Demand for satellite reconfigurability

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Abstract. This article analyzes several approaches to in-orbit satellite reconfiguration: rapid launch, reconfigurable satellite constellations, modular satellites and software defined radio. A number of significant projects are studied under each category. Software defined satellites is selected as the most promising technology.

1. Introduction
Design life of modern satellites can reach up to 15 years compared to 3-5 years a decade ago. This important achievement accelerated the growth in the number of active satellites. But it had a negative effect in the long run: payload of such satellites becomes deprecated. A vivid example of this tendency resides with communication satellites, which become deprecated due to swift evolution of communication standards and digital signal processing algorithms.

2. Approaches to solving the problem of satellite payload deprecation
A number of approaches to the problem of satellite payload deprecation exists:
1. Launching new satellites when the need for service improvement arises (rapid launch);
2. Reconfigurable satellite constellations;
3. Modular satellite architecture;
4. Designing the payload with flexibility and reconfigurability in mind.

3. Rapid launch approach
First approach mostly finds its use in satellite surveillance systems. An example is Air Force’s Operationally Responsive Space (OSR) program, which is aimed at enabling temporary improvement of surveillance coverage quality for military applications [1, 2]. This program assumes an existence of a pre-fabricated, ready to launch satellite pool and sets strict limits for launch procedures duration. Two week time frame is set for a satellite to be tested, launched and reach the destination orbit position in the earlier work [1]. The later work [2] sets even more severe requirements: 24 hours for launch vehicle integration and another 24 hours for reaching the destination orbital position. Another related program is DARPA SEEM [3], aimed at developing a low-cost satellites with design life of 60 to 90 days.

This approach has several disadvantages as a means of solving a problem of communication satellite payload depreciation. First of all, the effect of this approach is constrained by launch complex
resources and technologies, which could be limited. Secondly, current effort is focused on the launch procedures and does not mitigate the long development cycle for new payload. Lastly, this approach reduces the cost of satellites through the use of cheaper and/or commercial grade components, but does not affect the high cost of launching services. Those arguments indicate that rapid launch approach is ambiguous at solving a problem of payload deprecation. This conclusion is partially supported by the fact that rapid launch approach was developed for specialized military applications [4].

4. Reconfigurable satellite constellation
Second approach consist in forming a group of remotely controlled satellites (constellation), which are able to change their orbit promptly (reconfiguration) to reach desired coverage. This approach is aimed at increasing the link capacity for a particular area of land, e.g. world-grade sports or cultural event (olympic games, political forums, etc.).

The ReCon [4] is an example of satellite constellation project. This work describes to distinctive modes of operation for a group of satellites: global observation mode (GOM) as a basic constellation state and regional observation mode (ROM) aimed at increasing the quality of communication service for a particular region (figure 1). Later work [5] applies genetic algorithms and simulated annealing to facilitate constellation reconfiguration. The authors prove that this approach can applicable for radiolocation and radio occultation. Both works use model simulation and are not supported by field tests.

![ReCON modes of operation](image)

**Figure 1.** ReCON modes of operation

Modelling [5, 6] indicates, that reconfigurable constellations with large number of small spacecraft are more efficient. Reconfiguration efficiency increases with the number of satellites, while light class of the proposed satellites improves their maneuverability. On the other hand, the complexity of reconfiguration plan increases with the number of spacecraft involved as well. Traditional ground-based control model may be inadequate in terms of cost and complexity. This issue is addressed in [6] with the use of autonomous model of reconfiguration. The letter algorithm is only tested for a constellation of a single ring topology on GEO.

Economically efficient deployment is another problem that reconfigurable constellations face. Works [7, 8, 9] provide analysis for this problem with [9] focusing on light-class spacecraft. The letter work states, that launch and deployment for light-class satellites, that are preferable for constellations, suffer penalties compared to heavier spacecraft.

5. Modular satellite approach
Modular satellite is a spacecraft consisting from interchangeable modules partially or completely. The key principle for this approach resides with satellite upgrade in-orbit by replacing it’s modules with new ones implementing required functions. This approach is characterized with the following list of advantages:
- building block unification becomes economically efficient with mass production;
- design life of modular satellite management becomes viable through modules replacement;
- new satellite development time is reduced with an opportunity to use “off-the-shelf” modules.
Along with benefits this approach may provide, it also brings up a set of non-trivial problems:
- define module composition in terms of space, durability, complexity, etc;
- define module interface which would not place complex constraints on module assembly process.
This interface should ensure satellite flexibility as well as heat, energy transfer and high bandwidth;
- develop a flexible and reliable networking standard with possible redundancy for inter-module communication;
- develop a distributed application layer operating over a satellite with arbitrary composition;
- define deployment and reconfiguration procedures.
Reconfigurable satellites approach is being developed by “Intelligent Building Blocks for On-Orbit Satellite Servicing” (iBOSS) project [10] (figure 2). Most of the abovementioned problems were solved in a ground laboratory environment.

![Figure 2. iBOSS satellite model (iSAT)](image)

Under this project, a standard building block, iBLOCK, was developed [11] (figure 3). Each of such blocks consists of on-board computer (OBC), power control unit (PCU) and a router. TTEthernet (with RSTP and SNMP support) was selected as a final candidate for networking layer instead of SpaceFiber in earlier project papers. PCU of an iBLOCK is controlled by OBC thus enabling dynamic power scaling.

![Figure 3. iBOSS module (iBLOCK)](image)
The unified block interface standard \[12\] for connecting iBlocks to each other or to other components such as solar panels, additional payloads was developed under iBOSS project. Mechanical layer of this interface is an androgynous connector (figure 4). Fuel piping uses separate connectors with similar interface.

![Figure 4. iBOSS physical interface](image)

iBOSS project utilises distributed computing model for software application. Two distinctive types programming modules: one tied to specific iBLOCK, the other is iBLOCK independent, which could be executed on any available module. RSTP protocol is used to track changes in satellite composition. This information is handled by special device - monitoring and control node, which composes routing tables with redundant paths and configures routers over SNMP protocol in each iBLOCK. A special IDE is proposed for satellite construction and testing automatization.

iBOSS project authors report that they are working on in-orbit reconfiguration procedures for their modular spacecraft and a library of pre-tested functional blocks. It is worth noting that iBOSS project carried out successful testing of several laboratory prototypes and is still to carry out in-orbit tests for their reconfigurable spacecraft. It is important to note that there are several projects focusing on non-reconfigurable modular satellites. ARaMiS project \[13\] proposes standard block designs, which could be reused for CubeSat-class spacecraft. Authors state, that this particular initiative is intended to lower new satellite development and fabrication cost to make them affordable for universities and small businesses. Such projects fall under rapid launch approach as they are aimed at decreasing development time for new spacecraft rather then upgrade existing ones.

### 6. Reconfigurable payload approach

This approach is also known as software defined satellite (SDS), or a satellite, which functionality could be changed by software rather then hardware. The hardware of such a satellite is a redundant set of reconfigurable components like processors, FPGA, FPAA or microcontrollers. Such components do not define application directly, but provide an ability to set application by a set of configuration files and change it on demand. It worths noting that mass and size of such satellite has to be increased to house redundant set of components as a trade-off for reconfigurability. In-orbit reconfigurability could be utilized to manage payload depreciation.

SDS technology was addressed on World Satellite Business Week (WSBW) conference \[14\] and was acknowledged as perspective satellite architecture. Thales Alenia Space president declared, that under their SDS initiative, the company will focus on processor-controlled phased-array antennas. It was stated that medium-class satellite architecture is to benefit the most from adapting SDS approach. Airbus CEO declared that over 15 Airbus SDS satellites are already operating or ready to launch. Lockheed Martin Space Systems plans to provide financial support for start-ups developing SDS technology. Maxar’s SSL CEO stated that the company is aiming for integrating programmably-defined payloads with ground 5G segment.
Several projects exist that put effort into SDS technology development. GalacticSky works on a microsatellite that would be subject to in-orbit reconfiguration in accord with particular customer demands. Proposed payload technology is a virtualized platform under GalacticOS (figure 5) hypervisor. SDK, API and cloud simulation service is provided for developers. The core hardware is Intel Atom or Intel i7/Xeon processors on a platform providing standard interfaces: RS232, USB, PCIe, SATA and 1Gbit LAN. Client software is executed on guest machines with virtual processor, memory and sensors for multiple customers simultaneously. Citrix virtualization solution was chosen as hypervisor software.

GalacticSky and University of Southern California’s Space Engineering Research Center (SERC) developed GSky-1 (figure 6) spacecraft to test proposed technology. This satellite is to be launched in 2019 [15]. Payloads for this spacecraft were developed by NASA and Air Force Research Laboratory (AFRL).

Figure 5. SDS protocol stack solution from GalacticSky

Figure 6. GSky-1 satellite
Quantum project (figures 7, 8) by Eutelsat, Arbus and ESA is the most developed SDS, scheduled to be launched in 2019 [16]. This is the only heavy satellite design utilizing SDS technology. It is has reconfigurable coverage pattern, signal power and frequencies due to phased array antenna being used onboard.

![Figure 7. Quantum satellite platform](image1)

Figure 7. Quantum satellite platform

Specialized software on Quantum satellite monitors resources utilization efficiency, predicts the need for characteristic change and controls reconfiguration process. Also reconfiguration could be initiated with control center commands. On top of that Quantum spacecraft will be able to perform orbital position change.

![Figure 8. Quantum satellite model](image2)

Figure 8. Quantum satellite model

Eutelsat representatives state, that they already secured contracts for 50% satellite resources capacity, which indicates, that there’s demand for SDS technology.

7. Conclusion
Software defined satellite technology is the most efficient at managing payload deprecation out of the list of approaches analized in this article. While being beneficial in some spheres, rapid launch approach is the most expensive one. Reconfigurable constellation approach is not universal and is only effective on a limited range of satellite weight classes. Modular satellites approach is the second to top, but there is a number of problems that have be solved in order for it to be practically applicable.
Demand for SDS technology is stated by major aerospace-related companies. But current projects either intended for micro-class satellites, or restricted to radio transceiver reconfigurability.

All the presented information proves that software defined satellite technology is a promising course in spacecraft design sphere and should attract attention of Russian space agency developers.

At the time of writing, set of software tools, reconfiguration procedure specifications and SDS hardware platform is being developed by the group of authors as core parts of SDS technology. Current work consists in:

1. developing specification for SDS hardware platform;
2. automating DSP circuit development process and incorporate it into specialized IDE;
3. developing algorithms for digital circuit design segmentation and mapping such segments onto SDS platform resources;
4. developing specifications for reconfiguration process.

More information on SDS concept being developed as well as obtained results will be provided in future papers.

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