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The Potential Impact Of Small Satellite Radar Constellations On Traditional Space Systems

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Abstract

The number of NewSpace Synthetic Aperture Radar (SAR) constellations under development is growing. New entries will soon join the ranks of existing systems developed using well known traditional space industry practices. How will these systems perform with respect to existing and planned traditional systems? In order to compare SAR systems developed using well known practices (traditional systems) to SAR systems developed using innovative approaches (NewSpace systems), a specific performance index was devised. This performance index was computed for 15 existing or planned SAR constellations. Initial results show that small satellite constellations appear to offer high value solutions in many cases. Nevertheless, launch and operational costs may easily limit this value if projected cost reduction goals are not achieved in the near future.

Keywords

Synthetic Aperture Radar, NewSpace, satellite constellation

1. INTRODUCTION

Synthetic Aperture Radar (SAR) systems have unique imaging capabilities. They provide high-resolution two dimensional images independently from daylight, cloud coverage and weather conditions. SAR systems are ideal to monitor dynamic processes on the Earth surface in a reliable, continuous and global way [1].
The market of SAR satellites is in its early stages of development and until recently, SAR satellites have mostly had institutional applications. The entrance of new players in the SAR market has favoured application driven as opposed to performance driven satellite design. Low cost, small satellite solutions offer the opportunity to extend the realm of SAR applications and as a result, widen the EO commercial user community.
With the SAR market benefiting from the growing demand for Earth observation data (7.5% growth annually until 2024) and the advantages linked to SAR systems, the SAR market is expected to grow at a rate of 10.3% per year until 2024 [2].

2. THE NEWSPACE ENVIRONMENT

SAR satellites have been in orbit for almost 40 years, but SAR constellations have recently been multiplying. High revisit rates are a prime objective of SAR systems, since many potential data applications involve elements that change in time, such as the position of ships or disaster management. New SAR small satellite constellations, aim to achieve real time imaging.

Until recently SARs were difficult to implement on small satellites. However, the miniaturization of electronic components and recent technological advances, such as the gallium nitride (GaN) amplifier technology that reduces the number of elements in the antenna, has made SARs compatible with small platforms.
The term small satellites refers to satellites weighing less than 500 kg and developed with a low cost approach (use of COTS, short development cycle…). This design approach can be summarised by the following 6 cardinal rules [3]:

1) Keep it simple;

2) Use fast hardware iterations;

3) Use standardised space components;

4) Use a single string design on the system level (no redundancy);

5) Design with limited trust in the software;

6) Use simple, accessible and easily updatable documentation.

3. CURRENT AND FUTURE SAR CONSTELLATIONS

Not all identified constellations were considered in the work that follows since in some cases, the available information was not sufficient to allow for proper analysis. A subset of 15 constellations (see Table 2) were analysed and compared.

Table 1: SAR Satellite Constellations

Organisations	Constellation name	Launched/Planned Network	First Launch
German government, OHB	**SAR-Lupe**	5/5	2006
ASI, E-GEOS	**COSMO-Skymed**	4/4	2007
Hisdesat & Airbus D&S	**Airbus radar satellites constellation (PAZ, TSX, TDX)**	2/3	2007
European Space Agency	**Sentinel 1**	2/4	2014
Capella Space	**Capella Space**	0/36	2017
Iceye	**Iceye**	0/50	2017
SSTL & Airbus D&S	**NovaSAR**	0/3	2017
ASI, E-GEOS	**COSMO-Skymed 2d Generation**	0/2	2018
Canadian Space Agency	**RADARSAT Constellation Mission**	0/3	2018
Kongsberg Satellite Services & Space Norway	**MicroSAR System**	0/10	2018
German government, OHB, Airbus D&S	**SARah**	0/3	2019
JAXA	**MicroX SAR**	0/15	2020
XpressSAR Inc	**XpressSAR**	0/4	2020
UrtheCast	**OptiSAR**	0/8 SAR+8 optical	2020/21
DLR, Airbus D&S	**WorldSAR**	0/4	2020/22

Figure 1 shows how the companies developing the 15 analysed constellations are positioned with respect to users (government vs. commercial) and development approach (traditional vs. NewSpace).

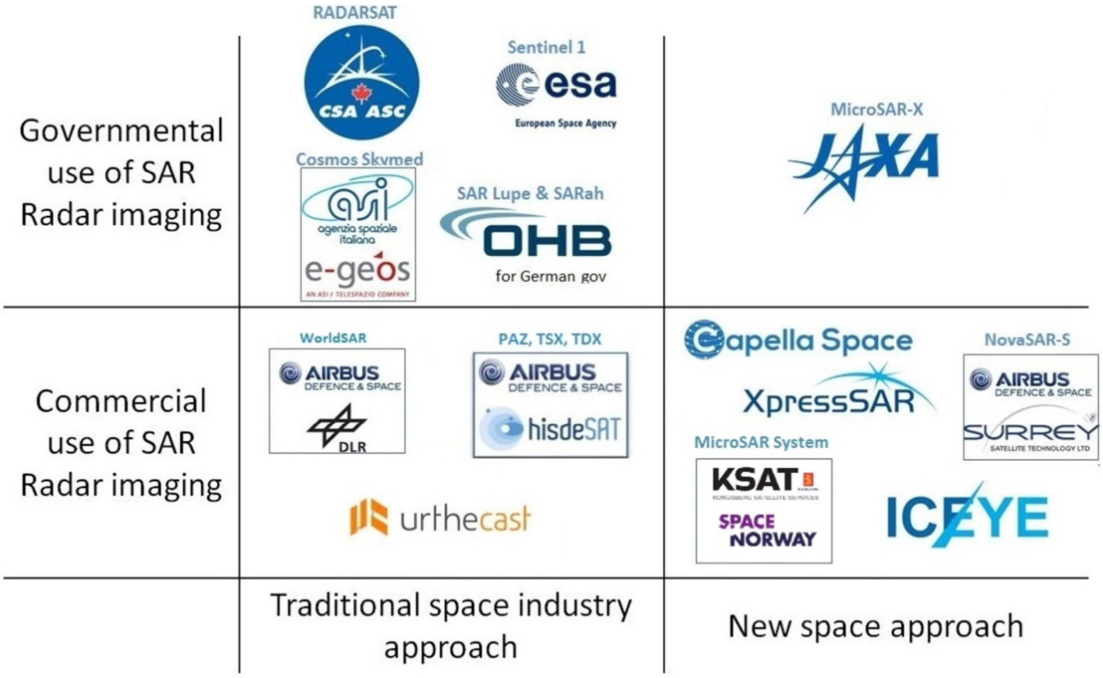

Figure 1: Positioning Of SAR Satellite Constellation Companies

4. SAR PERFORMANCE INDEXES

In order to compare NewSpace SAR systems to traditional SAR systems, a specific performance index was computed for each constellation.

4.1 SAR SATELLITE PERFORMANCE INDEX

In order to obtain the performance index of each constellation, a performance index of the spacecraft of each constellation was calculated based on 5 parameters affecting the satellite's performance:

- **Range resolution** (RR): Measure of the ability to determine whether only one or more than one different targets are observed. It's related to the signal bandwidth.
- **Swath width** (SW): Width of the survey area covered by a complete sweep of the scanner. It's related to flying height and the scanner half angle.
- **Acquisition time** (AT) per orbit: Time during which the SAR instrument operates in imaging mode. It is limited by power constraints.
- **Peak power** (PP): Maximum power necessary when the SAR instrument is operating.
- **Polarimetry** (P): Number of combinations of transmit and receive polarisation possible of the microwave radiation. Radar systems can have one, two or all four of these transmit/receive polarization combinations:

single polarized	HH or VV (or possibly HV or VH)
dual polarized	HH and HV, VV and VH, or HH and VV
alternating polarization	HH and HV, alternating with VV and VH
quadrature polarization	HH, VV, HV, and VH

The parameter values of each satellite were normalised with respect to the corresponding best performing value of the 15 satellites data set (%V).

For directly proportional parameters (i.e. increasing value corresponds to increasing performance, such as the swath width):

$$\%\mathrm{V} = \frac{\mathrm{n}}{\mathrm{N}}$$

For inversely proportional parameters (i.e. increasing value corresponds to decreasing performance, such as the range resolution):

$$\%\mathrm{V} = 1 - \frac{\mathrm{n}}{\mathrm{N}}$$

Where:

%V is the normalized value of a parameter;
n is the satellite's parameter value;
N is the best performing value in the parameter set (i.e. of the 15 satellite population).

Based on the 5 normalized parameter values, a satellite performance index is calculated as follows:

$$P_{satellite} = \frac{(\%RR + \%SW + \%AT + \%PP + \%P) * MW}{5}$$

In order to properly consider the uncertainty of the parameter values linked to the maturity of the system, a **maturity weight** (MW) was introduced.

The maturity weight is based on the following:

- The characteristics of the company (number of employees, date of creation, experience in the space sector);
- The launch date of the satellite (past or future);
- The status of development of the project (already launched, announced funding, signed launch contract/agreement, NOAA license…);
- The global number of information available about the project.

The maturity weight ranges between 1 (Sentinel 1) and 0.7 (XpressSAR).

Figure 2 shows the resulting 15 satellite performance indexes as a function of satellite mass.

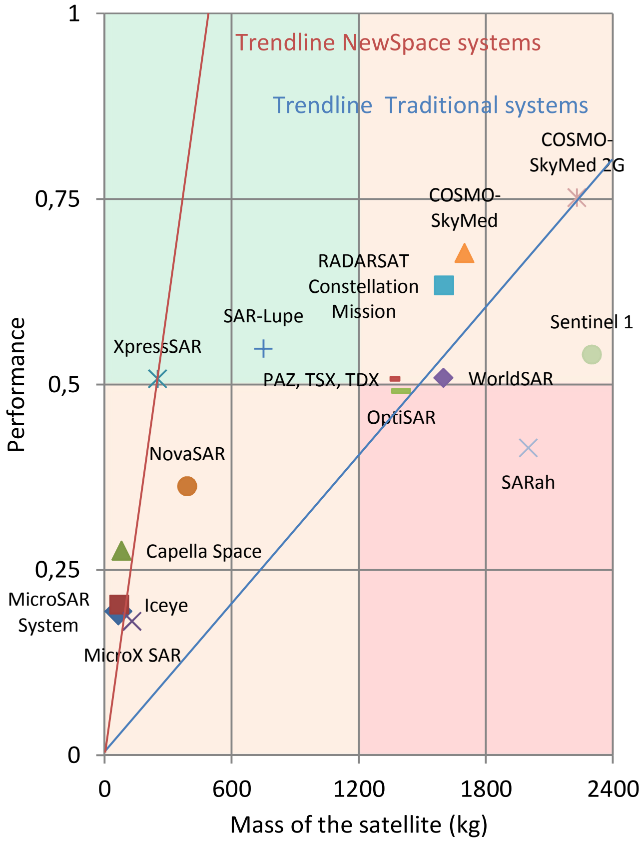

Figure 2: SAR Satellite Performance Index As A Function Of Satellite Mass

As expected, the satellite performance index of the traditional systems (i.e. Sentinel 1, RADARSAT, COSMO Skymed…) is significantly higher than the performance index of the NewSpace systems (i.e. Iceye, Capella Space…).

However, as seen in Figure 3[1], NewSpace small satellites have a better performance index to mass ratio than traditional systems. Disruptive CubeSat technology in the past few years has dramatically increased the performances of small SAR satellites while keeping size and weight unchanged.

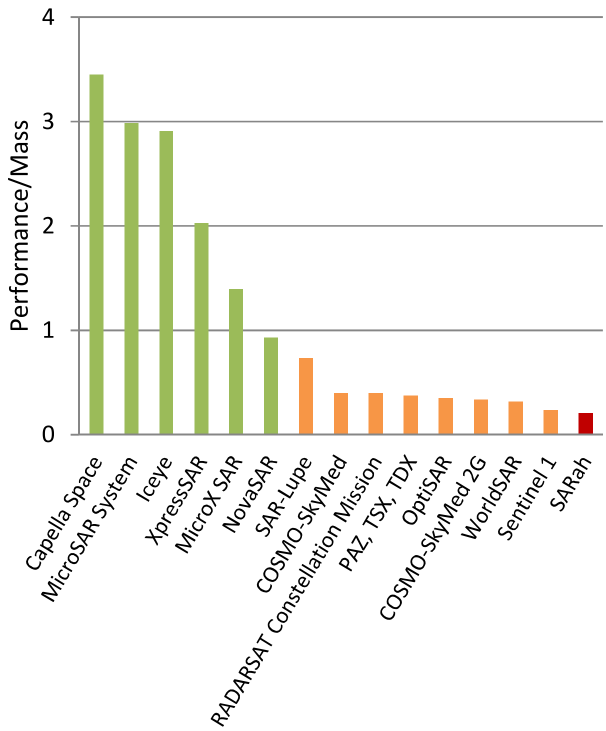

Figure 3: Satellite Ranking Of Performance Index To Mass Ratio

4.2 SAR CONSTELLATIONS PERFORMANCE INDEX

The performance index of the constellation is obtained by adding the normalized **revisit rates** of the constellations (%RT) multiplied by the percentage of the Earth covered by the satellite (I) (linked to the inclination angle of the orbit) to the satellite performance index as shown below.

$$P_{constellation} = \frac{(\%RR + \%SW + \%AT + \%PP + \%P) * MW + \%RT * I}{6}$$

For the purpose of this work, the **revisit rate** is defined as the time elapsed between two observations of the same point on Earth by the constellation. It depends on the orbit, the target location, and the elevation angle above the horizon required for a pass [4].

Figure 4 shows the obtained constellation performance indexes as a function of the total mass of all satellites in the respective constellations.

[1] The Capella Space and MicroSAR System spacecrafts reach respectively 1m and 4m resolutions in CubeSat platforms. The satellites' performance index, combined with their low mass explain Capella Space and MicroSAR System's high performance index to mass ratios.

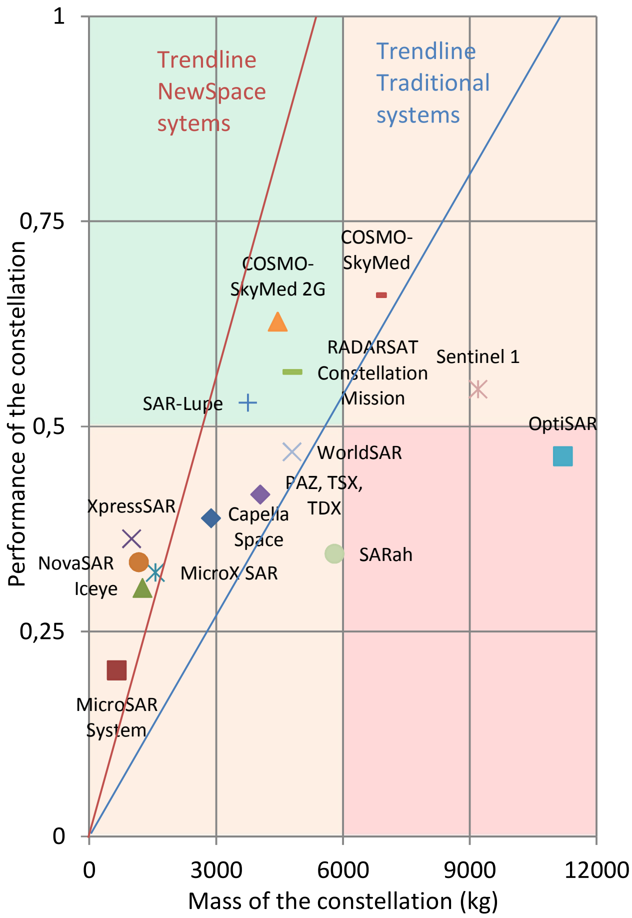

Figure 4: SAR Constellation Performance Index As A Function Of Constellations Mass

Traditional system constellation performance indexes only increases slightly with respect to the performance index of a single satellite since traditional constellations have better performing but fewer satellites per constellation (thus, limited revisit rates). On the contrary, the **performance index of the NewSpace constellations is much higher than the average performance index of the individual satellites.** Indeed, small satellite constellations have a larger number of satellites than traditional systems. This leads to a high revisit rate and consequently, to a high constellation performance index.

In most cases, SAR constellations using small satellites have a better performance index to mass ratio than traditional systems, as shown in Figure 5[2].

[2] The XpressSAR, MicroSAR System and NovaSAR constellation performance indexes to mass ratios are higher because although their constellation performance indexes are average (0.36 for XpressSAR, 0.2 for MicroSAR System and 0.33 for NovaSAR), they are small satellites and consequently have low masses**.**

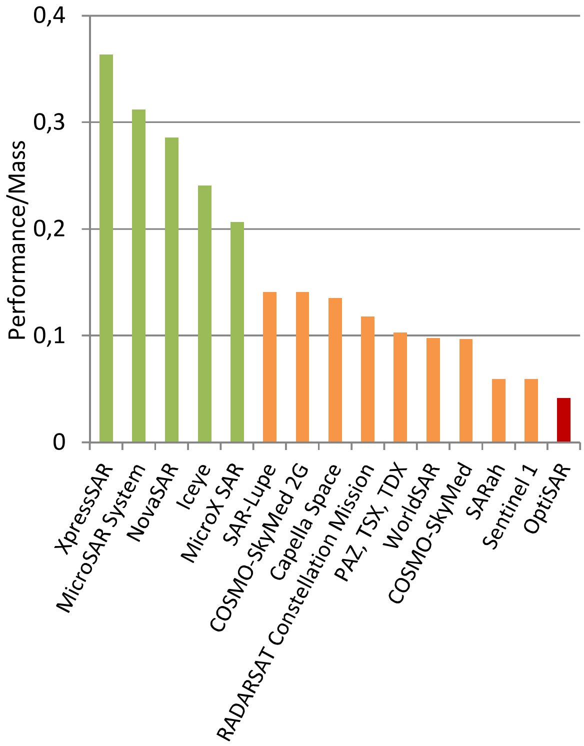

Figure 5: Constellation Ranking Of Performance Index To Mass Ratio

4.3 SAR EVOLUTION PERFORMANCE INDEX

Even though the overall performance index of constellations may prove higher for small satellites than for traditional systems, specific parameters such as range resolution may need to achieve certain values in order to meet specific observation needs independently of the high revisit rate. Today, traditional systems offer resolutions that are not achievable by small satellites. Nevertheless, small satellites have shorter satellite lifetimes and, as a result, go through a larger number of development cycles in a set timeframe and therefore, have a larger number of opportunities to harness new technologies than traditional systems. In other words, small satellites can quickly recover specific performance gaps with respect to traditional systems. In order to measure this capability, a SAR satellite evolution performance index was devised. To obtain the satellite evolution performance index ($P_{evolution}$), the normalized value of a satellite's designed lifetime is used since we assume that the satellite lifetime is inversely proportional to the satellite's opportunity to evolve (i.e. shorter lifetime=>more development cycles=>more evolution opportunities).

$$\mathrm{P_{evolution}} = 1 - \frac{\mathrm{Lifetime(years)}}{10}$$

The denominator 10 corresponds to the highest design lifetime value of the satellite population (SAR-Lupe & SARah).

Figure 6 shows the potential for evolution of traditional and NewSpace small satellite systems. **NewSpace small satellite systems are likely improve their capabilities (better resolution, wider swath…) more quickly than traditional systems**.

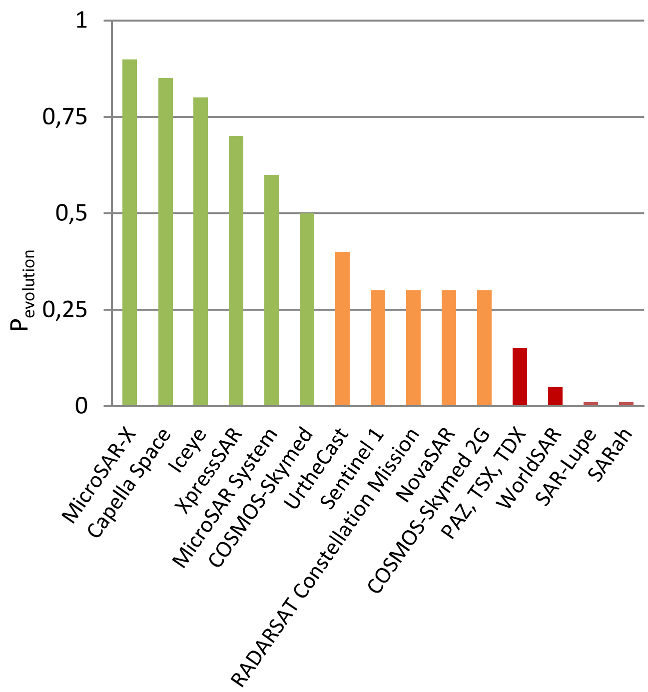

Figure 6: Evolution Rate Of The Satellites Performance Index

5. FINANCIAL ANALYSIS OF SAR CONSTELLATIONS

In order to assess the performance index achieved per euro invested, the aforementioned performance indexes of 12 constellations were analyzed as a function of cost.

The total cost of the constellation was obtained by adding the development cost of the satellites to the launch cost of the constellation.

The total constellation cost does not include ground segment or constellation operating service costs.

All considered cost were converted to 2017 economic conditions.

Prices assumed for launches are 20k€/kg for Ariane 5 and 25k€/kg for the Atlas and Proton launchers [5]. In order to calculate the launch price of the constellations, the value of 25k€/kg was assumed for the traditional heavy satellites and the value of 30k€/kg (target price of Electron small satellite launcher) was assumed for small satellites. Small satellites were assumed to be launched as secondary payloads or as main payloads of a dedicated small satellite launcher [6].

Table 3 shows the share of launch prices in the total cost of the constellations (%LP):

$$\%\text{LP} = \frac{\text{launch price of the constellation}}{\text{total cost of the constellation}}$$

Table 2: Launch Price Percentage Of Total Constellation Cost

Constellation	Percentage of the launch price in the total cost of the constellation
Iceye	42%
COSMO-SkyMed 2G	32%
OptiSAR	28%
SAR-Lupe	24%
NovaSAR	23%
Capella Space	21%
PAZ, TSX, TDX	20%
MicroX SAR	19%
Sentinel 1	16%
RADARSAT Constellation Mission	16%
SARah	16%
COSMO-SkyMed	13%

Figure 7 shows the total cost of the constellations per unit mass.

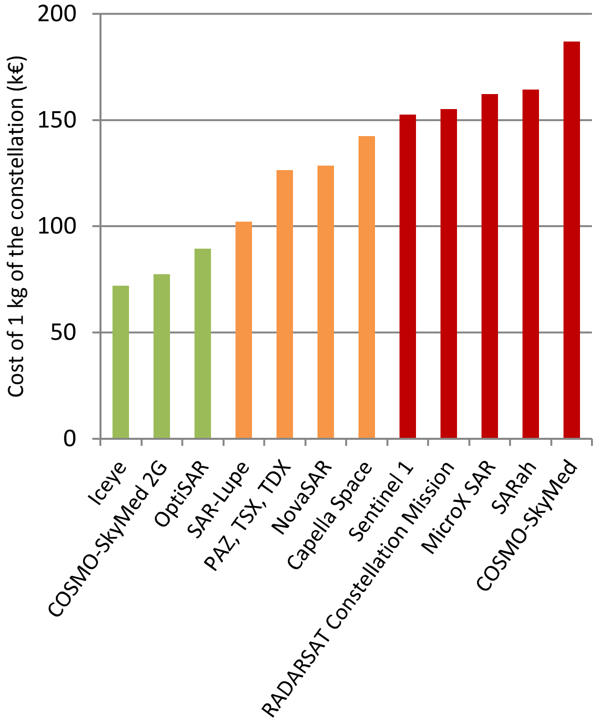

Figure 7: Cost Per Kg (K€/Kg) Of The SAR Constellations (Including Launch)

The NewSpace systems, developed with a low cost approach are mostly less expensive per unit mass than traditional systems.[3]

Figure 8[4] shows the ratio of the constellation performance index to the constellation total cost.

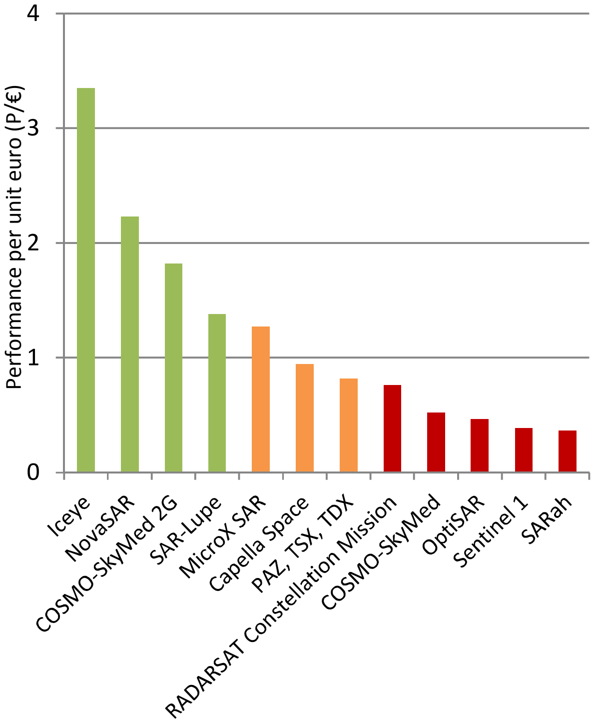

Figure 8: SAR Constellation Performance Index Per €Uro (Including Launch)

In most cases, the small satellites constellations have a higher performance index per euro spent for their development than traditional systems.

6. CONCLUSIONS

Based on the above initial results, **small satellite constellations** appear to **offer a high value per euro solution for the development of performing SAR space infrastructure.**
However, this result addresses only development and launch phases, and assumes set launch prices per kg that may change significantly over time. In order to complete the assessment, the costs and performance related to the operations and data dissemination aspects need also to be evaluated and compared between new space small satellites and traditional systems.

[3] Note: 1. MicroSAR-X is more expensive than many traditional systems. This suggests that small satellites are not per se necessarily competitive. Small satellites need to adopt innovative commercial approaches (i.e. Iceye, UrtheCast and Capella Space) in order to be financially competitive.

2. COSMO-Skymed 2G has a very low cost per Kg as a traditional system since it probably leverages COSMO-Skymed 1st generation investments.

[4] The Iceye and NovaSAR constellation performance indexes per euro are higher because they were developed with low cost approaches. With medium constellation performance indexes (~0.3), the Iceye and NovaSAR constellations still reach higher performance indexes per euro than other systems.

Once again, COSMO-Skymed 2G appears to benefit from COSMO-Skymed 1st generation investments.

7. REFERENCES

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