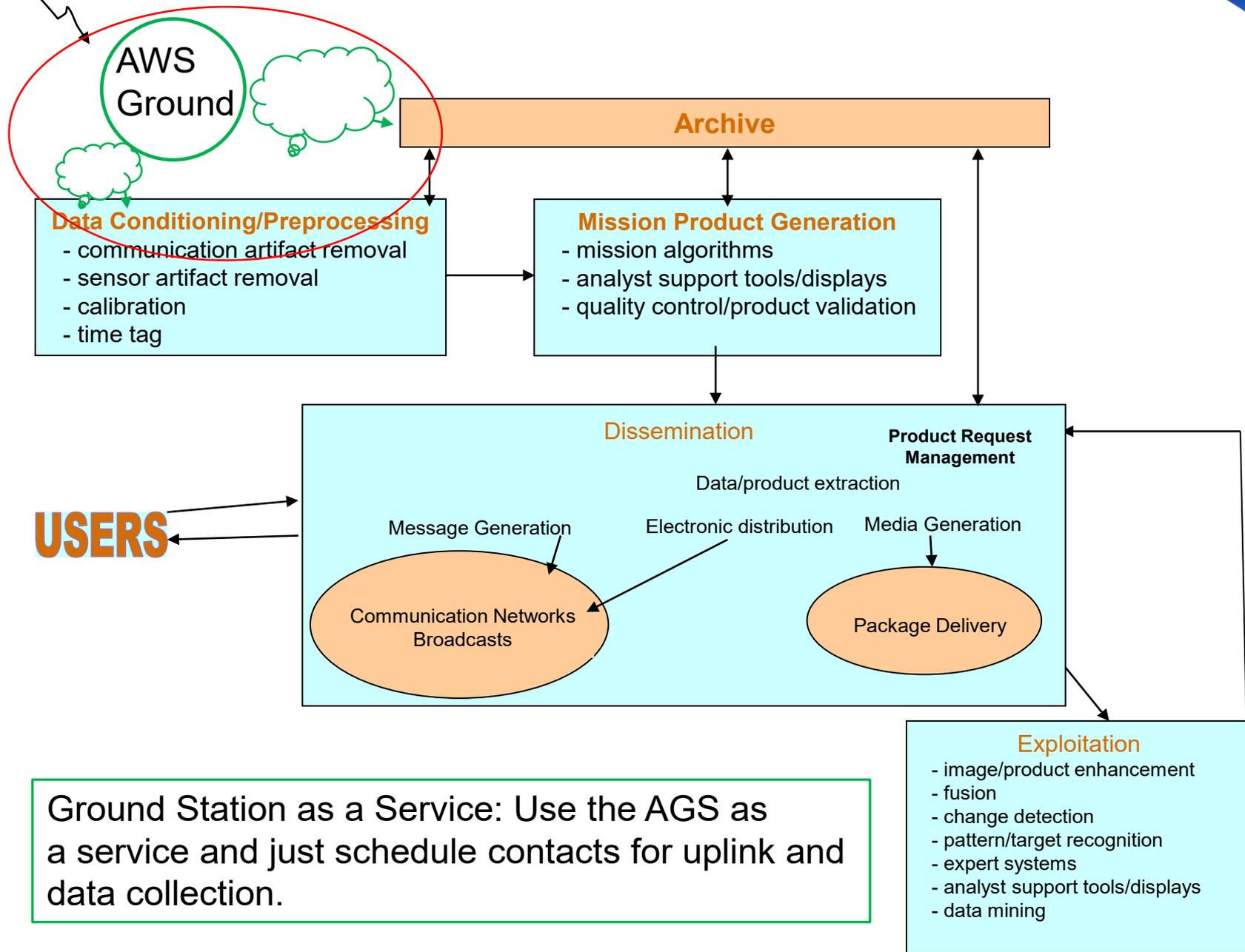
Amazon Ground Station

aka AWS Ground Station



- A global network of ground stations in close proximity to AWS data centers
 - *Ground station here is the fixed antenna and software to digitize the received signal*
 - *Data is stored at the data center or distributed to a location prescribed by the user over Amazon's private global network*
- The pay-as-you-go system
 - *You must be an AWS subscriber*
 - Provides access to the cloud and antenna scheduler
 - *You pay for minutes used to receive data from the satellite pass or time to transmit*
 - *Includes transport and storage of the data*
 - *You can process your data in the AWS Cloud or in your own processing facility*
 - Amazon will help with uploading your signal processor into the cloud
 - *Allows you to control, collect, ingest data, or send commands to orbiting satellites*
 - Without owning any antennas or ground station infrastructure
- Effectively makes the Ground Station a service

Ground Station as a Service



Ground Station as a Service: Use the AGS as a service and just schedule contacts for uplink and data collection.



CI/CD:
Continuous Integration / Continuous Delivery
OR
Continuous Integration / Continuous Deployment



Continuous Integration



- The practice of merging all developers working code into the code base several times a day
 - *A master code base is required for all source code*
 - *Integration of the new and changed code needs to happen often enough that it does not stray far from the code base*
 - Keep the number of errors small and manageable
 - *A build server and automated tests are used to look for integration conflicts and bugs*
 - Ideally this is an automated process that is part of a “pipeline”
 - Every merge should be completely built and tested to ensure a working baseline is maintained
 - *CI is often part of a combined CI/CD process*
- Benefits:
 - *Detect and fix bugs early and not at the end of development*
 - *Constantly updating the delivered code into a new delivery version*
 - *Provides flexibility to meet growing operator mission “needs”*
- Challenges:
 - *A lot of upfront work to create an automated test suite and automated build server*
 - *The process to merge working code from a large development team is complex*

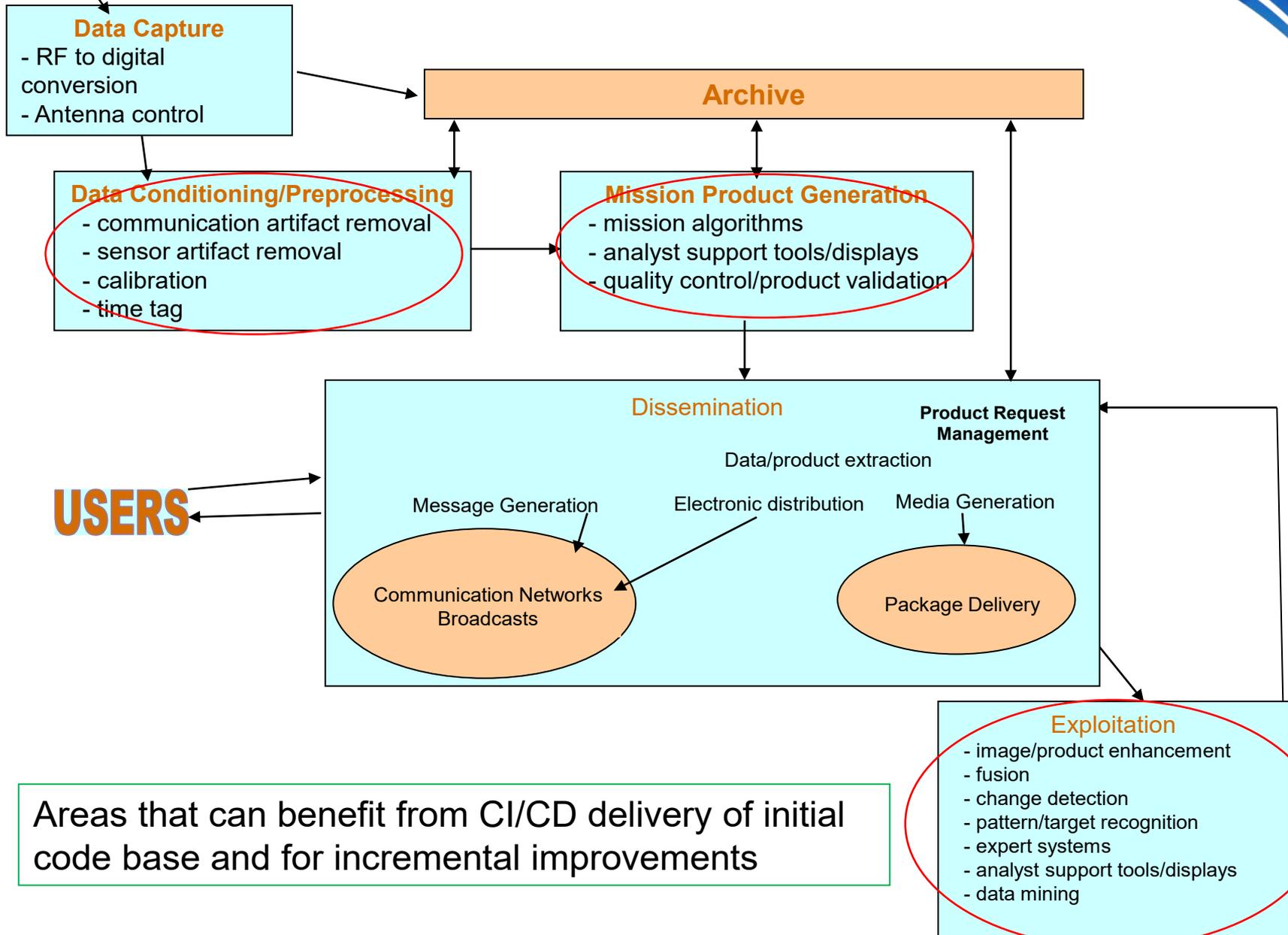


Continuous Delivery



- Goal is to build, test, and release software more often and more frequently
 - *Aim is to reliably release the software at any time*
 - *Allow for more incremental updates with a repeatable process*
 - *Continuous deployment provides updates automatically vice a schedule or request*
 - *DevOps can be the result of a continuous delivery process*
- Build and test process typically uses a “pipeline” to track the development
 - *All aspects of the process are visible to all team members*
 - *Team members are notified of problems as soon as they occur*
 - *The process allows any version of software that has completed the process successfully to be delivered*
- Benefits:
 - *Quicker more reliable deliveries*
 - *Improved efficiency and quality*
- Challenges:
 - *Not all elements of quality can be verified with automation*
 - *Some customers, telecom and medical for example, require “do no harm” testing before deployment*

Areas Benefiting from CI/CD





Agile Software Development



What is Agile Software Development?

- **Agile software development:**
 - *A set of principles for software development*
 - Requirements and Design are developed iteratively - Eat the Elephant in small bites
 - Uses cross-functional teams - Experts in their areas of expertise
 - Continuous Improvement of the developed code - Many short development cycles
 - Has rapid and flexible response to change - Can roll in changes on the next cycle
- Agile Teams should be reluctant to commit to locked time, resources, and scope
 - *Agile work practices are iterative and incremental*
- The goals of Agile developments:
 - *Reduce up front documentation*
 - *Focus on developing working code*

The principles for agile development have been around since ~1957

Agile Development Methods

- Agile Developments should apply:
 - *Daily automated testing to developed code*
 - *Continuous integration and test*
- Applications of agile process include Dev/Ops, Data Analytics, Big, Data, and Data Science/DataOps

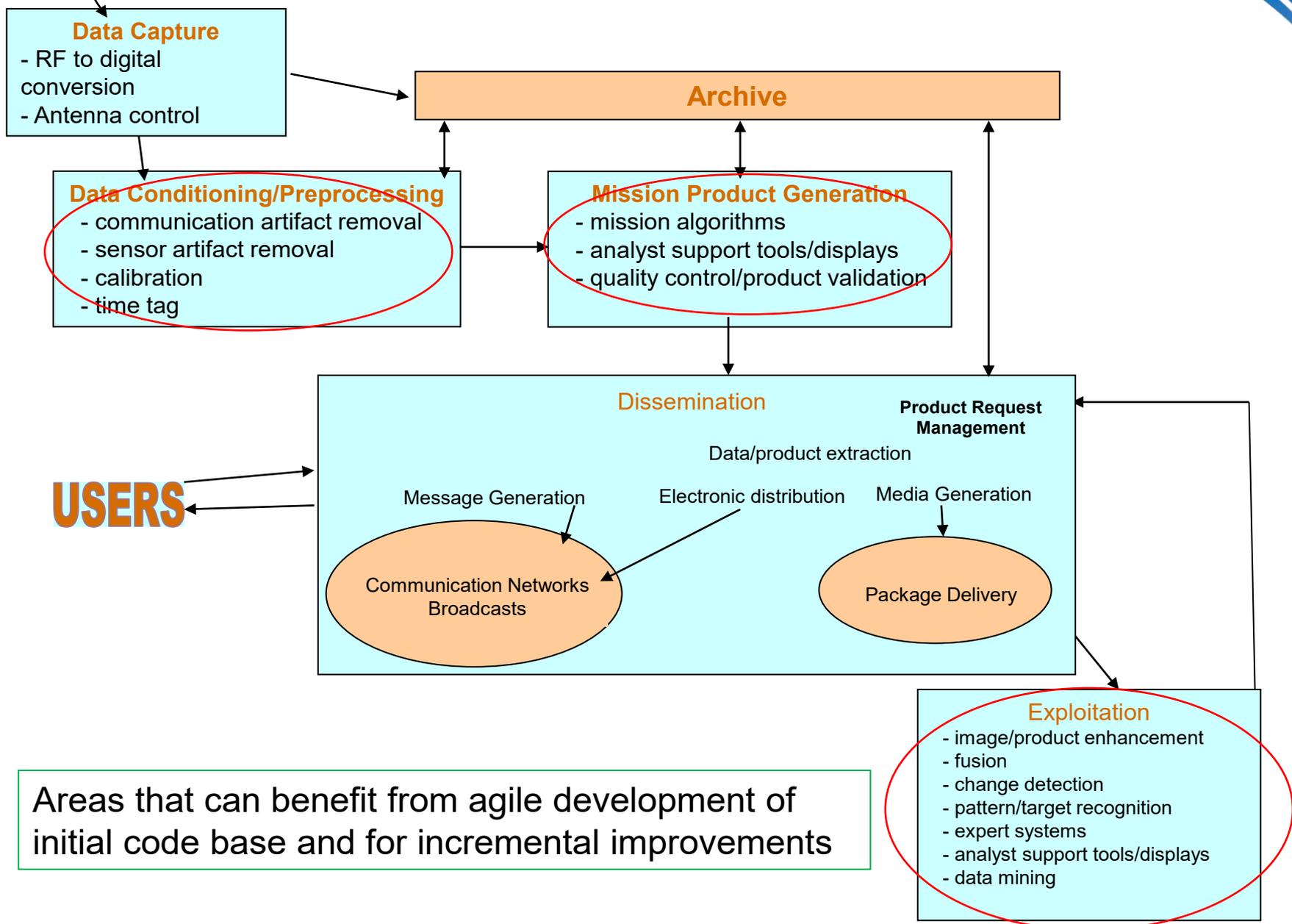
Agile methods	Plan-driven methods	Formal methods
Senior developers	Junior developers(?)	Senior developers
Requirements change often	Requirements do not change often	Limited requirements, limited features
Small number of developers	Large number of developers	Requirements that can be modeled
Culture that responds to change	Culture that demands order	Extreme quality



DevOps

- Common definition:
 - *Set of processes to reduce the time from defining a change to a system and the change being placed into operations with high quality*
 - *Multiple definitions and contexts*
- Common goals with agile and lean methods
 - *DevOps address the gap between developers and IT operations*
 - *Agile/lean address the gap between developers and users of the software*
- DevOps is commonly used with CI/CD
 - *Pipelines for development*

Areas Benefiting from Agile Development





Cloud



Cloud Computing

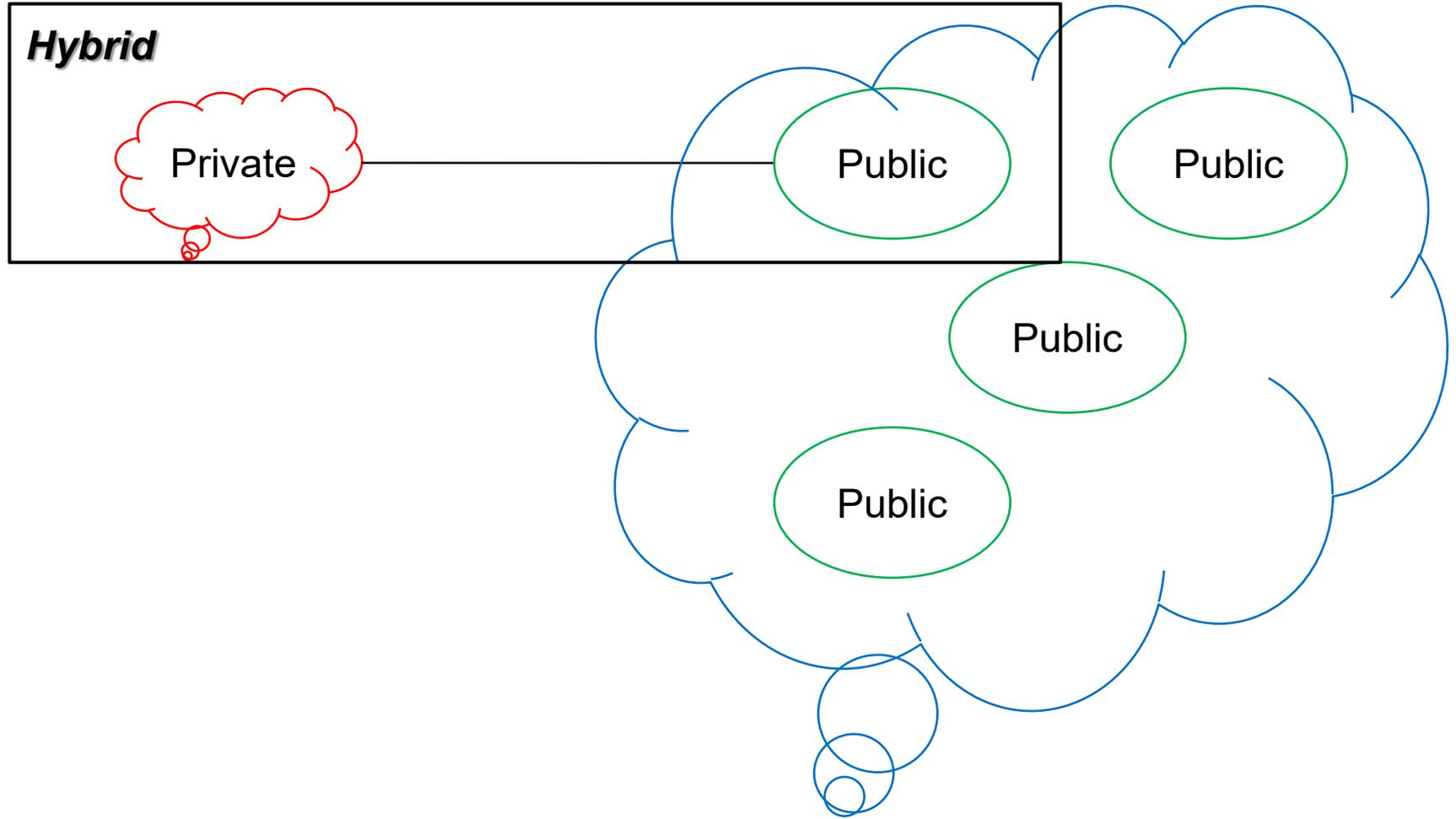
Using other peoples hardware



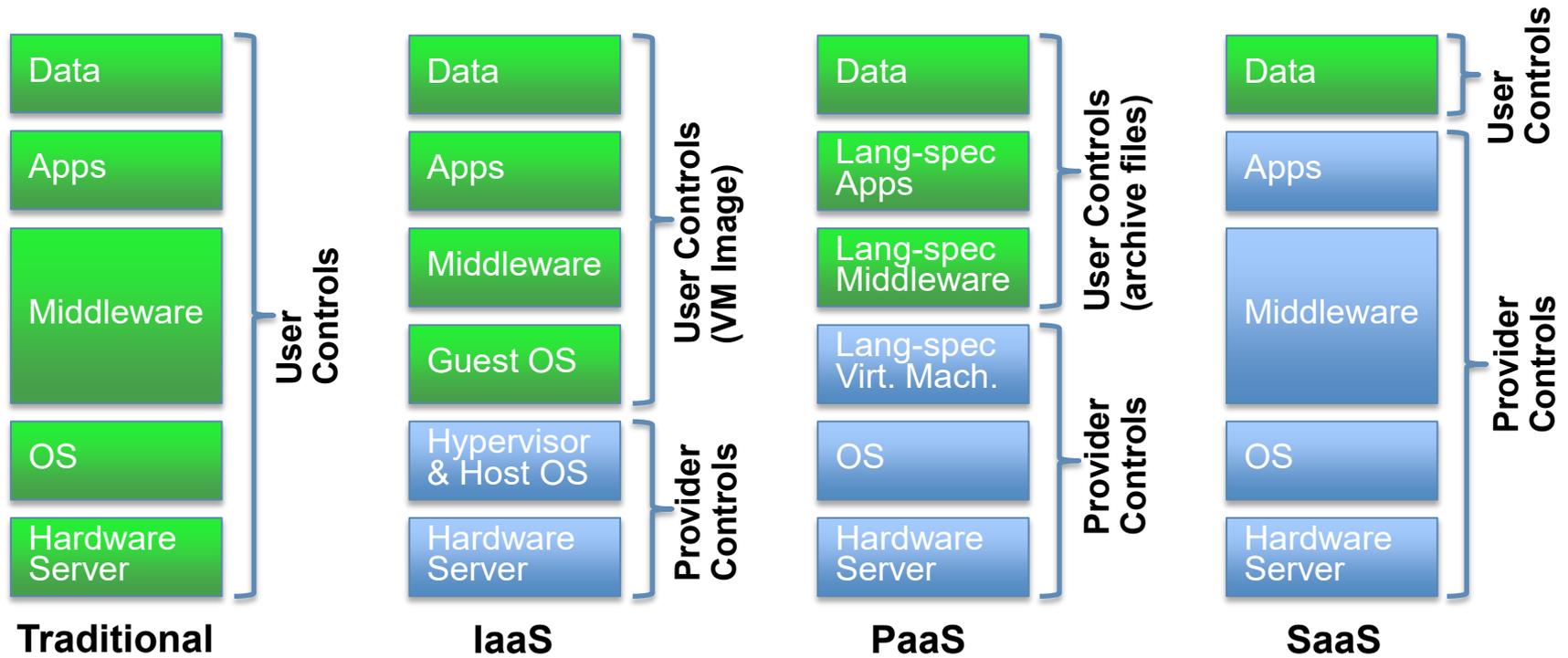
- On-demand availability of computer resources, such as data storage and/or computing without responsibility for the resources
 - *Designed to achieve economies of scale*
 - e.g. security costs are shared across many users
 - *Avoid or minimize up front infrastructure costs*
 - No need for knowledge or expertise to set up an infrastructure
 - *A virtual computing and storage service*
- Three types of clouds
 - *Public*
 - *Private*
 - *Hybrid*
- Three basic service models per NIST
 - *SaaS – Software as a Service*
 - *PaaS – Platform as a service*
 - *IaaS – Infrastructure as a Service*

NIST – National Institute of Standards and Technology

Cloud Types

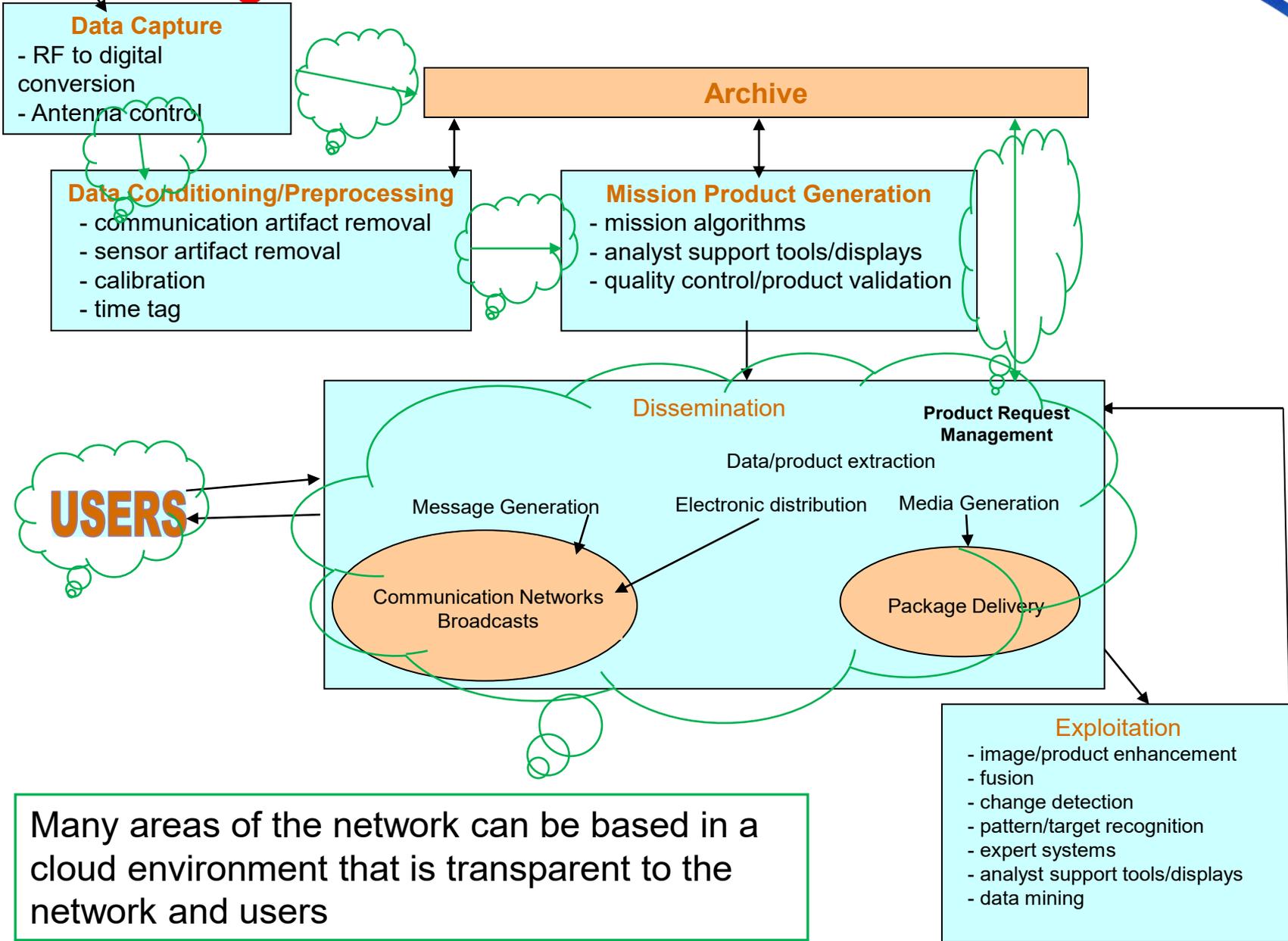


Cloud Service Models





Using the Cloud in the Mission Data Chain





Big Data and Data Mining



Big Data

- Use of predicative analytics, user behavior analytics, or other data analytics to extract additional insight from data sets
 - *Seldom used to describe the size of a data set*
 - *Used to spot business trends, prevent disease, increase security, improve decision making*
- Big data sets are a moving target, what was once a large data set is now considered normal or small
 - *Data in big data sets is typically produced continually*
- The focus of big data is unstructured data sets
 - *Text, images, audio, video, and the use of data fusion*
 - Acoustics, vibration, pressure, current, voltage, controller data from a satellite
 - *Real or near-real time information delivery*
- Big data Technologies
 - *Machine learning and cloud computing*
 - *Database storage*



Some Current Big Data Initiatives



- Using virtual machines and expert systems
- Mine sustainment databases to predict part failure
- Take burden off of humans in analysis
 - *Identify key elements and flag events for operators*
- Trending data flow and patterns
- Learn the “personality” of hardware, software, or systems
 - *Determine out-of-family behavior*
 - *Capture degradation during aging process*
 - *Anomaly investigation*
 - *Memory leak or storage nearing limits*
- DoD and IC are newcomers to harvesting Big Data

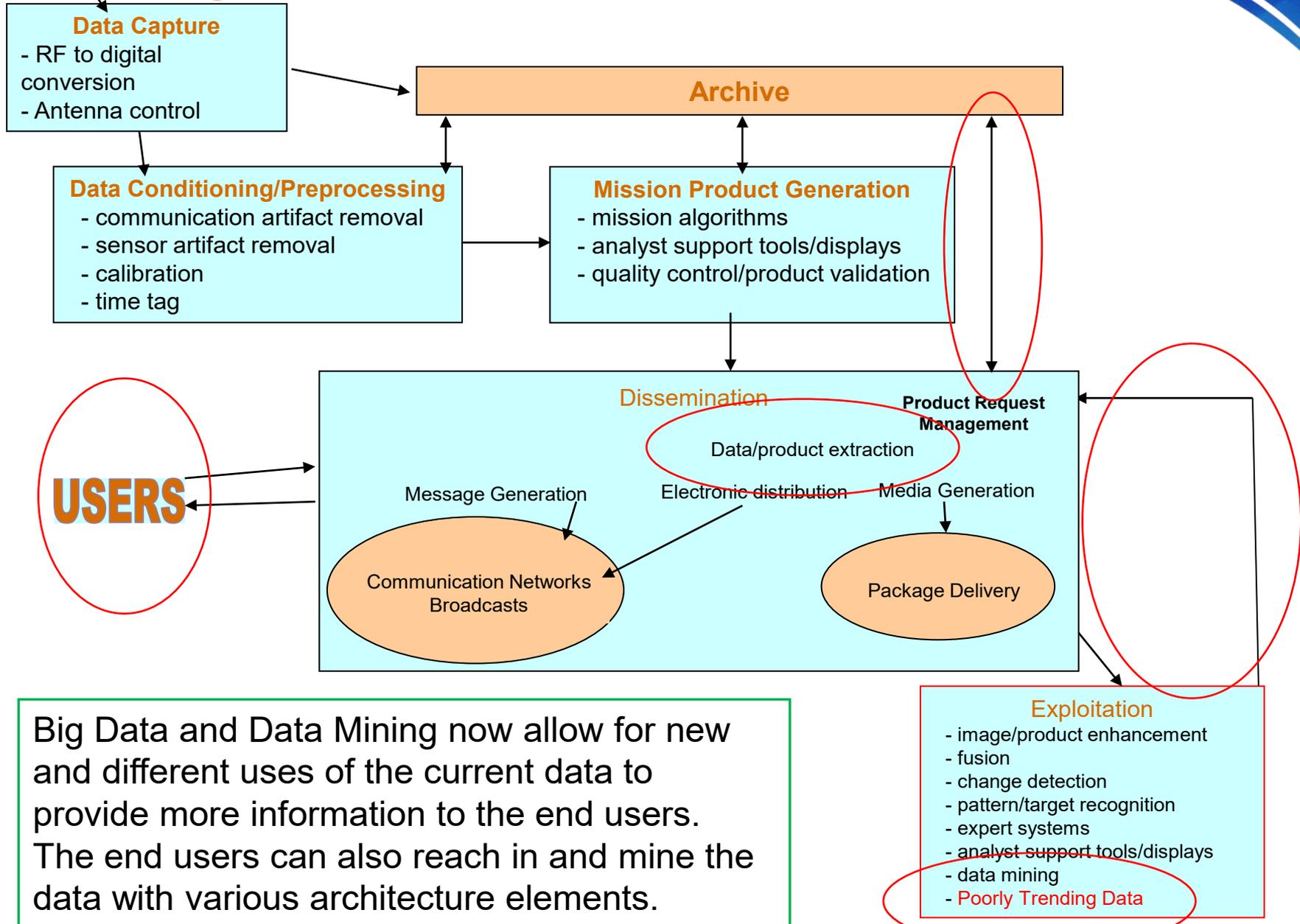
Reduce the latency from data to information



Data Mining

- The goal is to extract patterns and knowledge from large sets of data
 - *Due to size of the data sets the process is automated with ML and statistics*
- Looking for previously unknown or hidden patterns in the data
 - *Sequential patterns – similar groups or structures in the data*
 - *Anomaly detection – out-of-family or errors that require further study*
 - *Predicative Analytics – hardware or software degradation or failure rates*
 - *Decision support – hardware or software upgrades*

Big Data in the Mission Data Chain



Big Data and Data Mining now allow for new and different uses of the current data to provide more information to the end users. The end users can also reach in and mine the data with various architecture elements.



Artificial Intelligence / Machine Learning



Artificial Intelligence (AI)

Learning or Problem Solving

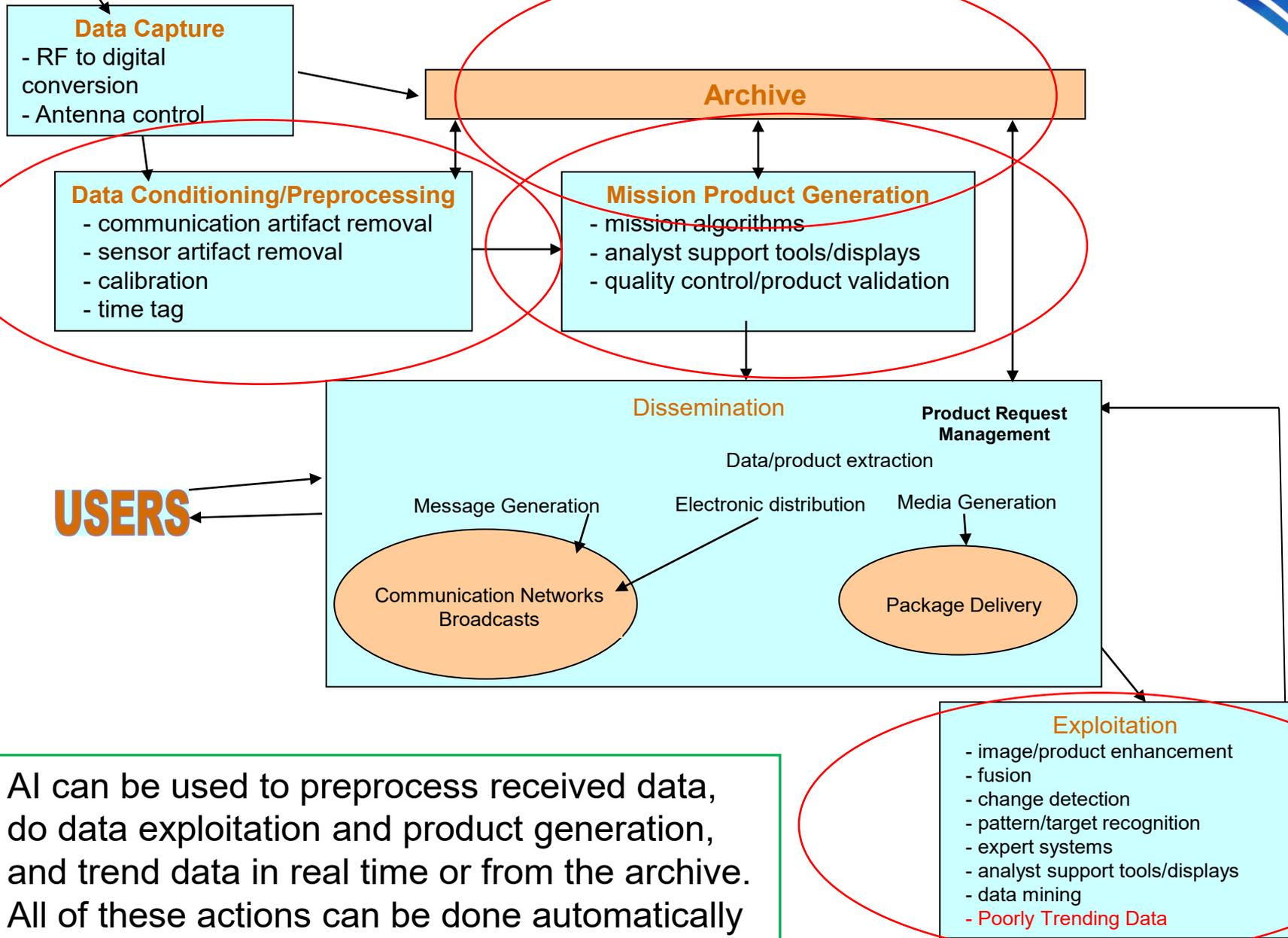
- AI is the ability to interpret external data, learn from this data, and use that learning to achieve goals and tasks through adaptation
- Due to increased processing power AI becoming mainstream
 - *Used by many commercial companies, i.e. Google and Microsoft*
 - *Expert Systems were the first form of AI simulating knowledge experts*
 - *Now AI is used in medical and logistical fields*
 - *Self-driving vehicles is pushing the state-of-the-art for AI*
- Examples include:
 - *Deep Blue – more of an expert system than AI*
 - In 1997 beat reigning chess champion at a game of chess
 - *Kinect body-motion interface for Xbox*
 - *IBM Watson*



Machine Learning (ML)

- Use of algorithms and statistical models to perform tasks with instructions
 - *Subset of Artificial Intelligence*
 - *Unsupervised learning to form models and predictive analytics are two categories used in business*
 - e.g. does an image contain certain object(s)
 - *Used in Self-Driving cars to steer clear of people*
 - Feed the algorithm telemetry data and look for patterns that do not fit
 - *Predictions based on trends*
- Algorithms and models may require training data
 - *For self-driving cars need images with and without people*
- ML and AI are sometimes combined with Big Data and Data Mining
 - *Sift through large amounts of data to highlight data sets for humans*

AI and ML use in the Mission Data Chain



AI can be used to preprocess received data, do data exploitation and product generation, and trend data in real time or from the archive. All of these actions can be done automatically in the background or initiated by operators.



- Scope
 - *Definitions*
 - *Within space missions*
 - *Within ground systems*
- Functionality
- Modes of Operation
- Allocation of functions to achieve the required capabilities
- Final Thoughts and Summary



Modes of Operation



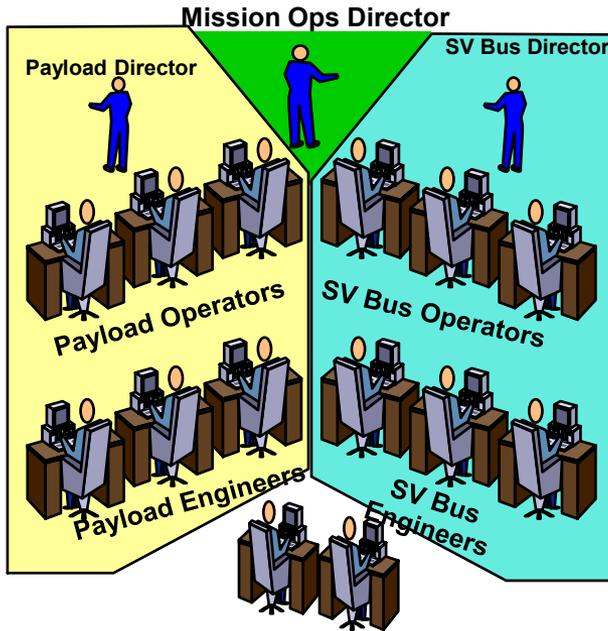
- Normal Operations
- Prelaunch
- Launch and Early Orbit
- Handover
- Contingency
- Test /Exercise /Rehearsal
- Maintenance
- Transition
- Ground Systems must have the capacity and capability to simultaneously support several of these operational modes
- Examples of mode unique requirements
 - *Factory Connectivity*
 - *Launch Complex Connectivity*
 - *Support for unusually large crews*
 - *Parallel operations*
 - *Non-Interference*
 - *Scenario Generation*
 - *Transportable ground station*



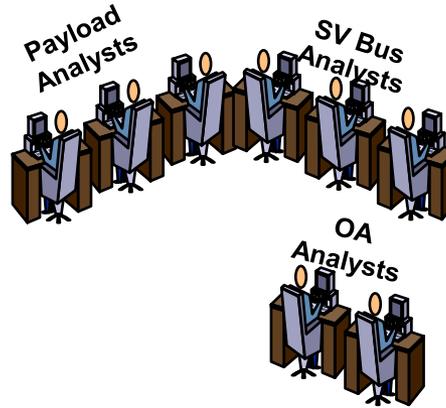
Mode Unique Requirements (1 of 4)



Real-Time Operations



Off-line Analysis



Normal Operations Mode

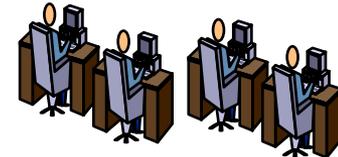
Activities Supported

- operational planning
- nominal operations

Special needs/considerations

- baseline functional architecture

Factory Support



Payload Engineers SV Bus Engineers
 Payload Analysts SV Bus Analysts



Mode Unique Requirements (2 of 4)



Prelaunch Mode

Activities Supported

- *Integration and Test support*
- *Compatibility testing*
- *End-to-end testing*
- *Early Orbit Test planning*
- *Operational procedure development and checkout*
- *Rehearsals*



Courtesy U.S. Air Force

Special needs/considerations

- *Telemetry and command connectivity to SV factory and launch complex*
- *Simulators*
- *Resources to support development and launch preparations*

Launch and Early Orbit Mode

Activities Supported

- *Launch and Early Orbit Test crew status monitoring and analysis*
- *Anomaly detection and response*
- *Early Orbit Test planning and execution*

Special needs/considerations

- *Additional crew connectivity and analysis capabilities*
- *Factory connectivity*
- *Augmented space to ground links*

Mode Unique Requirements (3 of 4)

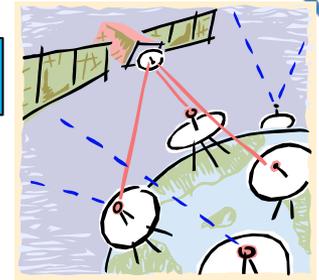


Handover Mode

- **Activities Supported**
 - *transfer of command and control (SCA) for space asset*
- **Special needs/considerations**
 - *synchronization of systems*
 - *communications connectivity*

Contingency Mode

- **Activities Supported**
 - *troubleshooting*
 - *anomaly response*
 - *SV recovery*
 - *GS reconfiguration*
- **Special needs/considerations**
 - *backups (commanding, telemetry processing, functional nodes)*
 - *augmented space to ground connectivity*
 - *simulations*
 - *analysis capabilities*
 - *logging*



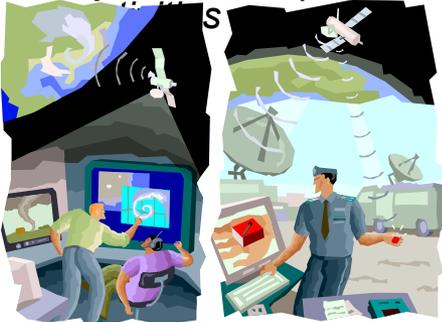
Anomaly Resolution Team

Mode Unique Requirements (4 of 4)



Test/Exercise/ Rehearsal Mode

- **Activities Supported**
 - non operational execution of system functionality and interfaces (partial to full system)
 - identification of system products as non-operational
 - external identification of system non-operational



- drivers, simulators

Maintenance Mode

- **Activities Supported**
 - checkout of upgrades/fixes in an operational-like environment
 - Troubleshooting
- **Common needs/considerations**
 - access to space asset data
 - access to system external interfaces
 - non interference to system operations
- **Mode –unique needs/considerations**
 - installation of HW & SW upgrades/fixes

Transition Mode

- **Activities Supported**
 - migration to new GS instantiation (facilities, HW, SW, architecture)
- **Mode –unique needs/considerations**
 - parallel operations

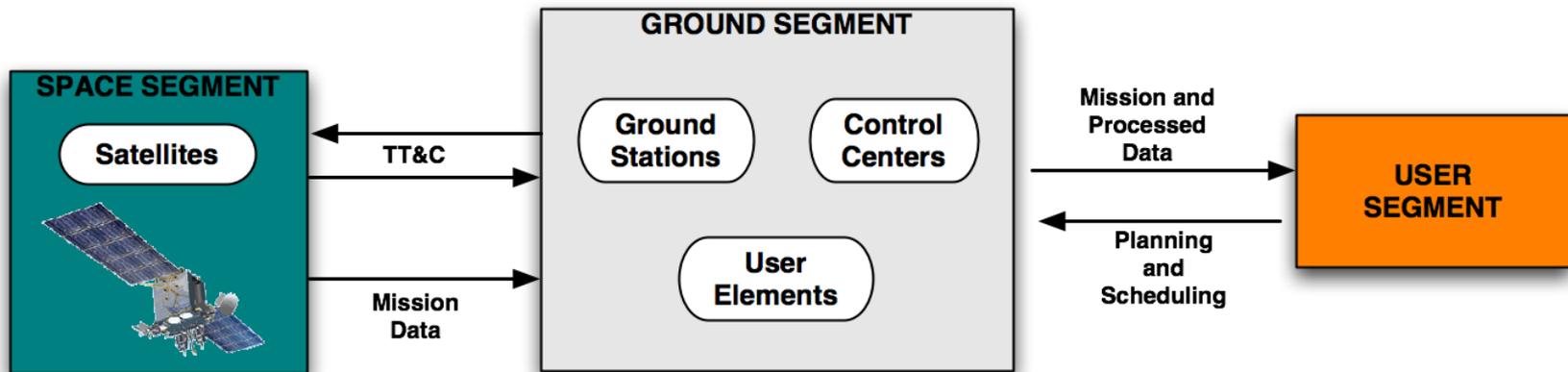


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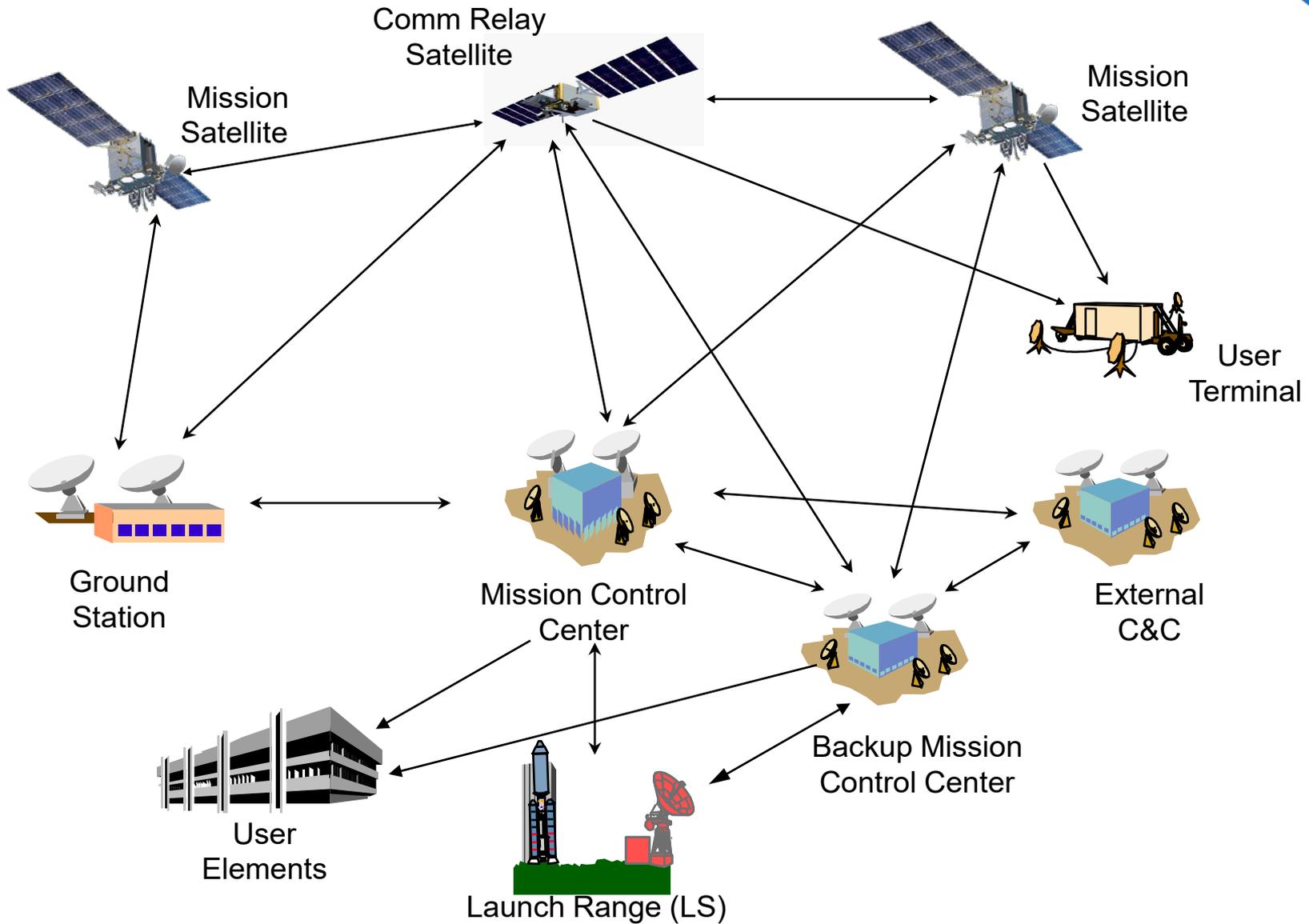


Ground Segment Interfaces

- Hierarchical description does not show relationship between segments
- Relationship to other System Segments and Elements



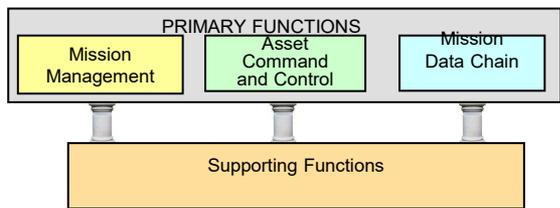
Generic Space System (Old Paradigm)



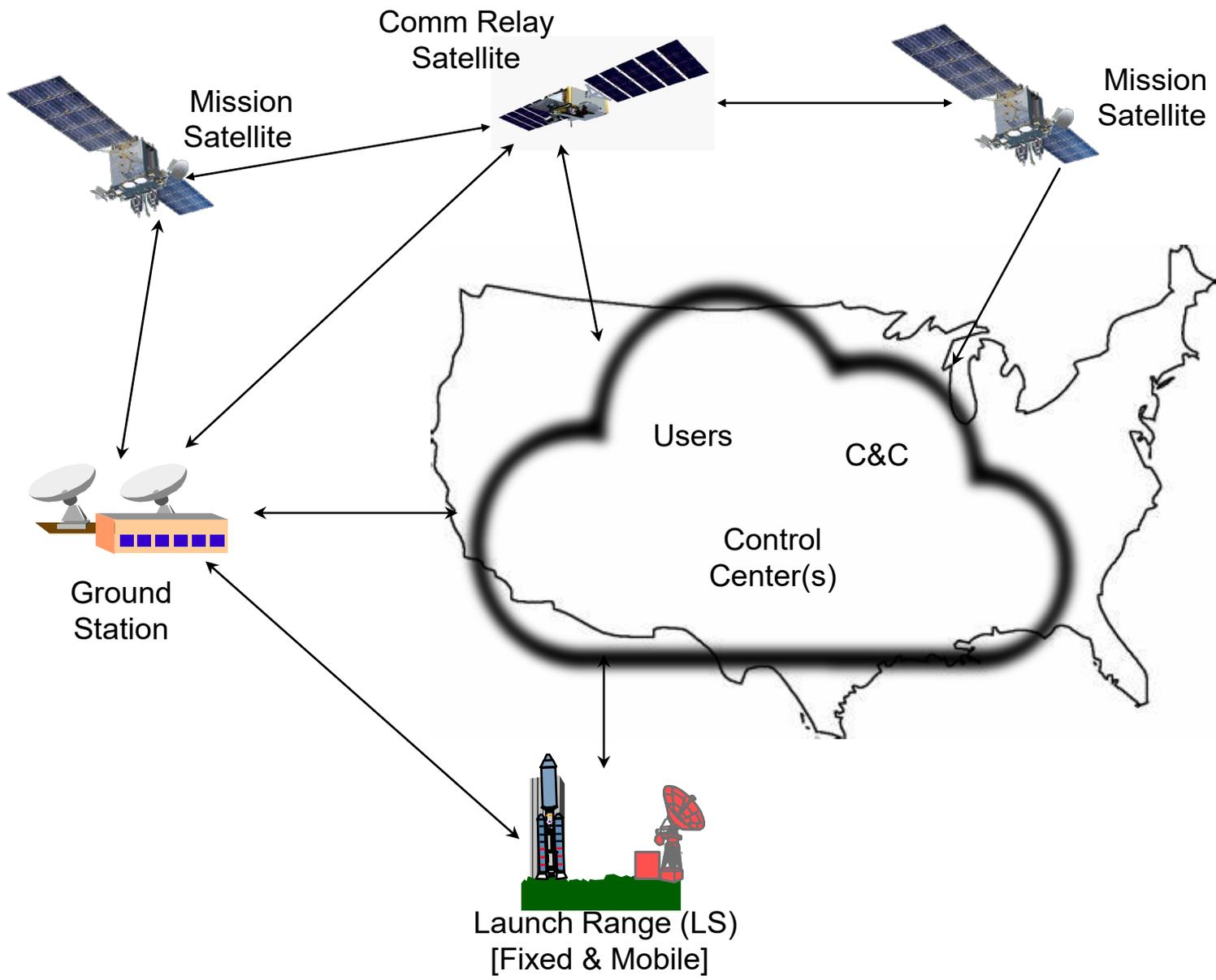


Allocation of Functions to Elements

	Mission Management	Asset Command & Control	Mission Data Chain	Support
Ground Stations				
Control Centers				
User Elements				

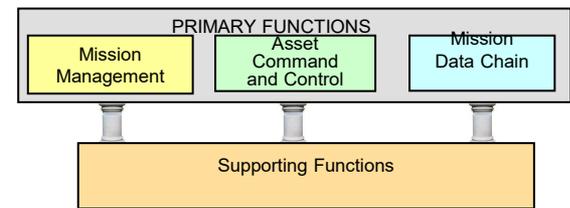
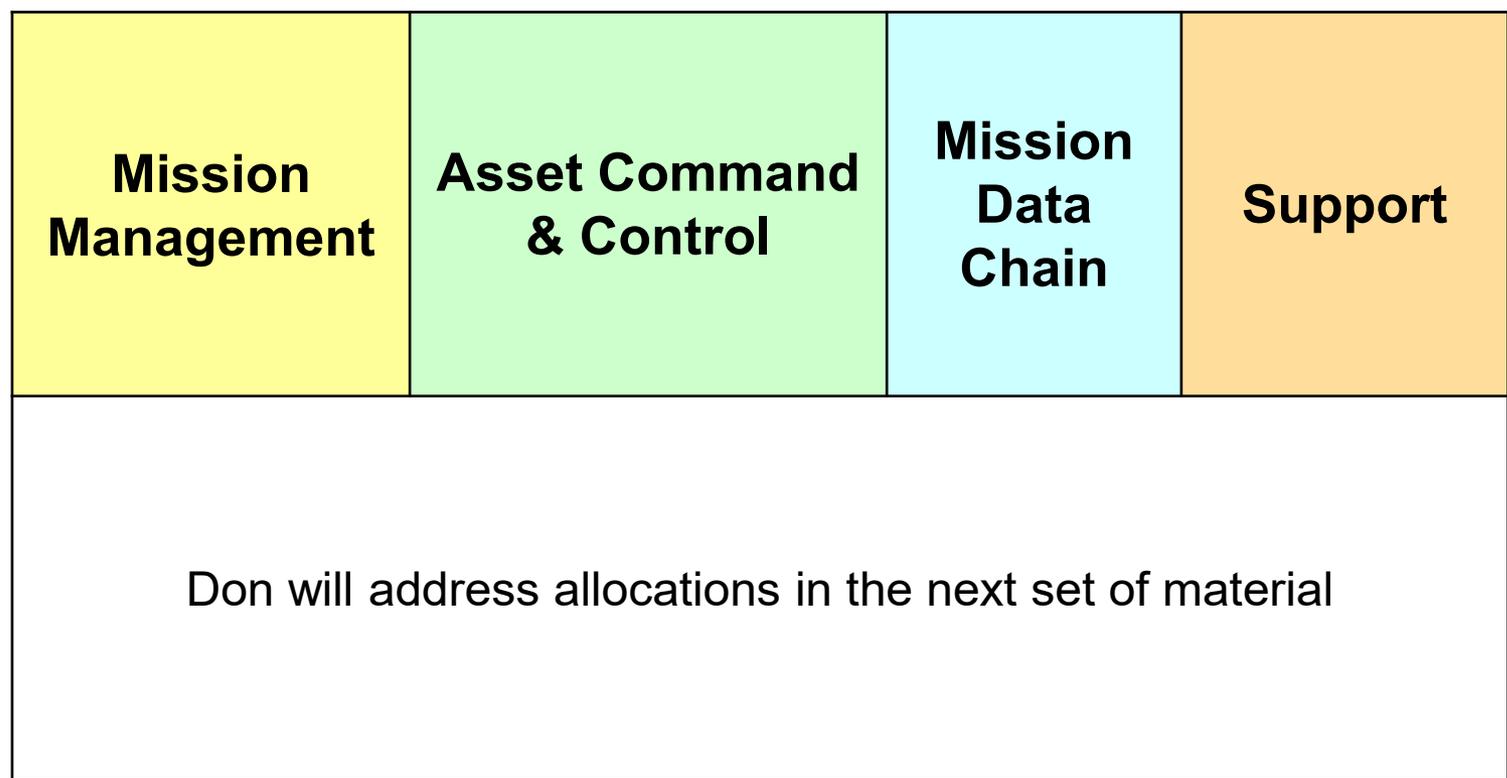


Generic Space System (New Paradigm)





Allocation of Functions to ?





- Scope
 - *Definitions*
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Fundamental Differences Between Ground Segments and Launch & Space Segments

- Major failures occurring after launch in launch & space segments
 - *In general, cannot be corrected*
 - *Represent major financial losses to taxpayers or commercial venture*
 - *Represent major capability losses which may take years to replace*
 - *Receive extensive negative media coverage*
- Major ground system failures
 - *Can be corrected*
 - *Seldom (never?) contribute to total mission loss*
 - *Seldom receive media coverage*
 - *Most (all?) systems are delivered and made operational with known (but non-critical) failure modes*
- So launch and space systems hardware and software are built and tested to criteria and oversight which is much more robust than is used for ground systems

Old Paradigm Functional Needs

- Site(s)
 - *Identification*
 - *Acquisition*
- Facilities (fixed, non-fixed)
 - *Design*
 - *Construction*
 - *Turnover*
 - *Maintenance*
 - *Enhancements*
- System(s)
 - *Operational*
 - Design
 - Development
 - Testing
 - Deployment
 - Turnover
 - Maintenance
 - Enhancements
 - *Training*
 - *Sustainment*
- Operations & System Maintenance Staff
 - *Number needed*
 - *Skill Set*
 - *Selection*
 - *Training*
 - *Relocation*
 - *Replacement*
- External Interfaces
 - *Identification*
 - *Definition*
 - *Stability*
 - *Availability*
 - *Changes*
- Depot
 - *Scope*
 - *Location*
 - *Facility*
 - *Staff*
- Site Activation (fixed)
 - System installation
 - Furnishings
 - Furniture
 - Floor coverings
 - Office machines
 - Utility hookup & activation
 - Initial expendables
 - Expendables resupply
 - Waste disposal
 - System maintenance
 - Building maintenance
 - Grounds maintenance
 - Security Staffing
 - Documented procedures

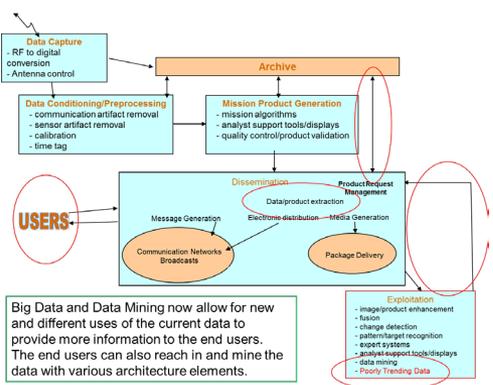
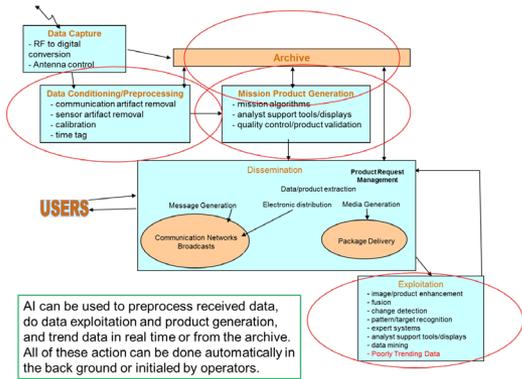
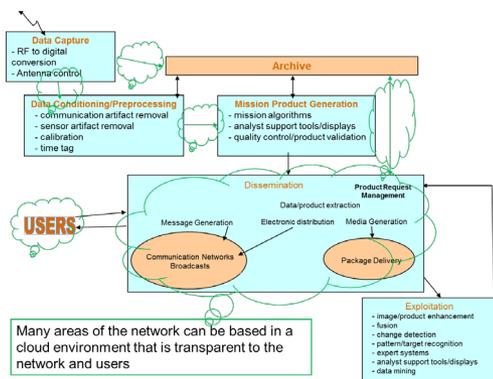
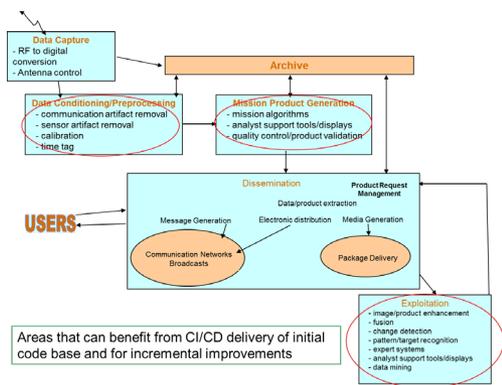
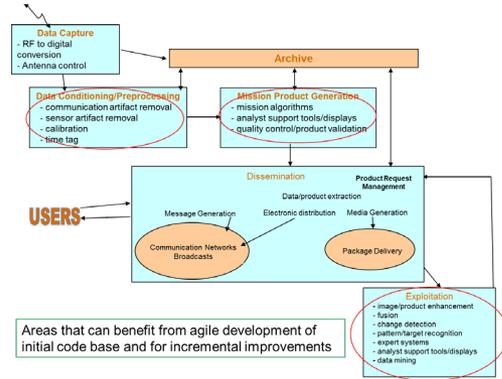
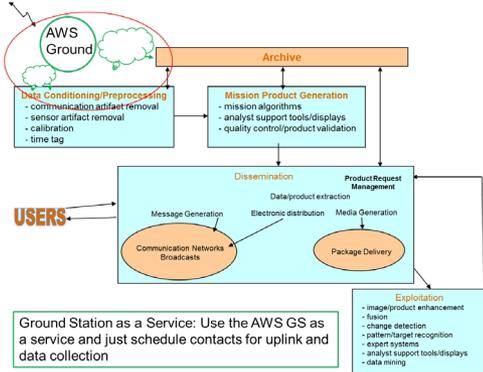
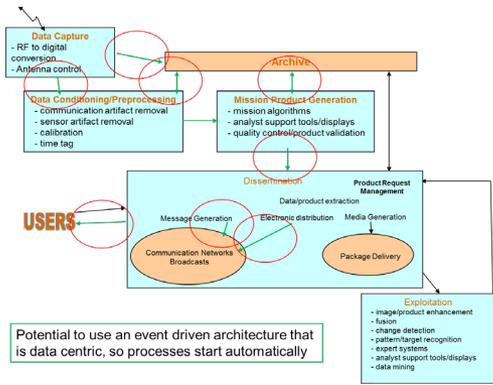
Training facility
Operational backup
Upgrade development & test
Sustainment management
Replacement parts testing
Software troubleshooting & repair



New Paradigm Functional Needs

- Functional needs may be accomplished by services
- Transparent services are separately deployed and maintained

So what do you require?



The network and technological elements discussed can be tailored to provide a variety of different and functional Ground Stations depending on your mission needs.



Summary

- Provided a system engineering view of ground systems, segments, and subsystems
- Examined the environment within which ground systems operate
- Identified necessary ground system functions
- Showed current ground functions not tied to physical entities



Ground Station in Australia*



Delta IV Launch**

**.... but the ground must be usable
before the satellite can launch!**

*Picture courtesy of U.S. Air Force

**Picture courtesy of Wikimedia Commons