Android Beyond the stratosphere:

On Google exploring phone-based nanosat swarms

Elisenda Bou-Balust
Eduard Alarcón
on behalf of the Google ABS team

NanosatLab
UPC BarcelonaTech

ANDROID
BEYOND the STRATOSPHERE

UPC NanoSat Lab

Google ABS grand vision:

Democratized Open access to Space through a cooperative **Space station**

The project. The Team

Project:

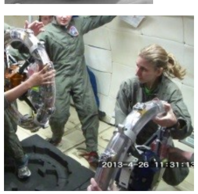
To design, implement and operate a low-cost, modular pico-satellite based on a phone towards the generation of an Open Space Station, accessible to anyone with a WiFi Antenna and which allows developers to **1) execute Android applications in-space** and entities to **2) customize and send their pico-satellites to the constellation**.

Google Faculty Research Award "Android Beyond the Stratosphere".
PIs: Prof. Eduard Alarcon, Prof. Adriano Camps.

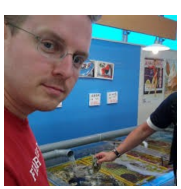
Team: Elisenda Bou-Balust (UPC/MIT), Adria Recasens (UPC/MIT), Íñigo del Portillo (UPC/MIT), Daniel Selva (MIT), Marc Marí (UPC), Carles Araguz (UPC).

Up to 20 graduate students in two years

Eduard Alarcon, *M.Sc. (national award) and Ph.D. degrees in EE from UPC in 1995 and 2000.*
Professor at UPC since 2001. Visiting Professor at Colorado Boulder and KTH.
Background in silicon chips, invited lecturer at Silicon Valley, MIT. Consultant with Google, Intel, Samsung, various startups.
Current research interests nanosats, wireless energy transfer and nanoscale communications



Elisenda Bou-Balust, *P.hD Candidate at UPC.*
Currently works on RIC systems in collaboration with MIT and UMD, supported by NASA and DARPA
She splits her time between her research on RIC and fractionated spacecraft/satellite constellations.
VP technology in various start-ups



Kenny Root, *Stanford University.*
Android engineer at Google, Mountain View headquarters, CA

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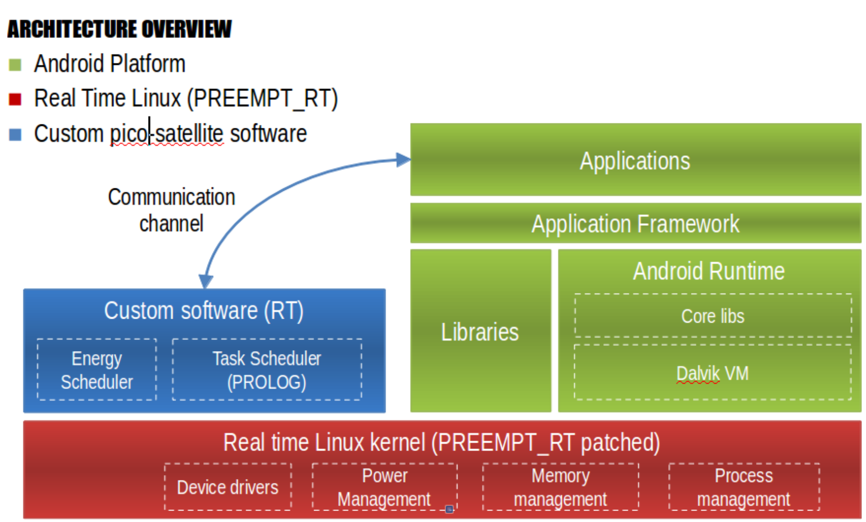
Google ABS Project

1st Generation: a Phone-Based Open Nano-Satellite Software & Hardware Platform

Allowing the execution of Android Apps in-Space

Open-Software Architecture:

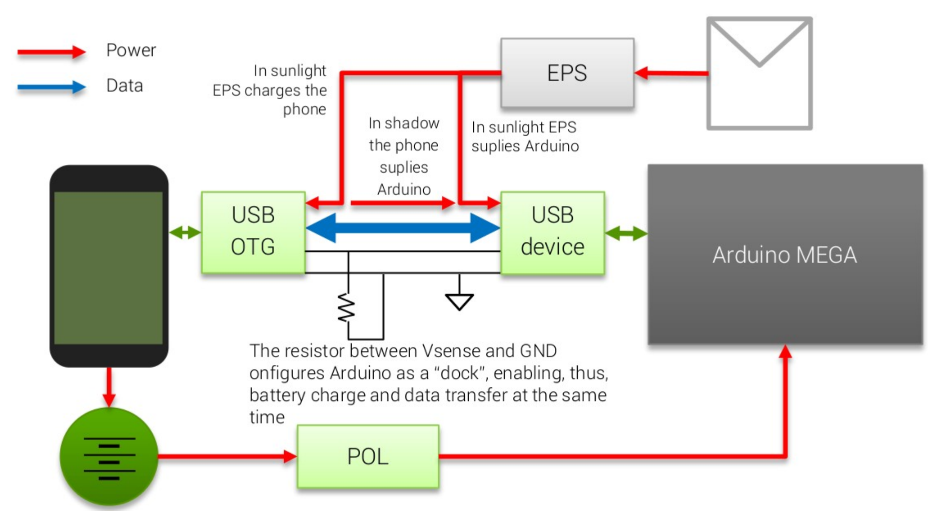
- Real-Time Android (ARTOS)
- Developer Environment and SDK
- Autonomous Scheduling of Apps



Designing an Open-Hardware Nano-Satellite Platform

Open-Hardware Architecture:

- EPS and Power Extraction Mechanisms
- New payloads through Arduino (Shields)
- WiFi Connectivity with Community Segment



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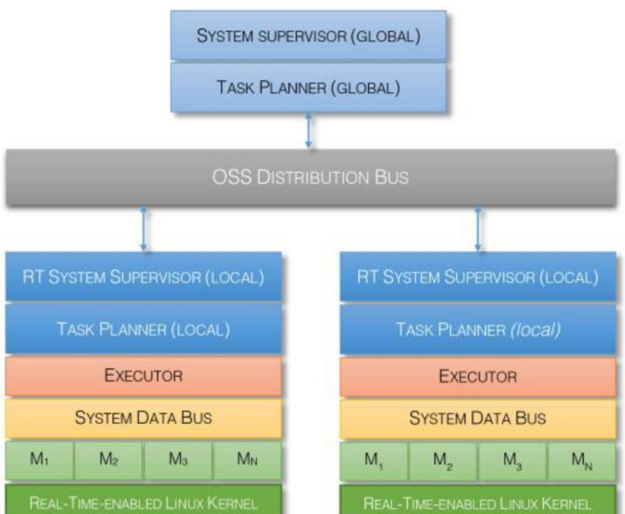
Google ABS Project

2nd Generation: towards an archipelago of ABS units conforming an Open-Access Space Station

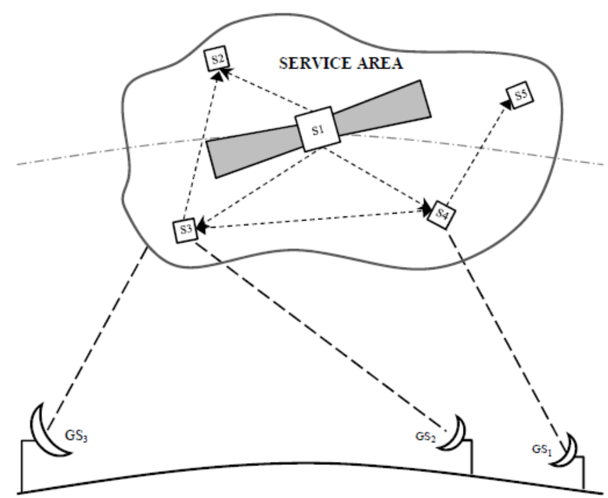
Allowing the execution of Android Apps on the Open Space Station

OSS Software Architecture:
- Multi-Node Scheduling Policies
- ABS API: enabling the execution of apps and commands on top of the ABS constellation trough the ABS-API.



Designing the Multi-Node Open Space Station

OSS Hardware Architecture
- Constellation Subsystems
  - Resource Exchange
  - Wireless Communications
- Constellation Scalability



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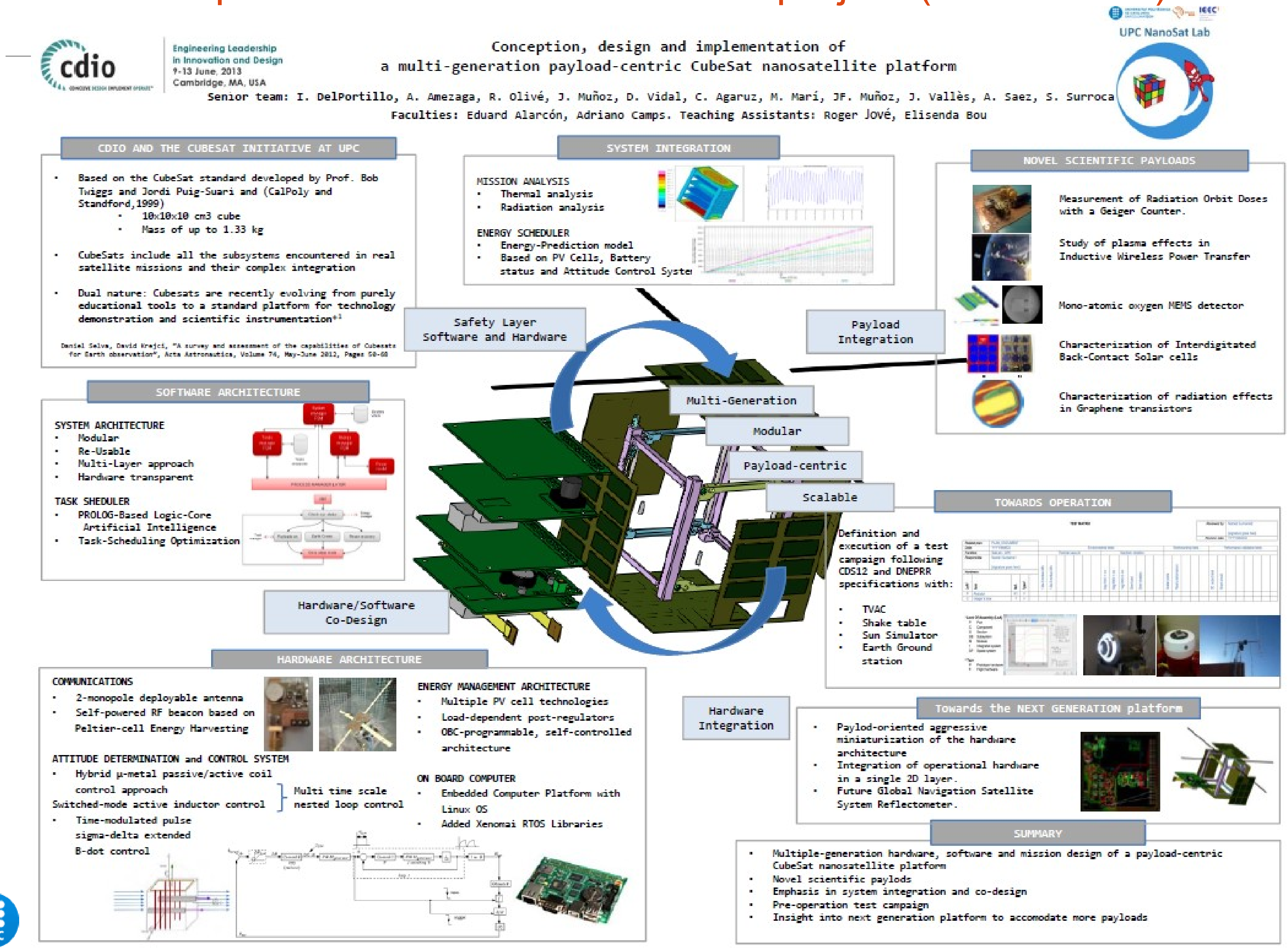
ABS precursor: UPC nanosatellite project (nanosat lab)



Engineering Leadership in Innovation and Design
9-13 June, 2013
Cambridge, MA, USA

UPC NanoSat Lab

Conception, design and implementation of a multi-generation payload-centric CubeSat nanosatellite platform

Senior team: I. DelPortillo, A. Amezaga, R. Olivé, J. Muñoz, D. Vidal, C. Agaruz, M. Marí, JF. Muñoz, J. Vallès, A. Saez, S. Surroca
Faculties: Eduard Alarcón, Adriano Camps. Teaching Assistants: Roger Jové, Elisenda Bou

CDIO AND THE CUBESAT INITIATIVE AT UPC

- Based on the CubeSat standard developed by Prof. Bob Twiggs and Jordi Puig-Suari and (CalPoly and Standford,1999)
  - 10x10x10 cm3 cube
  - Mass of up to 1.33 kg
- CubeSats include all the subsystems encountered in real satellite missions and their complex integration
- Dual nature: Cubesats are recently evolving from purely educational tools to a standard platform for technology demonstration and scientific instrumentation"[1]

Daniel Selva, David Krejci, "A survey and assessment of the capabilities of Cubesats for Earth observation", Acta Astronautica, Volume 74, May-June 2012, Pages 50-68

SYSTEM INTEGRATION

MISSION ANALYSIS
- Thermal analysis
- Radiation analysis

ENERGY SCHEDULER
- Energy-Prediction model
- Based on PV Cells, Battery status and Attitude Control Syste

NOVEL SCIENTIFIC PAYLOADS

- Measurement of Radiation Orbit Doses with a Geiger Counter.
- Study of plasma effects in Inductive Wireless Power Transfer
- Mono-atomic oxygen MEMS detector
- Characterization of Interdigitated Back-Contact Solar cells
- Characterization of radiation effects in Graphene transistors

Safety Layer Software and Hardware

Payload Integration

Multi-Generation

Modular

Payload-centric

Scalable

Hardware/Software Co-Design

Hardware Integration

SOFTWARE ARCHITECTURE

SYSTEM ARCHITECTURE
- Modular
- Re-Usable
- Multi-Layer approach
- Hardware transparent

TASK SHEDULER
- PROLOG-Based Logic-Core Artificial Intelligence
- Task-Scheduling Optimization

TOWARDS OPERATION

Definition and execution of a test campaign following CDS12 and DNEPRR specifications with:
- TVAC
- Shake table
- Sun Simulator
- Earth Ground station

HARDWARE ARCHITECTURE

COMMUNICATIONS
- 2-monopole deployable antenna
- Self-powered RF beacon based on Peltier-cell Energy Harvesting

ATTITUDE DETERMINATION and CONTROL SYSTEM
- Hybrid μ-metal passive/active coil control approach

Switched-mode active inductor control
- Time-modulated pulse sigma-delta extended B-dot control

Multi time scale nested loop control

ENERGY MANAGEMENT ARCHITECTURE
- Multiple PV cell technologies
- Load-dependent post-regulators
- OBC-programmable, self-controlled architecture

ON BOARD COMPUTER
- Embedded Computer Platform with Linux OS
- Added Xenomai RTOS Libraries

Towards the NEXT GENERATION platform

- Paylod-oriented aggressive miniaturization of the hardware architecture
- Integration of operational hardware in a single 2D layer.
- Future Global Navigation Satellite System Reflectometer.

SUMMARY

- Multiple-generation hardware, software and mission design of a payload-centric CubeSat nanosatellite platform
- Novel scientific paylods
- Emphasis in system integration and co-design
- Pre-operation test campaign
- Insight into next generation platform to accomodate more payloads

UPC

1st Gen. ABS: Open-Hardware

Rationale: The ABS project aims to assess the viability of developing a satellite using a commercial of the shelves (COTS) mobile phone.

Nexus 5 platform

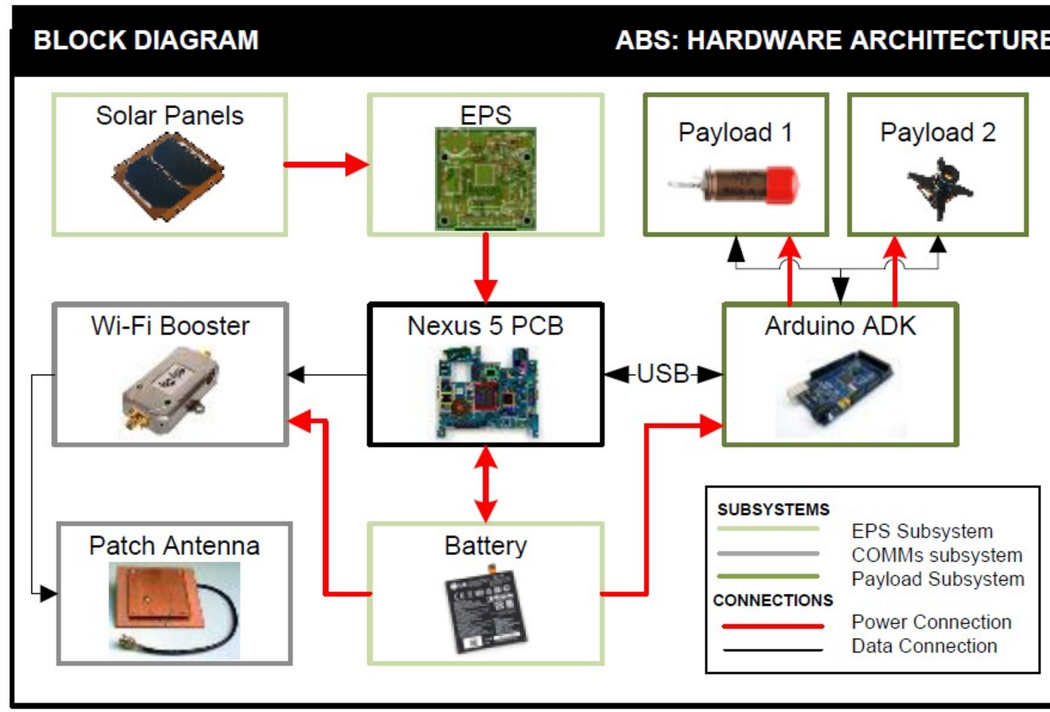
Performs the on-board data handling (OBDH) and on-board computation (OBC) functions.

EPS Energy processing architecture

The Electronic Power System (EPS) is responsible of regulating and distributing power to all the subsystems in the satellite.

Arduino as interface for payload developers

An Arduino Mega board is connected to the Nexus5 through USB. User payloads will be stacked on top of the Arduino board*.



*This approach is similar to the one followed by Google when releasing their Arduino-based Android Accessory Development Kit (ADK).

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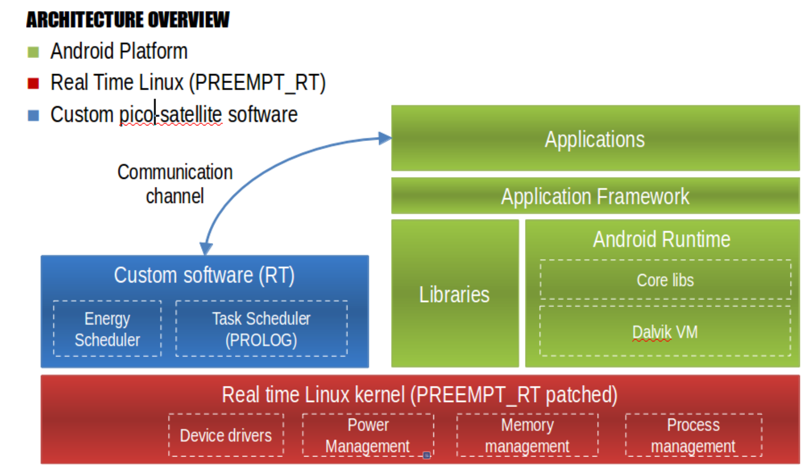
1st Gen. ABS: Open-Software

Rationale: a software architecture has to be implemented to allow the execution of all subsystems and payloads of the ABS satellite on top of Android.

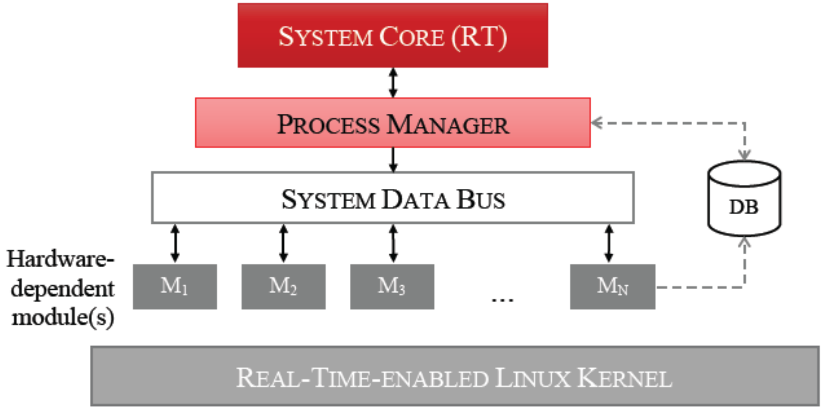
Android Real-Time OS (ARTOS)

Adding real-time capabilities (through Preempt-RT) to the Linux Kernel, and extending them to Android and the Java Virtual Machine.



Software System Architecture

A modular new software architecture has been developed to allow the execution of applications that interact with the satellite sub-systems and payloads.



Autonomous Scheduling of Apps

Implementing a ProLog constraint based task scheduler to allow autonomous decision making and scheduling of uploaded user applications.

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"In Pursuit of Real-Time Capabilities for Embededed Linux Systems: a qualitative comparison of Xenomai and Preempt-RT", Elisenda Bou, Marc Mari, Alexandru Lungu, Kenny Root and Eduard Alarcon. UPC BarcelonaTech and Google Inc.

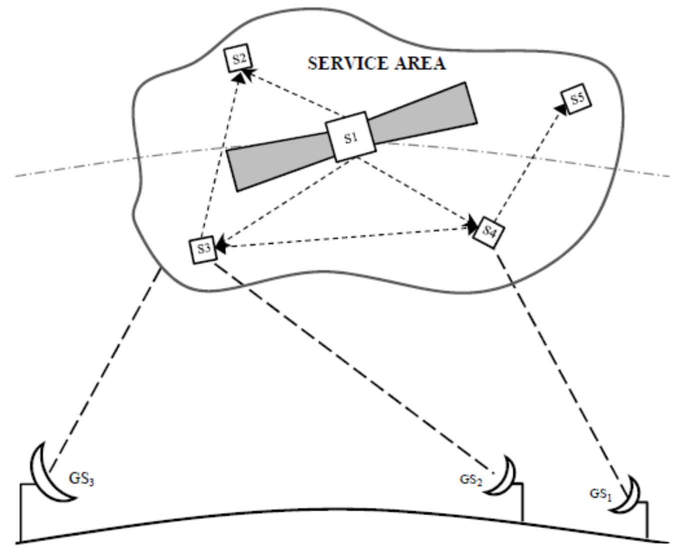
2nd Gen. ABS: OSS Architecture

Rationale: ABS Architectural Challenge: on Scalability of Nano-Satellite Distributed Architectures.

Scalability Analysis

Constellation Architecture Scalability Analysis and Resource Optimization

$$\begin{pmatrix} \eta_{1,d(t_1)} p_{1,d(t_1)}^{R,t_1} & \cdots & \eta_{N_s,d(t_1)} p_{N_s,d(t_1)}^{R,t_1} \\ \vdots & \ddots & \vdots \\ \eta_{1,d(t_{N_t})} p_{1,d(t_{N_t})}^{R,t_{N_t}} & \cdots & \eta_{N_s,d(t_{N_t})} p_{N_s,d(t_{N_t})}^{R,t_{N_t}} \end{pmatrix} \begin{pmatrix} R_1^R \\ \vdots \\ R_{N_S}^R \end{pmatrix} = \begin{pmatrix} R_{obt}^{R,t_1} \\ \vdots \\ R_{obt}^{R,t_{N_t}} \end{pmatrix}$$



Wireless Resource Exchange

Wireless Energy and Data exchange oriented to Google-Phone Constellation Swarms.

Wireless Communications

Multi-Standard Wireless Communications.

$$[MAX]\ z = \sum U_t p_t = \sum U_t \prod p_t^R = \sum U_t \prod \frac{R_{obt}^R}{R_{need}^R}$$

s.t:

$$R_{need}^R \geq \left((T \cdot \eta^R) \circ p^R \right) R_s^R$$

$$1 \geq (p^R)^T 1$$

$$p_{ij}^{R,t} \geq 0$$

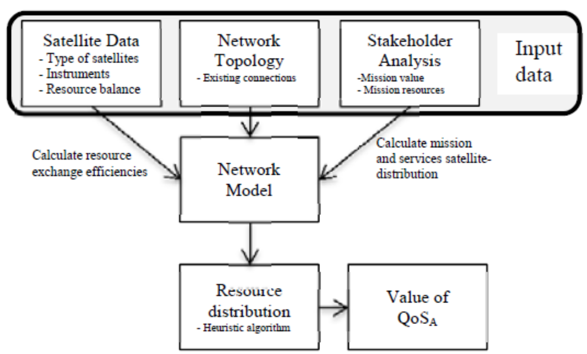
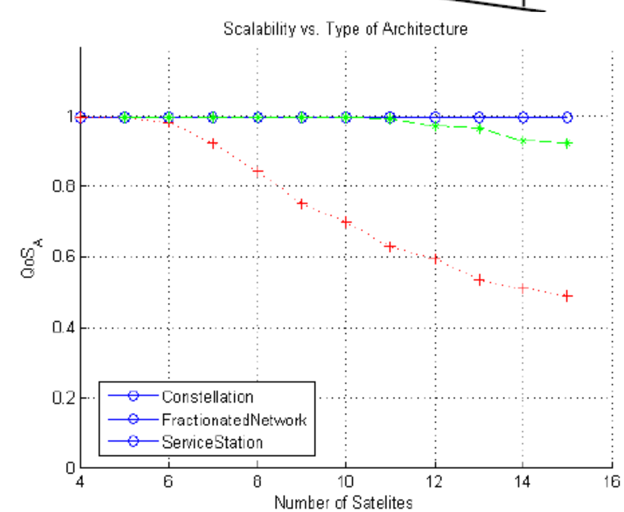


Fig. 3. Methodology for assessing the QoS$_A$ for a certain fractionated satellite network configuration.



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"On Scalability Limits of Resource Constrained General Purpose Fractionated Satellite Network Architectures " Iñigo del Portillo, Elisenda Bou-Balust, Marc Sanchez, Daniel Selva, Eduard Alarcón, (UPC / MIT AeroAstro)

2nd Gen. ABS: OSS Software Architecture

Rationale: The Open Space Station Phone-Satellite Archipelago requires a distributed software architectures capable to combine the execution of user application requests with the tasks corresponding to the constellation functionality (power systems, communications to earth).

Autonomous Distributed Planner

Sheduler that generates a list of timed activities based on system constraints and external requests

Modular Multi-Threaded Software Architecture

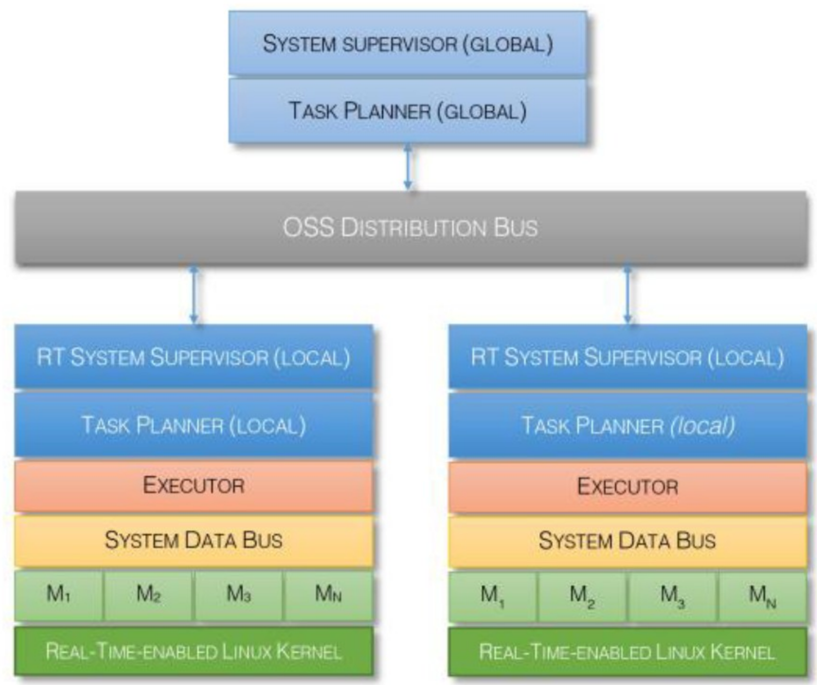
A robust multi-threaded executive that executes the plan and interacts with the system at a lower level

Autonomous Supervisor

A model-based failure and diagnosis engine that monitors the system response and proposes actions in the event of failure (Autonomous Supervisor).

The operation of the OSS has to guarantee:

a) The execution of all the necessary tasks/operations of the ABS units independently
b) Execution of the applications uploaded by the users to the OSS.



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Future Community Contributions

ANDROID
BEYOND the STRATOSPHERE

Development of New Applications to be executed in Space
Easy access to space data and services/payloads.

Catapult Space Access to new Payloads
New payloads can be customized and added using the ABS-Arduino Standard.

New enabling era of pico-satellite missions.
Low cost standarized platform to start the mission
Spaceborn access to the constellation resources (energy & data).

A . B . S