SpaceX's Starlink Constellation Program

Network protocols in orbit: Building a space-based ISP

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Points to discuss:

- **What is Starlink project**
- **How it works?**
- **Advantages**
- **Disadvantages**
- **Starlink Developers Insight**
- **When is it coming to India?**

Starlink Project:

Starlink is a satellite internet constellation being constructed by SpaceX providing satellite Internet access. The constellation will consist of thousands of mass-produced small satellites in low Earth orbit (LEO), which communicate with designated ground transceivers. The SpaceX satellite development facility in Redmond, Washington houses the Starlink research, development, manufacturing, and orbit control teams. The cost of the decade-long project to design, build, and deploy the constellation was estimated by SpaceX in May 2018 to be at least US$10 billion. SpaceX intends to provide satellite internet connectivity to underserved areas of the planet, as well as provide competitively priced service in more urbanized areas. The company has stated that the positive cash flow from selling satellite internet services would be necessary to fund their Mars plans. SpaceX has long-term plans to develop and deploy a version of the satellite communication system to serve Mars.

Technologies involved:

- **Ku Band 12-18GHz (Satellite TV & VSAT - Very-small-aperture terminal System for Ships)**
- **Ka Band 26.5-40GHz (Uplink frequency for satellite communications)**
- **E Band 60-90GHz (RF/Microwave backhaul links)**
- **Phased array (a phased array usually means an electronically scanned array, a computer-controlled array of antennas which creates a beam of radio waves that can be electronically steered to point in different directions without moving the antennas)**
- **Laser Communication (Space-to-space)**
- **Spacecraft type: small satellite (smallsat)**
- **Launch Vehicle: Falcone 9 Rockets (First Orbital Class Rocket Capable of Re-flight)**

How it works?

Falcon 9 is a two stage rocket the first stage uses MERLIN D (M1D) Engine (cluster of 9 engines) which support rocket grade kerosene & Liquid Oxy as rocket propellants. Thrust produced is 845KN which means (2.0 km/s). it travels 10 times the speed of sound. It takes around 158 seconds for it to reach the Escape Velocity of earth and the First Stage Engine is shut down to initiate stage separation, this is called Main Engine Cut Off (MECO) so the FS can descend back to earth for reuse. The second stage, powered by a single Merlin Vacuum (MVac) Engine, delivers Falcon 9's payload to the desired orbit. The second stage engine ignites a few seconds after stage separation, and can be restarted multiple times to place multiple payloads into different orbits. The Payload is 60 Satellites which are enclosed by FAIRING made of a carbon composite material, the fairing protects satellites on their way to orbit. The fairing is jettisoned approximately 3 minutes into flight, and SpaceX continues to recover fairings for reuse on future missions. The whole launch to deployment takes roughly 1.3 hrs. Post deployment, these 60 satellites use their ion thrusters to separate themselves and move to their final set orbit which is 550km from surface (the LEO zone).

Fun Fact: Falcon 9 is from the Millennium Falcon in the "Star Wars" Movies, the 9 refers to the number of engines that power it.

The satellites will employ optical inter-satellite links (Free-space optical communication (FSO)) and phased array beam-forming and digital processing technologies in the Ku- and Ka-bands.

Early satellites were launched without laser links. The inter-satellite laser links were successfully tested in late 2020. The SpaceX non-geostationary orbit communications satellite constellation operate in the high-frequency bands above 24 GHz, Starlink satellites use Hall-effect thrusters with krypton gas as the reaction mass for orbit raising and station keeping. So having a lower propellant cost.

User Terminals (User End Device - Dish):

The system will not directly connect from its satellites to handsets. Instead, it will be linked to flat user terminals the size of a pizza box, which will have phased array antennas and track the satellites. The terminals can be mounted anywhere, as long as they can see the sky. Partial satellite constellation in August 2020 suggested users experienced download speeds from 11 Mbit/s to 60 Mbit/s, and upload speeds from 5 Mbit/s to 18 Mbit/s.

Ground station:

A ground station, Earth station, or Earth terminal is a terrestrial radio station designed for extraplanetary telecommunication with spacecraft or reception of radio waves from astronomical radio sources, it establishes a telecommunications link. A principal telecommunications device of the ground station is the parabolic antenna. SpaceX's ground stations would also be installed on-site at Google data-centers world-wide.

Advantages:

- Latency is very low. Latency is the time it takes to send data from one point to the next. When satellites are far from Earth, latency is high, resulting in poor performance.
- Starlink satellites are over 60 times closer to Earth than traditional satellites, resulting in lower latency and the ability to support services typically not possible with traditional satellite internet.
- Starlink is ideally suited for areas of the globe where connectivity has typically been a challenge. Unbounded by traditional ground infrastructure, Starlink can deliver high-speed broadband internet to locations where access has been unreliable or completely unavailable.
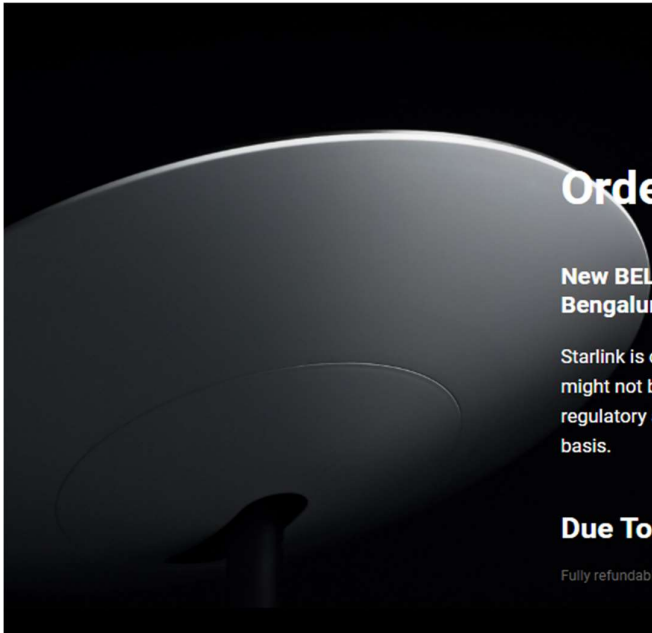
Disadvantages:

- **Light pollution:** The planned large number of satellites has been met with criticism from the astronomical community because of concerns over light pollution. Astronomers claim that the number of visible satellites will outnumber visible stars and that their brightness in both optical and radio wavelengths will severely impact scientific observations. Because the Starlink satellites can autonomously change their orbits, observations cannot be scheduled to avoid them. The International Astronomical Union (IAU), National Radio Astronomy Observatory (NRAO), and Square Kilometer Array Organization (SKAO) have released official statements expressing concern on the matter.
  Solution: SpaceX has official solution theory release for the issue. Usage of visor and Advance Early Mission (Orbit Raise and Parking Orbit) Roll Maneuver
  https://www.spacex.com/static/images/updates/orientationroll2.png
- **Space debris:** The large number of satellites employed by Starlink also creates a long-term danger of space debris resulting from placing thousands of satellites in orbit and the risk of causing a satellite collision, potentially triggering a phenomenon known as Kessler syndrome, which is like a pinball effect between all of the satellites on Earth that can cause all of the satellites to become inoperable.
  Solution: SpaceX has said that most of the satellites are launched at a lower altitude, and failed satellites are expected to deorbit within five years without propulsion & will burn out in transit to earth in a safe way.

Starlink Developers Insight:

Starlink software, both in satellites and on the ground, is written almost exclusively in C++, with some prototyping development in Python. The software is developed in a continuous integration (CI) environment, with teams merging into the master development branch often and deploying to the fleet of satellites in space each week. They use C++ for most of the vehicle control software. There is a lot of heritage with it at SpaceX as it's a very low-level language we can use on bare metal microcontrollers. This lets them use it on their

embedded Linux computers that we use throughout all different vehicles like Falcon 9, Crew Dragon.

When is it coming to India?