

## **Evolving Goals and Techniques of Satellite Constellation Design for Navigation, Communications and Remote Sensing: 1958-2018**

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Low Earth Orbit (LEO) satellite constellations were first deployed over half a century ago for use in navigation, Earth-space communications and Earth observation missions. Most satellite constellation design methodologies focus on methods for deploying multiple satellites in a manner that guarantees minimum position uncertainty (for navigation), continuous Earth-space or inter-satellite coverage (for communications) or minimum re-visit time (for Earth observation) over a given region. The emergence of low cost CubeSats and efforts to lower launch costs through development of reusable launch vehicles has contributed to recent interest in satellite constellation design. However, despite the growing importance of satellite constellations in space mission design, very few surveys of the field have been published and those that have generally pay scant attention to the perspectives of those who are developing the navigation, communications or Earth observation payloads carried by these satellites.

Here, we have sought to overcome this oversight through a systematic survey of the satellite constellation literature with particular focus on the manner in which the goals and techniques of satellite constellation design have evolved over the past sixty years. While the earliest efforts focused on optimal techniques for ensuring a minimum level of terrestrial coverage using the smallest number of satellites, the field has rapidly evolved to consider: 1) optimal techniques for deploying, maintaining and repairing constellations using the least fuel, 2) techniques for ensuring optimal performance of inter-satellite relays, 3) techniques for accommodating satellites with limited transmit/receive capabilities such as Cubesats, and 4) wireless networking protocols such as Delay Tolerant Networking that account for long but predictable link outages. We conclude by identifying key specialized and evolving requirements of navigation, communications and Earth observation payloads that radio scientists must return to developers of satellite constellation design techniques.