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Nanosats take off, but they don't take over

Deloitte predicts that by the end of 2015 over 500 nanosatellites (nanosats) will be in orbit. Nanosats have a mass of between one and ten kilograms,[141] compared to hundreds or even thousands of kilograms for the average commercial satellite. They also tend to be sized in increments of ten centimeters (cm), with a 30 cm x 10 cm x 10 cm configuration being the most common, whereas most commercial satellites measure at least one meter or more in every dimension.[142] Prior to November 2013, only 75 nanosats had ever been launched, and another 94 were put in orbit in the three months ending January 2014, for a total of nearly 170.[143] Our prediction calls for a nearly 200 percent increase in the installed base. Nanosats are attractive for many reasons: they are cheaper than conventional satellites, lighter, easier to build and test, easier to launch, and (as a result of Moore's Law exponentially adding to the functionality of the electronics) increasingly capable of more complex computational tasks.

Students of technology history may wonder whether this is another case of innovative disruption. Although nanosats are currently much less capable than traditional small, medium and heavy satellites, will they follow a similar path to personal computers, MP3 players and camera phones – come in at the low-end, keep improving and eventually dominate the market?

Deloitte predicts that the answer is probably not. Although taking something the size of a small house and replacing it with something that fits on a desktop worked for the PC industry disrupting mainframe computers, nanosats are likely to be additive, and not disruptive for the commercial satellite market, and not just in 2015 and 2016, but in the medium-term. There are specific barriers related to the laws of physics that will likely prevent nanosats from capturing significant parts of the markets that the larger satellites now dominate: in this case, it is 'rocket science'.

The global commercial satellite industry generates about $200 billion in revenues annually.[144] Services (such as satellite pay-TV subscriptions) are the largest part at $115 billion;[145] ground equipment (mobile terminals, dishes, gateways and control stations) $55 billion; launch is 'only' about $7 billion;[146] and the satellites themselves $15 billion.

A $200 billion market should present significant opportunities: that's about the size of the entire US fast food restaurant industry or more than double global tablet sales.[147] If nanosats could capture a significant part of the market from larger satellites, it could be a game-changer. So why is this unlikely to happen, especially when media articles trumpet the potential of nanosats?[148]

Price and processing performance matter a lot, both in space and on the ground. However over 90 percent of the commercial services currently delivered by satellites of any size require certain fundamental characteristics: the ability to stay in their correct position in orbit; the ability to transmit enough power back down to Earth that even small receivers will find usable; and the ability to sense relatively small features.

Staying in their correct position in orbit is a potential problem for nanosats. At less than ten kilograms, and ten centimeters on a side, they have very little internal capacity. Larger satellites use gyroscopes and reaction wheels to make sure they are always pointed in the right direction (attitude control) and have between four and 12 thrusters, powered by propellant (such as hydrazine or xenon) which allows them to maintain a stable orbit (station keeping) given the perturbation effects of gravity or drag from the tenuous upper atmosphere.

Nanosats can use miniature gyroscopes and reaction wheels for attitude control, but they generally have no room for thrusters[149] (or propellant for that matter) for orbital maintenance. This means that some are likely to have usable lives no more than 12-36 months and so require more frequent replacement launches.[150] Most proposed nanosat applications involve Low Earth Orbits (LEO), below 2,000 kilometers; and the inability to stabilize orbits is most severe for LEOs with orbits from 160 to 500 kilometers.[151]

Further, one of the principal potential advantages for nanosats in communications is extremely low latency. Most communications applications involve geostationary (GEO) satellites with an orbital radius of about 36,000 kilometers.[152] Although radio waves travel at the speed of light, the round trip still takes about 250 milliseconds, which can be an unacceptable delay for some communications services. A constellation of nanosats in very low earth orbits would have very low latency, but would also have more severe station keeping needs.

141. Miniaturized satellite, Wikipedia, as accessed on 11 December 2014: http://en.wikipedia.org/wiki/Miniaturized_satellite

142. Satellites are classified strictly by weight, rather than size. However, assuming similar densities, the average 10 kilogram satellite will be not much larger than 3-4 10 cm by 10 cm by 10 cm modules, or less than 5 liters in volume. This is before any components may be unfolded or unfurled: there are three meter satellites that have antennas or solar panels that can extend more than ten meters.

143. Nanosats are go!, The Economist, 7 June 2014: http://www.economist.com/news/technology-quarterly/21603240-small-satellites-taking-advantage-smartphones-and-other-consumer-technologies

144. Report cites gains by U.S. industry in commercial market, Space News, 17 June 2013: http://www.spacenews.com/article/satellite-telecom/35827report-cites-gains-by-us-industry-in-commercial-market

145. The various Direct-to-Home satellite TV services are the majority, at $90 billion or almost 80 percent of services. Ibid

146. Terrestrial GPS receivers are the lion's share, at $32 billion or almost 60 percent of ground equipment. Ibid

147. Revenue of the United States fast food restaurant industry from 2002 to 2018 (in billion U.S. dollars)*, Statista, 2014: http://www.statista.com/statistics/196614/revenue-of-the-us-fast-food-restaurant-industry-since-2002/; The tablet sales revenue are estimated at $80 billion for 2015.

148. Nanosats are go!, The Economist, 7 June 2014: http://www.economist.com/news/technology-quarterly/21603240-small-satellites-taking-advantage-smartphones-and-other-consumer-technologies

149. Although some work is being done on electric thrusters for nanosats.

150. That being said, most nanosats are expected to have relatively short design lives anyway: a few years in most cases, not the 10-15 years that larger satellites are designed for. So orbital stabilization won't be the limiting factor in some cases.

151. Low Earth orbit, Wikipedia, as accessed on 11 December 2014: http://en.wikipedia.org/wiki/Low_Earth_orbit

152. Geostationary orbit, Wikipedia, as accessed on 11 December 2014: http://en.wikipedia.org/wiki/Geostationary_orbit

Power is another problem, not so much in terms of processing the data (due to the effect of Moore's Law), but with taking the output of that processing, whatever it might be, and beaming it back down to Earth. Whether a TV satellite is distributing a show, or is one of the GPS constellation of satellites emitting a timing signal that allows a smartphone to determine its location, the signal received by the consumer device on Earth is often only microwatts or even nanowatts in signal power. But as with all radiofrequency transmissions, there is an inverse square law in effect, which means that the satellite needs to transmit down output power of tens, hundreds, or even thousands of watts, even from the nearest Low Earth Orbits, for most home or consumer applications. Depending on footprints, antennas and frequency bands, small receivers on Earth require more power density to come down from space, and even ten watts is a large amount of power to transmit: that's about 40 times as much as the maximum output from a 3G smartphone.

Luckily, there is a free power source in space: the Sun. A few square meters of super-efficient gallium arsenide solar panels provide up to thousands of watts of power,[153] more than enough for GPS, sensing or communication satellite needs. Add another 30-50 kilograms of Lithium Ion batteries for those periods[154] when the Sun is behind the Earth, and all is usually well. But nanosats (which weigh up to ten kilograms) don't have enough room for solar cells or batteries of the requisite capacity. Although both solar and battery technologies are improving, they are doing so slowly. Even a decade from now, although some nanosats should be capable of beaming a signal to Earth that is detectable by the average consumer receiver, they are unlikely to be competitive with larger satellites.

An associated problem is that size also matters for antennas, even assuming equal power. Bigger antennas are better for sending information down to Earth or receiving signals from a ground station. There are various kinds of antennas on satellites: reflectors, horns and phased arrays. Large satellites can use unfurlable mesh reflectors that are up to 12 meters across; solid antennas are up to 3.2 meters in diameter; and even the LEO Iridium constellation of voice and data satellites have phased array antennas that are 188 cm by 86 cm. Nanosats, at least a couple of whose dimensions are no more than ten centimeters, must use antennas that (even if unfurled) are commensurately smaller than for larger satellites resulting in decreases in gain, taper or coverage area, depending on frequency).[155] There are articulated antennas with a 30 cm diameter on satellites today, but this stretches the definition of nanosat.[156]

Many of the commercially useful things that satellites can do require sensitivity. Any kind of observation satellite needs to look down hundreds of kilometers or more, through a turbulent atmosphere, and accurately resolve and image features (optically or with radar) that can be less than a meter across. This is very difficult. Or they need to pick up Earth-originated signals that may be one or two watts in strength on Earth but have attenuated in their journey and are now only picowatts in strength. This is also very difficult.

Either the sensors needs to be ten centimeters or more across, or there need to be optics and filters in front of the sensor that are usually 10-100 cm long. Neither sensor nor optics will fit on a nanosat. There is a useful analogy with cameras on smartphones. Although improvements in semiconductor technologies allow manufacturers to put a ten megapixel sensor chip on a smartphone, it is typically only about 15-25 millimeters square, and the lens is usually no more than four millimeters away from the focal plane.[157] Professional photographers who sell their pictures for money use cameras with physically larger sensor chips that can be up to 2,000 mm square (about 100 times larger) and telephoto lenses that can be 500 mm or more in length (once again, over 100 times longer.) In the same way, any satellite trying to capture Earth Imaging at sub-meter resolutions will likely require devices (lenses, mirrors, and sensors) that won't fit in a cube 10 cm on two of its sides.

Although stability, power and sensitivity are the most important challenges for nanosats, it is worth mentioning some other issues briefly. There are decades of experience with processes and procedures for launching, deploying and even servicing large satellites. There is no similar knowledge base at present for nanosats, especially for some of the proposed large constellations of dozens or even hundreds of them. It is not an insuperable problem, but it isn't trivial either. Next, just like down on Earth, there are only certain slices of the electromagnetic spectrum that are suitable for transmitting information, and that spectrum is finite and needs to be allocated. This constraint is most severe for satellites in LEOs (which will include almost all nanosats) and those using lower frequencies. Finally, there are already concerns about the amount of space debris in orbit: there are nearly 20,000 objects larger than five centimeters being tracked at present.[158] With potentially thousands of nanosats being launched into orbits, with some failing to be deployed and others going out of service over time, the problem will get worse.

153. Some future satellites are expected to have even higher power requirements. The Alphabus platform will provide 22 kW. See: High-throughput satellite market still expanding, Aviation Week: 30 December 2013: http://aviationweek.com/awin/high-throughput-satellite-market-still-expanding

154. Depending on the orbit, the Sun may not be visible for some hours out of 24.

155. For those who are interested, the following website has a discussion of the various antenna types, as well as the optimization of characteristics like gain and taper. See: Antennas for satellite communications, Geosats, as accessed on 11 December 2014: http://www.geosats.com/antennas.html

156. Opening up the sensor suite beyond GNSS (slide 22), University of Graz, 2013: http://www.uni-graz.at/opacirowg2013/data/public/files/opac2013_Chris_McCormick_presentation_824.pdf

157. Oppo's latest smartphone may feature a gut-busting 50MP camera, Techradar, 3 March 2014: http://www.techradar.com/news/phone-and-communications/mobile-phones/oppo-find-7-snaps-a-new-image-reveals-a-50-megapixel-sensor-1230579

158. Space debris, Wikipedia, as accessed on 11 December 2014: http://en.wikipedia.org/wiki/Space_debris

It needs to be stressed that nanosats are an important innovation in satellite technology. Their low cost and flexible design will likely make possible many kinds of scientific experiments, or Earth Imaging at more frequent capture rates but lower resolutions. Tracking ships at sea requires neither particularly large sensors nor high power transmission:[159] another ideal market for nanosats.

But if we look at the $200 billion existing satellite market, roughly 80 percent is almost certainly not addressable by any space-based device smaller than ten kilograms – either today, or even by 2025

159. Automatic Identification System (AIS) is a mandatory navigation safety communications system under the provisions of the Safety of Life at Sea (SOLAS) Conventions., exactEarth, as accessed on 11 December 2014: http://www.exactearth.com/technology/satellite-ais

Bottom Line

In the short or even medium term nanosats may not be able to capture or disrupt many of the market segments currently served by larger satellites but they do lower the cost and challenges of getting a useful object into space; they will likely attract investor attention and get the public more interested in the satellite market. They will almost certainly enable testing of new technologies on low cost and 'disposable' platforms, which in turn may foster the emergence of new applications or services.

It is also worth noting that the many technologies that improve nanosats, and make them feasible in the first place, also make the larger satellites better, lighter and cheaper too.

The price of satellites and associated costs for most applications will not be disrupted downwards. Based on the announced plans for nanosats to date, over half will be technology prototypes or for the science and education markets, and 40 percent will be targeted at the military and commercial Earth Observation market, but with the limitations noted above (power, station keeping and sensitivity.) Only five percent of nanosats are even trying to compete in the communications satellite sector, which generates over 80 percent of the annual $160 billion in the services and ground equipment satellite markets.

Launch or deployment risk will be much the same for nanosats as for larger satellites. Regardless of the size of satellite, an exploding launch vehicle will continue to be a risk, and deploying nanosats once they are in orbit is likely to carry similar risks to larger satellites.

Although this prediction focuses on nanosats, there are microsats (10-100 kilograms) and minisats (also known as small satellites, and weighing 100-500 kilograms) which are bigger than nanosats but smaller than the majority of satellites deployed today. Over time, these categories of small satellite are almost certain to have more disruption potential than nanosats.

Nanosats are an important innovation in satellite technology. Their low cost and flexible design will likely make possible many kinds of scientific experiments.

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