

Space System Architecture

Lecture 1: Space Systems and Definitions

Framing Document by Annalisa Weigel

Required reading:

- a) Framing document (01010 week_1 framing.pdf)
- b) ESD Architecture document (01020_ESD_Sys_Arch.pdf)
- c) Rehtin & Maier – Chaps 1 & 2 (01030Rehtin_and_Maier_Ch_1_2.pdf)
- d) Dave Clark on Internet Architecture (01031 NatureOfArch-1.pdf)
- e) Maier on System of Systems: Mark W. Maier, “Architecting principles for systems-of-systems,” *Systems Engineering*, Vol. 1, No. 4, pp 267-284, 1998.
(<http://www3.interscience.wiley.com/cgi-bin/abstract/40003635/ABSTRACT>)
- f) Sage & Lynch on System Views: Andrew. P. Sage and Charles L. Lynch, “Systems integration and architecting: An overview of principles, practices, and perspectives,” *Systems Engineering*, Vol. 1, No. 3, pp 176-227, 1998.
(<http://www3.interscience.wiley.com/cgi-bin/abstract/30002173/ABSTRACT>).
- g) Iridium Trades: Garrison, T. P., M. Ince, J. Pizzicaroli, and P. A. Swan, “System Engineering Trades for the IRIDIUM Constellation,” *Journal of Spacecraft and Rockets*, Vol. 34, No. 5, pp. 675-680, 1997.
http://www.aiaa.org/journals/index.cfm?addI=1&PubVolIssue=00224650_v34n5
- h) NASA new design paradigm; Golden, Daniel S., Samuel, L. Venneri, and Ahmed K. Noor, “New frontiers in design synthesis,” *Acta Astronautica*, Volume 44, Issues 7-12, pp. 407-418, April-June 1999,
<http://www.sciencedirect.com/science/journal/00945765>

Recommended reading:

- i) History of US MILSATCOM: Donald H. Martin, “A History of U.S. Military Satellite Communication Systems,” *Crosslink*, Vol. 3, No. 1, Winter 2001/2002.
<http://www.aero.org/publications/crosslink/winter2002/01.html>; see also
<http://www.losangeles.af.mil/SMC/MC/milsatcom.html>
- j) GPS site: <http://gps.losangeles.af.mil/>
- k) GPS primer: <http://www.aero.org/publications/GPSPRIMER/index.html>

This framing document is divided into three parts. The first will present different definitions of the word “architecture,” and discuss the notion of different views one can take on an architecture. The second part overviews the three different space communities: commercial, civil and military. The third part contains descriptions of space architectures, and concludes by reviewing different classes of space missions and their typical architectures.

Part 1

Definition of Architecture

There are many different definitions of the word *architecture*, and which definition is most appropriate in any situation is largely context-specific. To start, Webster's Dictionary states architecture is a "formation or construction as or as if as the result of conscious act," or "a unifying or coherent form or structure."¹ From a product development perspective, Ulrich and Eppinger offer that an architecture is an "arrangement of the functional elements into physical blocks."² From a mechanical systems design perspective, Frey suggests architecture is the "structure, arrangements or configuration of system elements and their internal relationships necessary to satisfy constraints and requirements."³ Looking across different types of products and systems, Crawley thinks architecture is the "embodiment of concept, and the allocation of physical/informational function to elements of form, and definition of interfaces among the elements and with the surrounding context."⁴ Further applying the word architecture at an Engineering Systems level, the ESD Architecture Committee defines system architecture as "an abstract description of the entities of a system and the relationships between those entities."⁵

These different definitions all share several things in common, including the sense of an architecture being composed of parts that work together or interact together in some fashion. The specifics of what those parts are, and how precisely they are connected, can be unique to each domain of application of the term *architecture*.

Different Views of an Architecture

Every system can be thought of as having an architecture, but there are many different views or representations of that architecture that can be conceived. Levis (1999) suggests that there are four main views of an architecture:

- "The *functional* architecture (a partially ordered list of activities or functions that are needed to accomplish the system's requirements)
- The *physical* architecture (at minimum a node-arc representation of physical resources and their interconnections)
- The *technical* architecture (an elaboration of the physical architecture that comprises a minimal set of rules governing the arrangement, interconnections, and interdependence of the elements, such that the system will achieve the requirements)

¹ Miriam-Webster Online Dictionary,

² Ulrich, Karl T., and Steven D. Eppinger. 2000. *Product Design and Development*, 2nd ed. New York: Irwin/McGraw-Hill.

³ Need Dan's paper citation here

⁴ Crawley, Ed. 2003 ESD.34 Lecture Notes, Lecture 1, page 15.

⁵ Crawley, Ed et al. 2004. "The Influence of Architecture in Engineering Systems," in *Engineering Systems Monograph* of the Engineering Systems Symposium, March 29-31, MIT, Cambridge, MA.

- The dynamic *operational* architecture (a description of how the elements operate and interact over time while achieving the goals)⁶

In addition to these four views, which are very typical of a military perspective on architecture, one can imagine that an *informational* architecture showing what information content is passed between parts of the architecture could be a very useful view of an architecture. Similarly, especially with respect to large Engineering Systems, an *organizational* architecture describing the groups of people involved in an architecture, what system responsibilities they have, what inputs they need and what outputs they produce, can help understand stakeholder interactions and relationships in an architecture.

Part 2

Communities that Use Space Systems

Generally, world-wide use of space systems is broken down into three user communities: Commercial, Civil and Military. Each of these communities share common needs, interests, and uses of space systems and services.

Commercial

The commercial space community is composed of those for-profit companies that provide services in, from or enabled by space. Typically, the commercial companies are only interested in fielding services that will be profitable. The commercial space user community today is primarily interested in broadcast communications, point-to-point communications, position and navigation services, and imagery. DirecTV, XM Satellite Radio, and Digital Cinema are examples of broadcast communications, while Iridium phones and Connexion in-flight internet services are examples of point-to-point communications. Commercial GPS receivers are produced for applications ranging from recreational boating to precision farming, and many areas in between. While still a young and small business, commercial imagery companies such as Space Imaging and Digital Globe, provide visual spectrum pictures of locations nearly worldwide.

Civil

The civil space community is composed of non-military and non-intelligence government agencies that use space. In the U.S., the largest civil organizations engaged in space are NASA and NOAA. NASA is charged with exploring space, doing science missions focusing on the earth and our solar system, and developing technology for use in space. NOAA is responsible for weather monitoring and forecasting, which relies heavily on space-based assets. Also involved in the civil space community are the FAA (space-based navigation for airplanes and remote airports) and the USGS (space-based mapping and measurements).

⁶ Ibid.

Military

The military space community is composed of the armed forces and the intelligence agencies that use space as a medium from which to gather information or as an environment in which to execute operations. Intelligence users are interested in employing satellites to monitor activities in denied areas. Military users are interested in satellites to help with navigation, weather forecasting, and worldwide communication, in addition to intelligence gathering to support specific military engagements.

Part 3

Space Architectures

While there are different kinds of space architectures, they all have several components in common. Typically, a space architecture can be broken down into main three physical parts: the space segment, the launch segment, and ground segment. The satellites contain the payloads that will accomplish the primary mission, as well as a bus that provides the infrastructure for operating the payload. The launch vehicles transport the satellites to orbit. The ground segment consists of gateways where data is downlinked from satellites (the moniker of “ground segment” notwithstanding, sometimes these gateways can be located in space), as well as processing and distribution facilities to put the raw data in the appropriate form and location for users.

The space segment can be either a single satellite or a constellation of satellites in the same or multiple orbits. In turn, each satellite can be monolithic, with all its payload and bus equipment on the same physical structure, or distributed, with its payload and bus functions split among more than one physical structure. To date, most satellites have been monolithic in nature. Work on distributed satellites has been largely theoretical, with very limited technology demonstration.

The launch segment can be relatively simple for a single satellite architecture, or very intricate for a many-satellite architecture (like Iridium, or GPS). For space architectures with multiple satellites, the launch segment can receive significant attention, and plays an important role in mission risk reduction and constellation replenishment and maintenance strategies.

The ground segment often includes a choice of whether to use data downlink gateway systems in space (i.e. TDRSS) or on the earth (i.e. the Deep Space Network, or AFSCN). Also of consideration is where data processing will take place, and how mission data will be stored and distributed. For a space system taking high resolution imagery, assuming it takes 50 pictures of 500mb each, every day, for 10 years, that leaves a system architect with a whopping 91 terabytes of information to store. That’s nearly the equivalent of the entire contents of the U.S. Library of Congress, and not a trivial amount of data to accommodate.

Classes of Space Systems

Generally, we can classify space systems by the mission they perform. Each mission also generally has a characteristic architecture, which is described below in this final section.

Communication

Communication space systems provide broadcast (i.e. DirecTV) or point-to-point (i.e. Iridium) communication services to users around the globe, as well as data and voice relay between spacecraft in orbit and controllers on the ground (i.e. TDRSS). Broadcast missions typically have a set region on the earth to which they are broadcasting, and typically utilize geostationary orbits and a single satellite to cover a single region, or four satellites in GEO to provide worldwide broadcast coverage. Point-to-point missions are typically accomplished with either one or several GEO satellites (like the broadcast mission), or with a MEO or LEO constellation of 10 to dozens of satellites that provides adequate coverage for the system's geographical mission area. Communication missions that relay data between space and the earth typically use GEO satellites.

Positioning and Navigation

Positioning and navigation (POS/NAV) missions typically provide near global coverage and use triangulation as a strategy to provide the POS/NAV service. Thus, multiple satellites need to be in view of a ground receiver at any point in time, leading architects to use MEO orbits. Currently, the U.S. fields GPS, and the Russians field Glonass. The European community is in the planning stages of their Galileo POS/NAV satellite system, and will likely field it later this decade.

Weather

Weather missions typically utilize two different kinds of space system architectures. One architecture uses GEO satellites, but these do not provide adequate coverage near for higher latitudes. The other architecture uses polar orbiting satellites, which provide coverage to the higher latitude areas of the globe that GEO satellites cannot see well enough.

Remote Sensing

Broadly speaking, remote sensing satellite missions use sensors to collect data of many sorts from the earth's surface. These data could produce visual spectrum images, IR spectrum images, elevation measurement, atmospheric gas measurement, ocean states, and the list goes on and on. The architecture of remote sensing missions largely depends on the frequency and range of coverage required, as well as strength of the signal being sensed. For persistent coverage in a fixed small area with a strong signal, GEO satellites can work well. For infrequent coverage of a large area with a weaker signal, a single or multiple LEO satellites might be a good choice.

Launch

The launch mission differs dramatically from the previous four missions, and is an enabler for accomplishing them. Architectures of the launch vehicle itself (which is different than a launch architecture for a satellite) may be expendable or reusable, single

or multiple stages, solid or liquid propellant, and support different inclinations and orbital altitudes as a function of its launch site(s). Often, the launch vehicle architecture is a combination of all these different choices, selected to optimize performance for a given set of requirements the launch vehicle will serve.