Common Subsystems Design Requirements for Performance and Reliability in an FPGA

Intel PSG
Military / Aerospace / Government Business Unit
Strategic & Technical Marketing
Ching Hu

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Agenda

- [10min] Space System Design Trends
- [10min] System Architectures & Common Sub-Systems
- [10min] DSP Centric Sub-Systems
- [10min] Network Traffic Centric Sub-Systems
- [10min] AI and Data Analytics
- [10min] Q&A

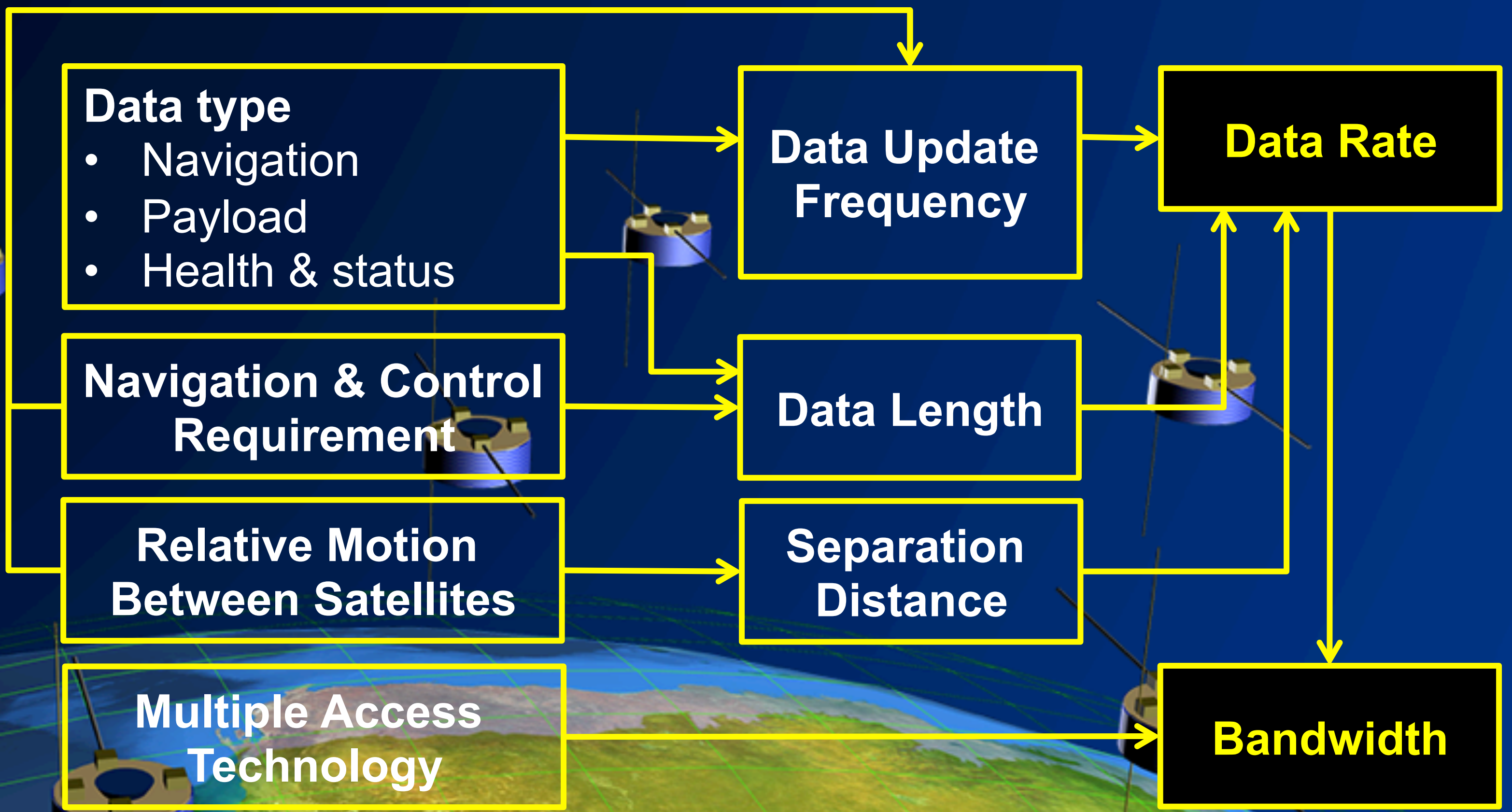
Commercialization of space

- Catalyst
  - Commercially available deep submicron IC shown to have “good enough” radiation resilience
  - Space electronics is no longer under ITAR restriction

- Market drivers
  - Scientific research
  - Government systems
  - Commercial remote sensing
  - Commercial in-flight internet access
  - Commercial global internet infrastructure
  - Commercial air traffic control and navigation
  - High altitude platforms (HAP) > 65k Ft (or 19.8km)
  - Hobbyist / amateur remote sensing and experiments
  - Etc.

Operational Challenges

- Inter-satellite link (ISL)
- Maintain cluster formation
- System fault recovery



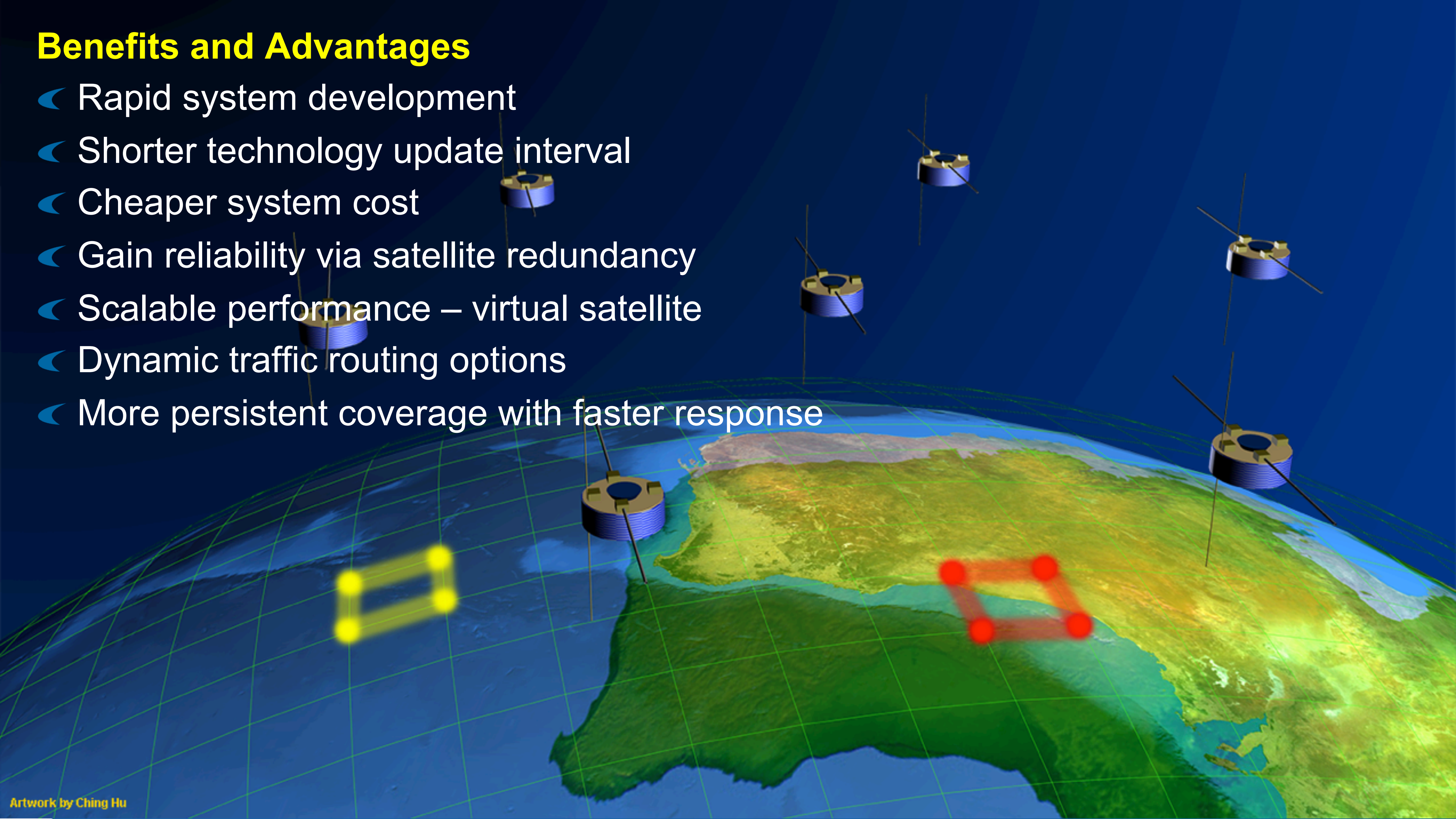
Performance Challenges

- Up/Down link bandwidth
- Multi-hop relay latency
- On-board processing
- Dense traffic management

Artwork by Ching Hu

Benefits and Advantages

- Rapid system development
- Shorter technology update interval
- Cheaper system cost
- Gain reliability via satellite redundancy
- Scalable performance – virtual satellite
- Dynamic traffic routing options
- More persistent coverage with faster response



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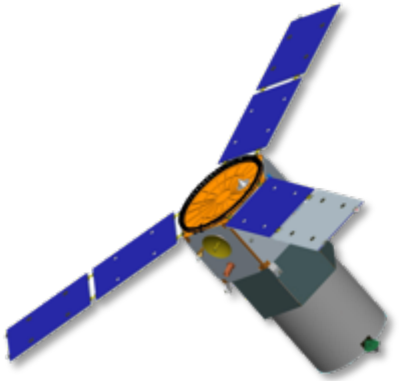
Common Subsystems



Bus / Airframe

- System health monitor
- Navigation
- Telemetry
- Command & Control
- Wideband data link
- Sensors / Apertures
- Mission computer
- Flight control / maneuver
- Payload Interface/Control

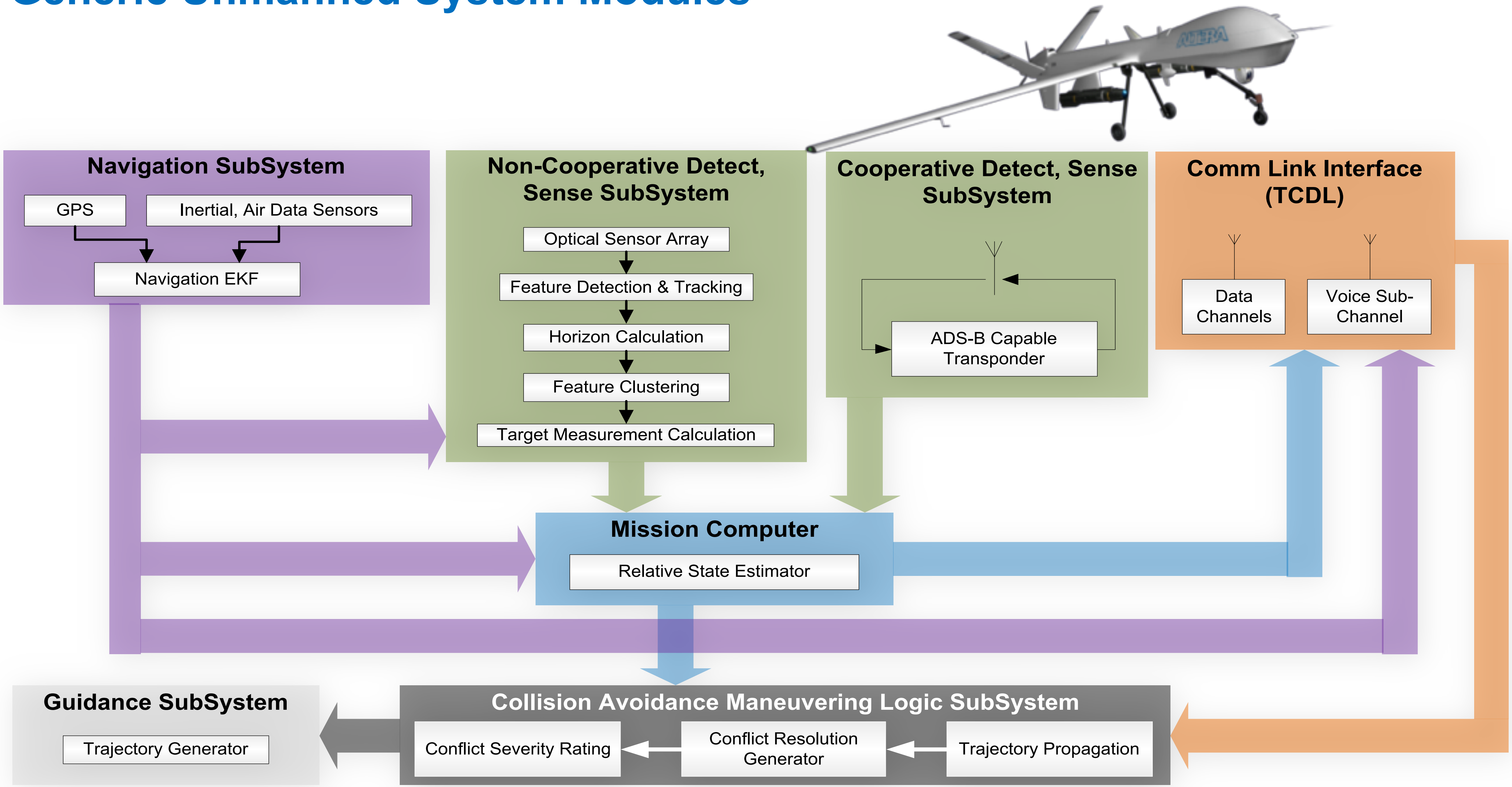
Data Bus

- High speed serial
- Wideband
- Robust

Payload

- Image / Video processor
- Signal processor
- High speed data switch
- Network Traffic Management
- Data analytics
- Data storage
- Data processor (Encrypt / Decrypt / CODEC, etc.)

Generic Unmanned System Modules



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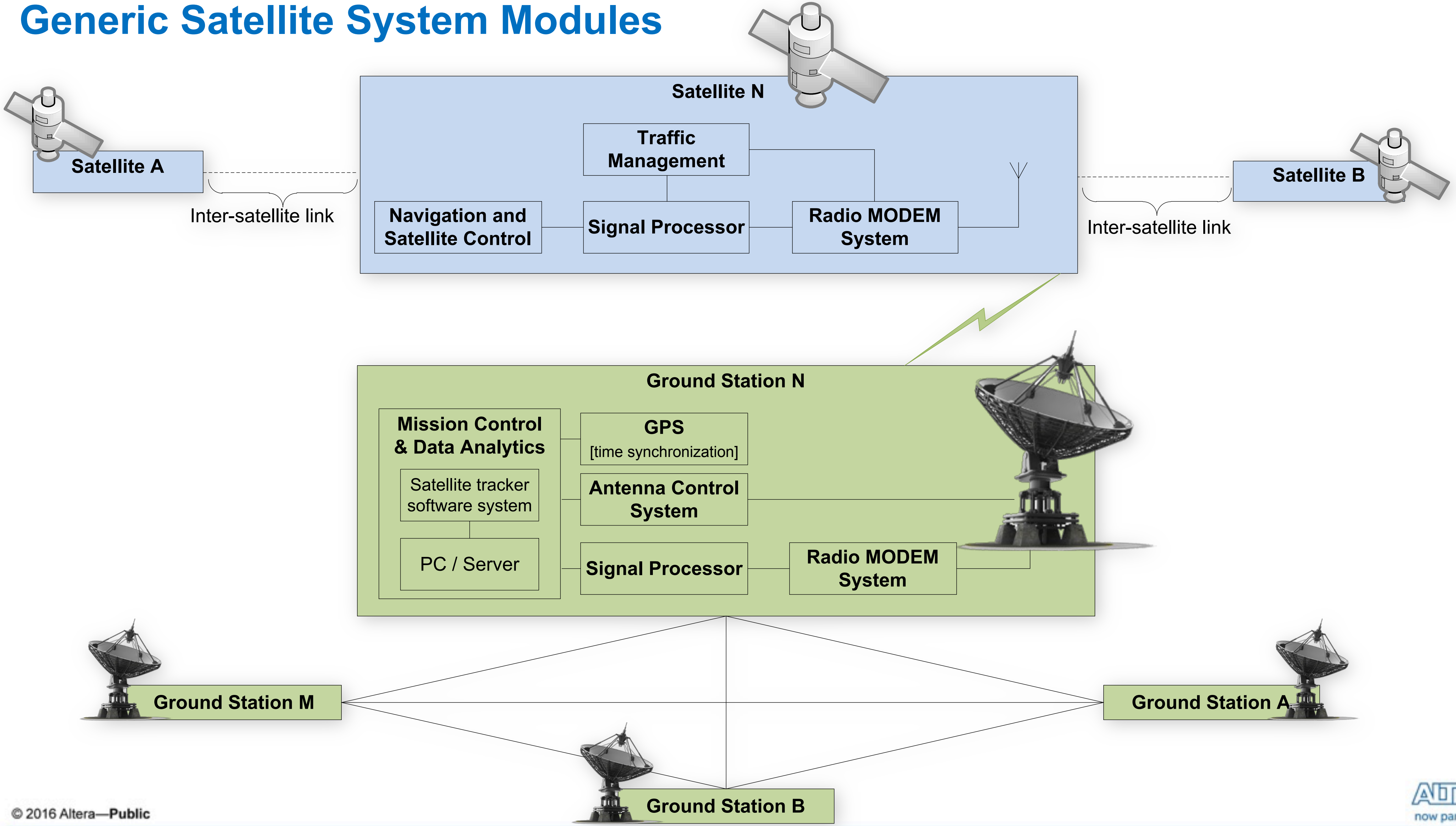
Generic Satellite System Modules



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DSP Centric Subsystem

- Primary DSP applications on satellites
  - Image processing
  - Data compression
  - Modem and waveform processing
  - RF signal and data processing

- DSP requirements in space context
  - Power efficient → get the most GFLOPS per Watt
  - High dynamic range and precision → variable precision floating point capable
  - Small footprint → integrated memories, DSP blocks, and logics in small packages
  - Multi-waveform capable → software defined radio architectures or equivalent

Example: Synthetic Aperture Radar Back Projection Image Formation Algorithm

- Superior Quality
- Unconstrained Path
- Multi-Resolution
- Topographic Overlay
- **Power Efficient**

Rolling back reflectivity samples

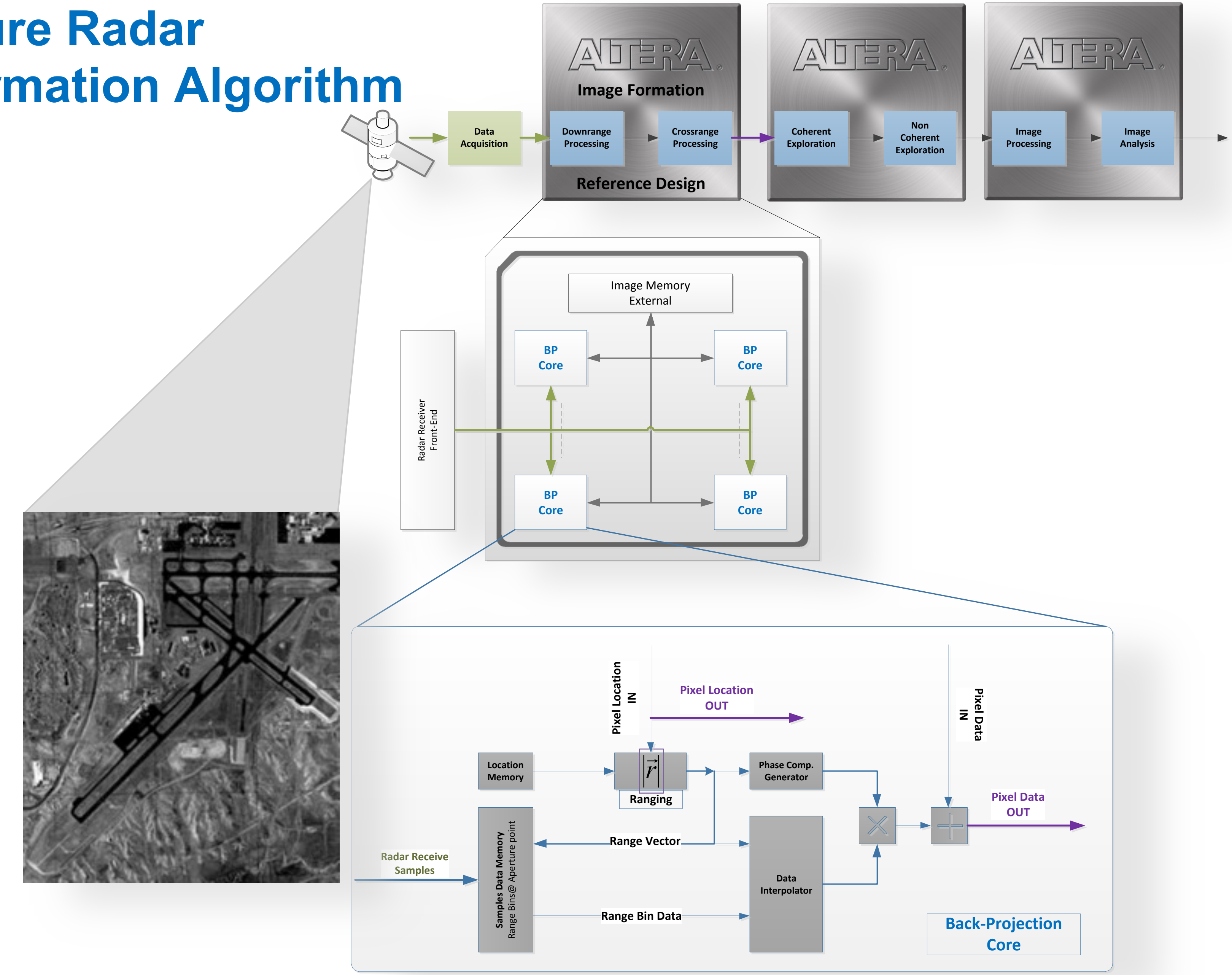
$$f(x,y)=\sum_{k} f_{x,y}(r_k,\theta_k)\cdot e^{j\omega\cdot 2\cdot|\vec{r}_k|}$$

Range Calculation

Phase Rolling Factor

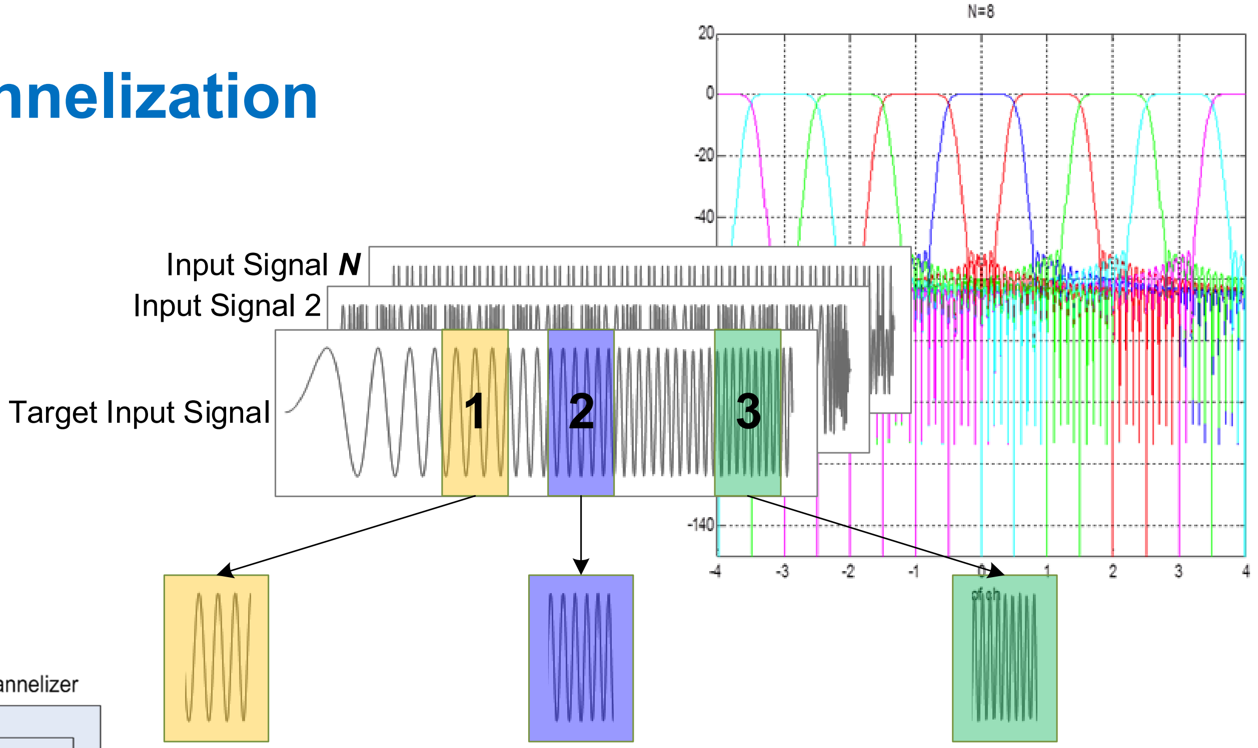
Interpolation of Reflected Samples

Accumulation



Example: Ultra-wideband Signal Channelization

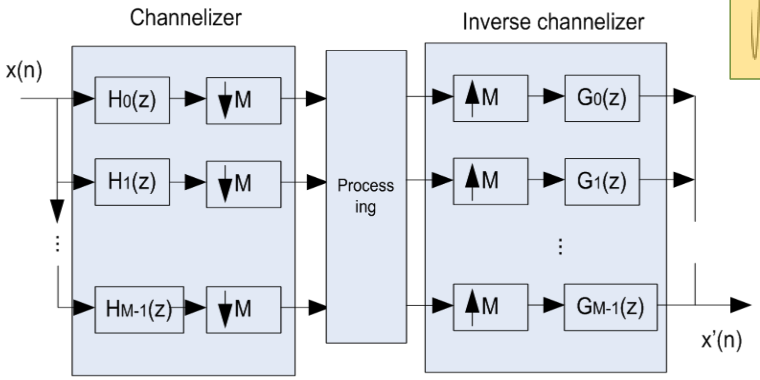
- Hyper spectral remote sensing
- Signal intelligence
- MIMO radar system infrastructure
- Commercial wireless infrastructure

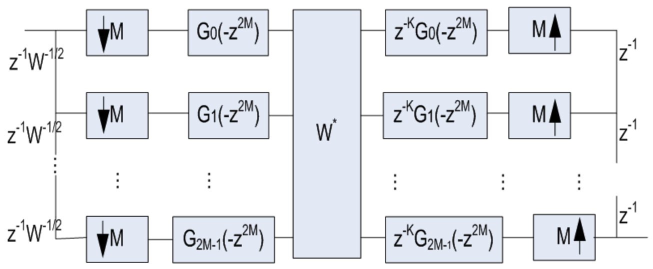


$$\hat{X}(z) = \boldsymbol{U}(z)^T \boldsymbol{G}(z)$$

$$\boldsymbol{U}(z) = \begin{bmatrix} V_0(z^M) \\ V_1(z^M) \\ \vdots \\ V_{M-1}(z^M) \end{bmatrix} = \frac{1}{M} \begin{bmatrix} \sum_{l=0}^{M-1} H_0(zW^l)X(zW^l) \\ \sum_{l=0}^{M-1} H_1(zW^l)X(zW^l) \\ \vdots \\ \sum_{l=0}^{M-1} H_{M-1}(zW^l)X(zW^l) \end{bmatrix}$$

$$\boldsymbol{V}(z) = \begin{bmatrix} V_0(z) \\ V_1(z) \\ \vdots \\ V_{M-1}(z) \end{bmatrix} = \frac{1}{M} \begin{bmatrix} \sum_{l=0}^{M-1} H_0(z^{1/M}W^l)X(z^{1/M}W^l) \\ \sum_{l=0}^{M-1} H_1(z^{\frac{1}{M}}W^l)X(z^{\frac{1}{M}}W^l) \\ \vdots \\ \sum_{l=0}^{M-1} H_{M-1}(z^{\frac{1}{M}}W^l)X(z^{\frac{1}{M}}W^l) \end{bmatrix}$$





$$\underbrace{\frac{1}{M}\sum_{k=0}^{M-1} X(z)H_k(z)G_k(z)}_{\text{Desired Term}} + \underbrace{\frac{1}{M}\sum_{l=1}^{M-1} X(zW^l)\sum_{k=1}^{M-1} H_k(zW^l)G_k(z)}_{\text{Alias term due to folding}}$$

$$h_k(n) = 2p_0(n)\cos\left(\frac{\pi}{M}(k+0.5)\left(n-\frac{N}{2}\right)+\theta_k\right)$$

$$g_k(n) = 2p_0(n)\cos\left(\frac{\pi}{M}(k+0.5)\left(n-\frac{N}{2}\right)-\theta_k\right)$$

$$\theta_k = (-1)^k \pi/4$$

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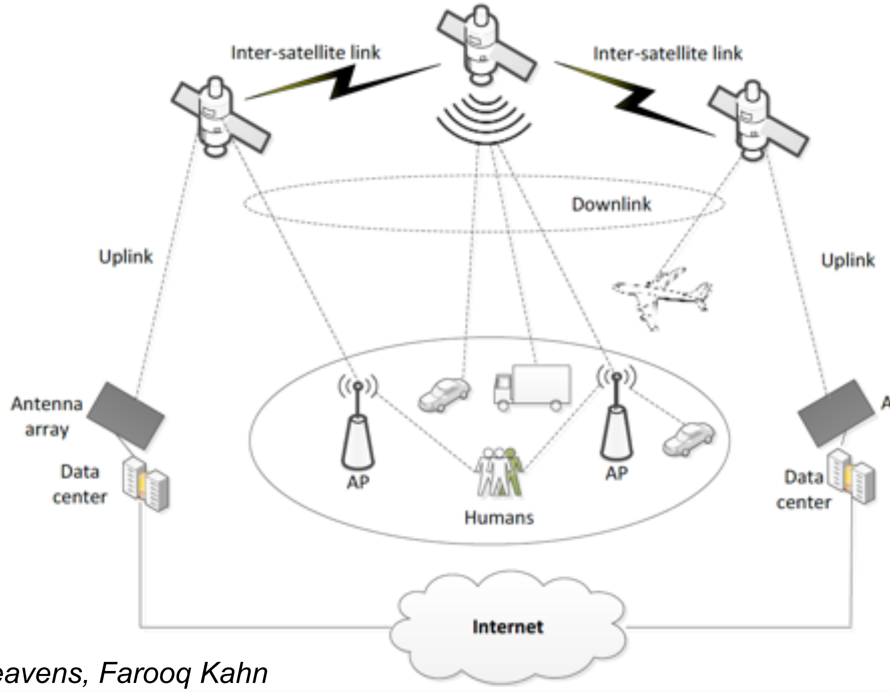
High speed network traffic system

- "Omnify" – Order of Magnitude increase every Five Years
- In 2028, Zetabyte/month (10e21)
- 4600 satellite required
- 3200 links at 1Tb/s

Parameter	Value	Comments
Transmit Power	33 dBm	Multiple PAs
Transmit Antenna Gain	53 dBi	Element + array gain
Carrier Frequency	100 GHz	Ref. for calculations
Distance	1500 Km	LEO orbit
Propagation Loss	195.92 dB	
Other path losses	0	Always LOS
Tx front end loss	3.00	Non-ideal RF
Receive Antenna Gain	53.00	Element + array gain
Received Power	-59.92	
Bandwidth (BW)	1 GHz	BW / comm-core
Thermal Noise PSD	-174 dBm/Hz	
Receiver Noise Figure	5.00 dB	
Thermal Noise	-79 dBm	
SNR	19.08 dB	
Implementation loss	5 dB	Non-ideal Transceiver/ BB
Spectram Efficiency (SE)	4.73 b/s/Hz	
Data rate / comm-core	**4.73 Gb/s**	SE × BW
Number of comm-cores	256	BW and MIMO cores
Aggregate data rate	**1.21 Terabit/s**	256×5.86 Gb/s

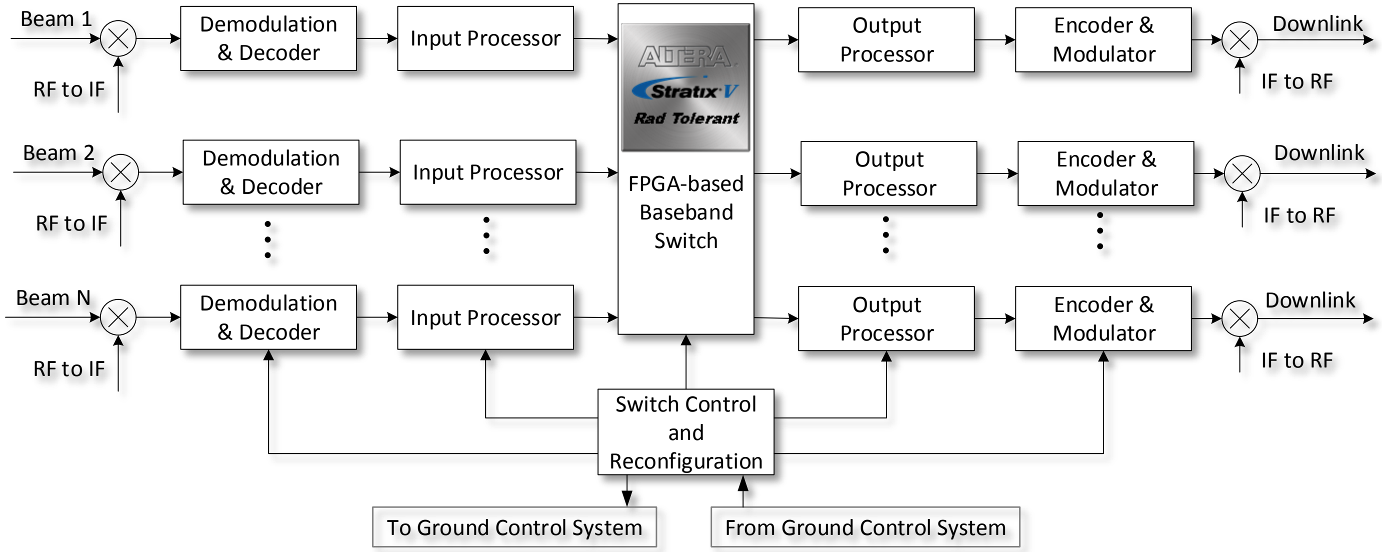
Uplink		Downlink		Inter-Satellite	
Frequency [GHz]	BW [GHz]	Frequency [GHz]	BW [GHz]	Frequency [GHz]	BW [GHz]
12.5-13.25	0.75	10.7-11.7	1.0	22.55-23.55	1.0
13.75-14.8	1.0	17.7-21.2	3.5	25.25-27.5	2.25
27.5-31.0	3.5	37.0-42.5	5.5	59.0-66.0	7.0
42.5-47.0	4.5	66.0-76.0	10.0	66.0-71.0	5.0
48.2-50.2	2.0	123.0-130.0	7.0	116.0-123.0	7.0
50.4-51.4	1.0	158.5-164.0	5.5	130.0-134.0	4.0
81.0-86.0	5.0	167.0-174.5	7.5	174.5-182.0	7.5
209.0-226.0	17.0	191.8-200.0	8.2	185.0-190.0	5.0
252.0-275.0	23.0	232.0-240.0	8.0		
Total	**57.75**	Total	**56.2**	Total	**38.75**

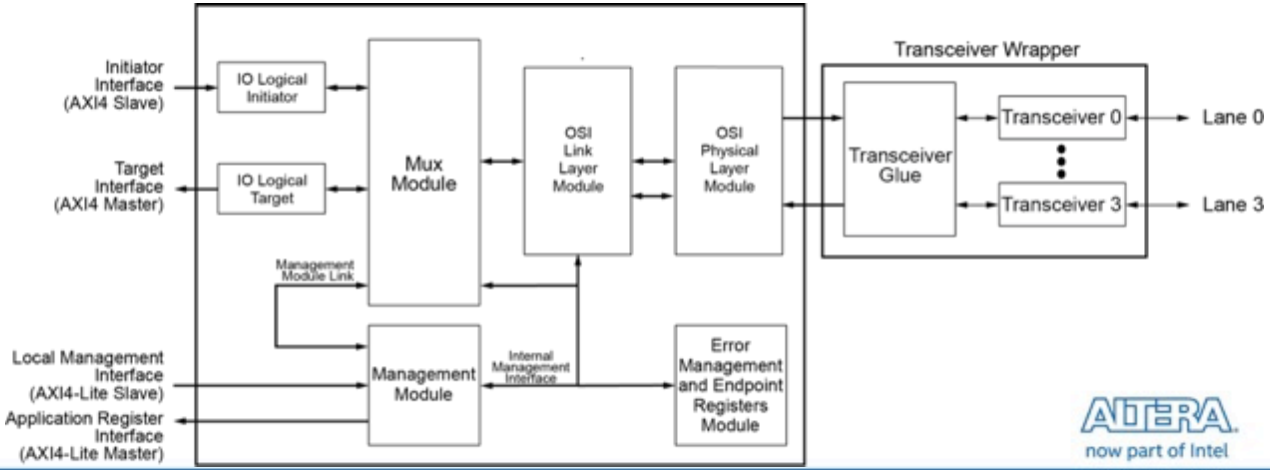


Source: Mobile Internet from the Heavens, Farooq Kahn

Example: high speed network switch

- Next Generation Space Interconnect Standard (NGSIS)
  - SpaceVPX (VITA78)
  - RapidIO 3.1 Part S
- RapidIO switch and endpoint
  - Test vectors
  - Data generators and results comparators
  - Integration and validation services
- Supports
  - Streaming data
  - Ethernet/IP packet networking
  - Shared memory semantics
  - Using OpenCL programming model
- Performance
  - Starting at 170GFLOPS and scale to TFLOPS





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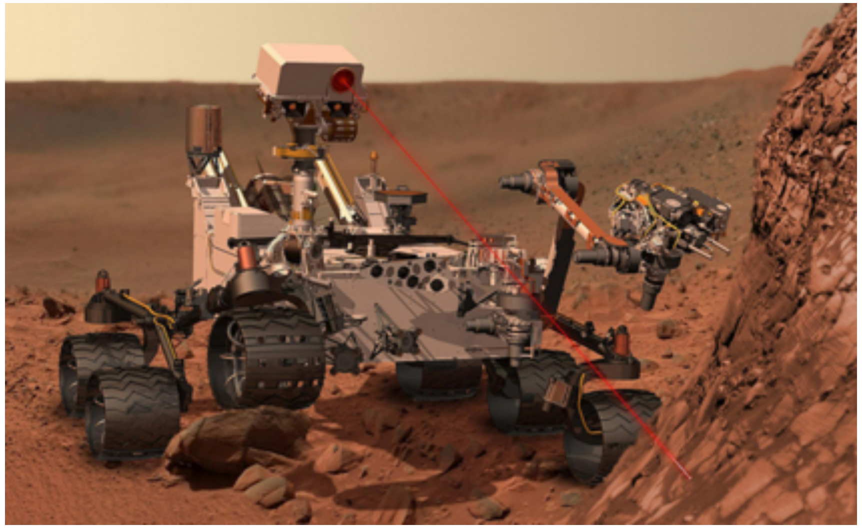
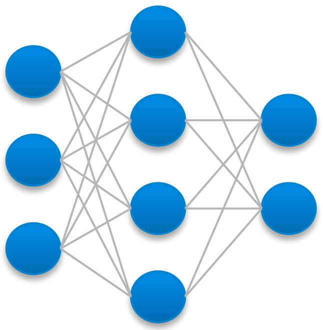
Artificial Intelligence (AI) in satellite application

- Current and future usages
  - Synchronization of constellation formation or clusters
  - Coordinating with new constellation members or replacements
  - Real time inter-satellite link stabilization
  - Up/Down link coverage optimization
  - On-board data analytics
  - Optimize network traffic management
  - Network/traffic security monitoring/enforcement
  - Etc.



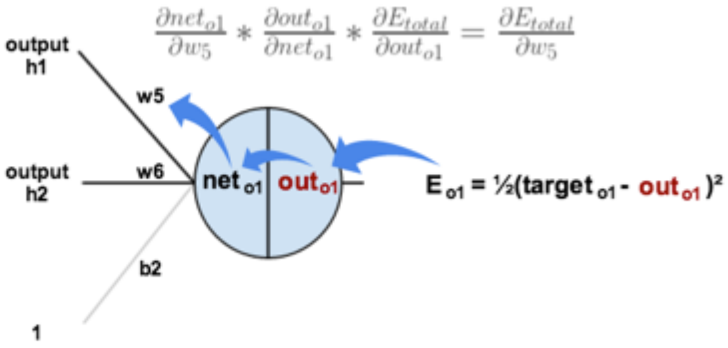
- Companies investing in AI
  - Google
  - Facebook
  - Intel
  - Apple
  - Amazon
  - Toyota
  - Etc.

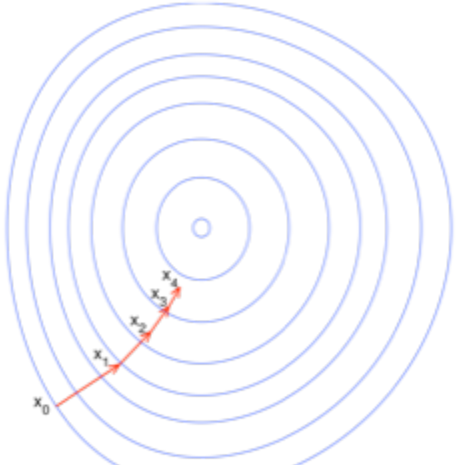
Toward AI in satellite systems: Convolutional Neural Network

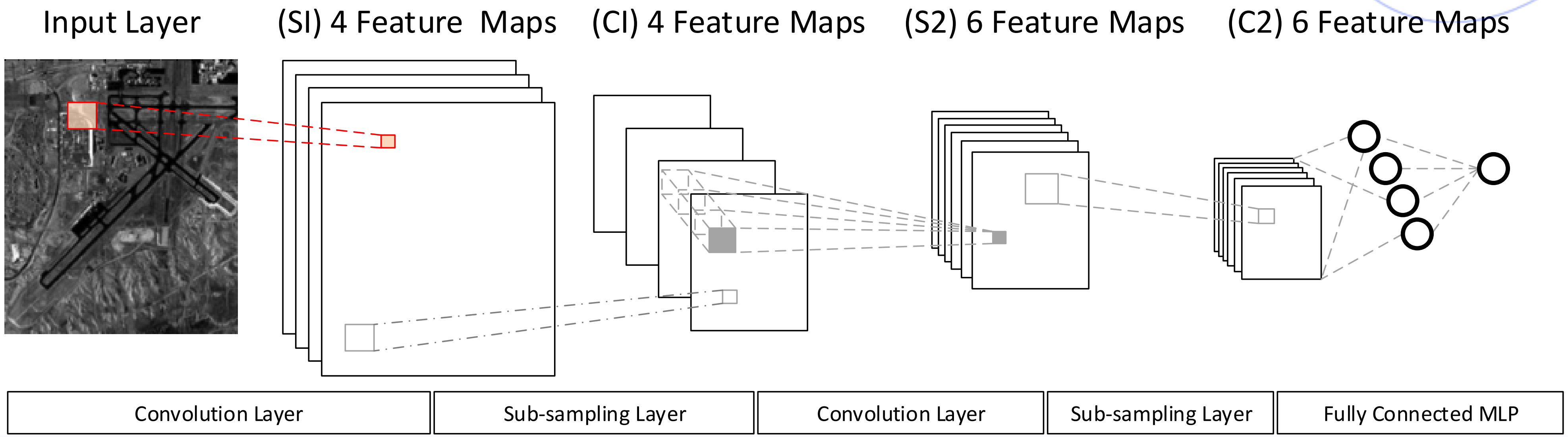


- CNN Layer types
  - Input
  - Convolution (filters/weights)
  - Pooling (sub-sampling)
  - ReLU (max(0,x))
  - Fully connected / Output

- Training
  - Gradient decent
  - Back propagation







Roadmap – more details available under NDA, please contact us directly

- Silicon
- Tools
- Soft/hard IP
- System reference designs
- Radiation test systems
- Qualification report

Conclusion

- Cost is becoming top priority
- Cluster of small sat replacing single large satellite
- Compressed technology refresh cycles
- High performance and cost effective reliability
- System level expertise and support from component level can ***greatly*** increase end system performance and capabilities!

Q&A: For Radiation Test Results and Business Discussions

Please contact any one of us to schedule private meeting




Luc Marquet	Karen Horovitz	Christian Stenzel	Ching Hu	Adrian Fitzgerald
lmarquet@altera.com	khorovit@altera.com	cstenzel@altera.com	ching.hu@altera.com	afitzger@altera.com

Thank You

For questions, please contact mil@altera.com

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