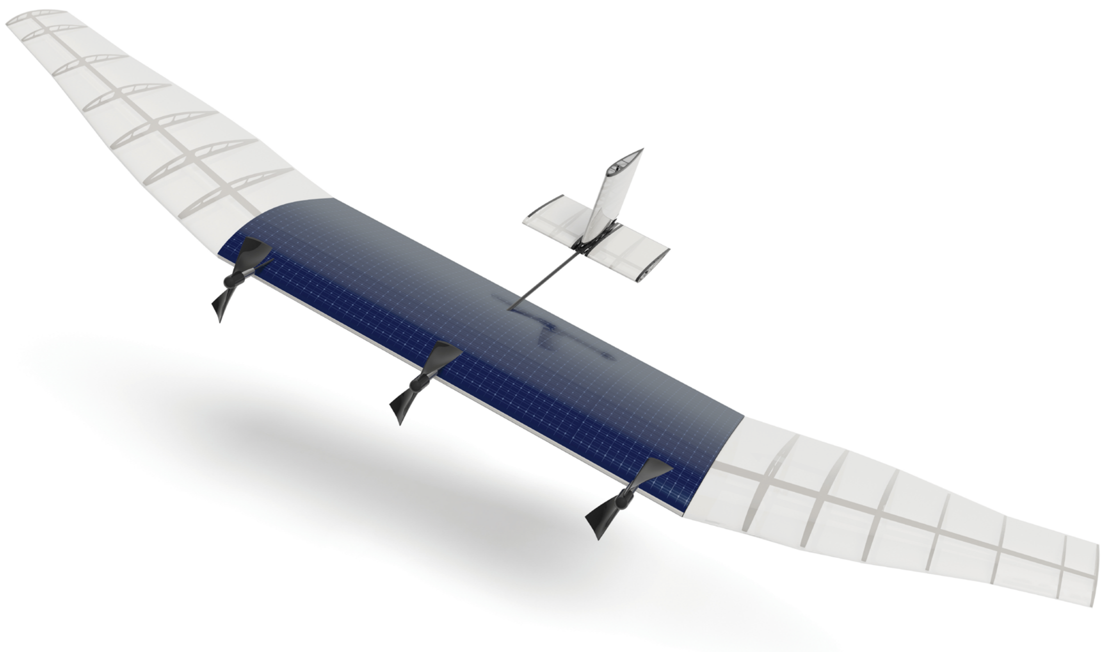


Connecting the World from the Sky

Last August, Facebook partnered with leading technology companies to launch Internet.org — a global effort to make affordable basic internet services available to everyone in the world.

Connecting the world is one of the fundamental challenges of our time. When people have access to the internet, they can not only connect with their friends, family and communities, but they can also gain access to the tools and information to help find jobs, start businesses, access healthcare, education and financial services, and have a greater say in their societies. They get to participate in the knowledge economy.

Building the knowledge economy is the key to solving many of our big social and economic challenges, and creates new growth and opportunities for people in every country. A recent study by Deloitte found that the internet is already an important driver of economic growth in many developing countries. Expanding internet access could create another 140 million new jobs, lift 160 million people out of poverty, and reduce child mortality by hundreds of thousands of lives. Connectivity isn't an end in itself, but it's a powerful tool for change.

However, there are significant obstacles to building the knowledge economy, and the internet is growing very slowly. Today, only around 2.7 billion people have access to the internet — just a little more than a third of the world's population. That number is only growing by about 9% every year.

If we want to connect the world, we have to accelerate that growth. That's our goal with Internet.org.

Internet.org progress to date

In my last paper, I outlined a plan to deliver basic internet services to everyone by working to decrease the costs of connectivity, building more efficient services that use less data, and by partnering with mobile operators on new models for access that can help the industry grow while also bringing more people onto the internet.

Since then, we've achieved promising early results from our first set of partnerships. In the Philippines, we worked with mobile operator Globe to offer free data access to our apps, make it easier for people to register for a data plan and get a loan for their plan. In just a few months we helped double the number of people using mobile data on Globe's network and grew their subscribers by 25%. In Paraguay, by working with TIGO we were able to grow the number of people using the internet by 50% over the course of the partnership and increase daily data usage by more than 50%. These two partnerships alone helped almost 3 million new people access the internet.

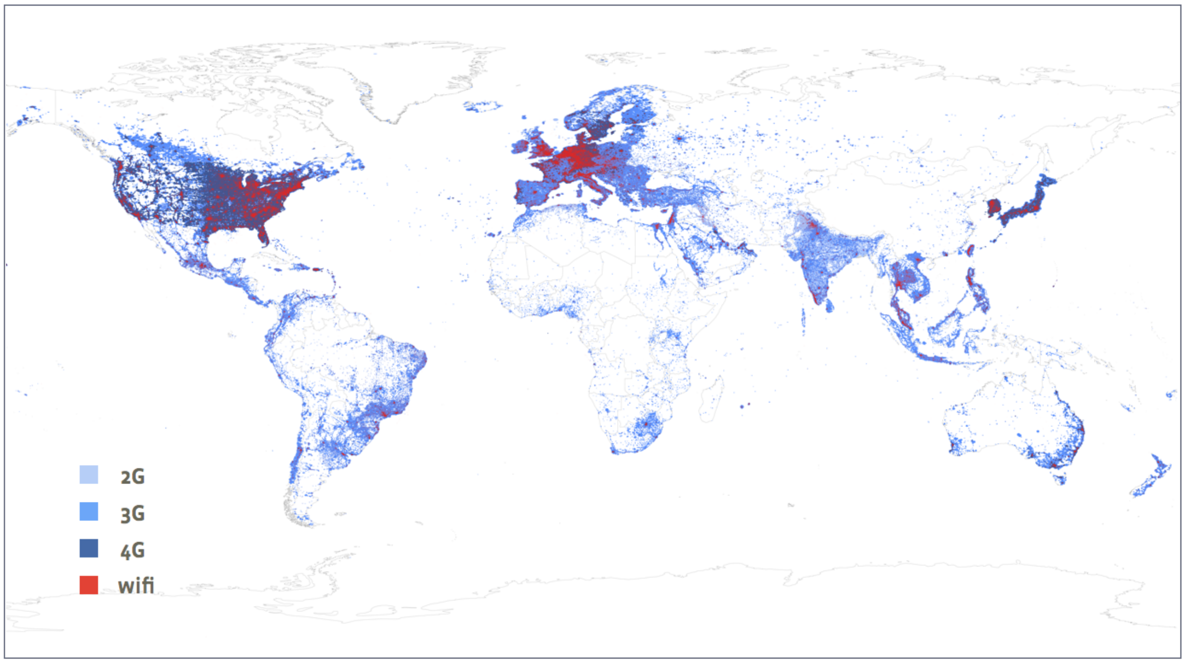
These are still early partnerships, and over the coming years we will expand these efforts in additional markets. By working together with operators to drive awareness and demand for internet services, and by collaborating on new models for access that decrease the cost of data, we think we can bring billions more people onto the internet over the next few years.

But partnerships are only part of the solution. To connect everyone in the world, we also need to invent new technologies that can solve some of the physical barriers to connectivity. That's why Facebook in investing in building technologies to deliver new types of connectivity on the ground, in the air and in space.

Different communities require different technology

Facebook's approach to developing new platforms is based on the principle that different communities need different technical solutions.

Our research has shown that approximately 80-90% of the world's population lives today in areas already covered by 2G or 3G networks. These environments are mostly urban or semi-urban, and the basic cell and fiber infrastructure has already been constructed here by mobile operators. For most people, the obstacles to getting online are primarily economic.

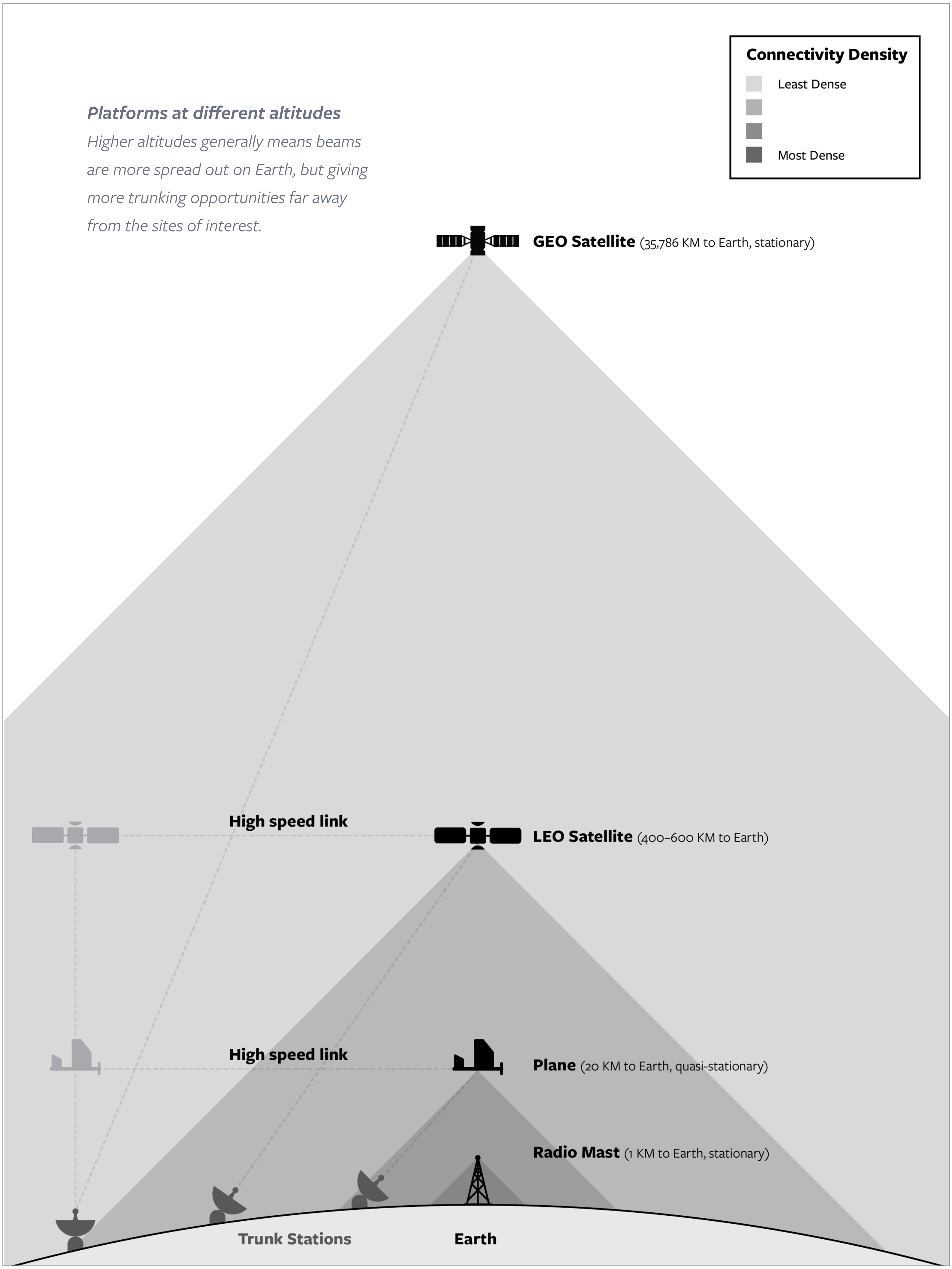


Coverage Heat Map

For the remaining 10-20%, the economic challenges also apply, but in this case they also explain why the basic network infrastructure has yet to be built out. The parts of the world without access to 2G or 3G signals are often some of the most remote places on Earth, where physical access to communities is difficult. Deploying the same infrastructure here that is already found in urban environments is uneconomical as well as impractical.

But deploying the same infrastructure solutions for everyone is also unnecessary when we consider the different population densities found in different communities. In dense urban areas, greater network capacity is needed to serve a larger population. That means we need to build cell towers, small cells or a big network of wi-fi access points. But in the less urban and less connected markets, there are also fewer people distributed over a wider area. Deploying other infrastructure solutions like satellites might be more efficient and cost effective.

Our strategy is to develop different types of platform to serve different population densities.


Connectivity Density
Least Dense
Most Dense
Platforms at different altitudes
Higher altitudes generally means beams are more spread out on Earth, but giving more trunking opportunities far away from the sites of interest.
GEO Satellite (35,786 KM to Earth, stationary)
High speed link
LEO Satellite (400–600 KM to Earth)
High speed link
Plane (20 KM to Earth, quasi-stationary)
Radio Mast (1 KM to Earth, stationary)
Trunk Stations
Earth

Dense urban areas: in urban environments, wireless mesh networks can provide simple to deploy and cost effective solutions. We will discuss this further in a later paper.

Medium density areas: for limited geographical regions, unmanned aerial vehicles can provide a novel and efficient method of access. High altitude solar-powered aircraft can be quickly deployed and have long endurance.

Low density areas: across the largest areas of territory with the lowest population densities, satellites can beam internet access to the ground. Communications satellites today are expensive to deploy, but space-based methods of connectivity are becoming smaller and cheaper to launch.

Our teams in Facebook's Connectivity Lab are working on projects in each of these areas. The following sections of this paper will focus on how we're doing this for aerial and space-based platforms.

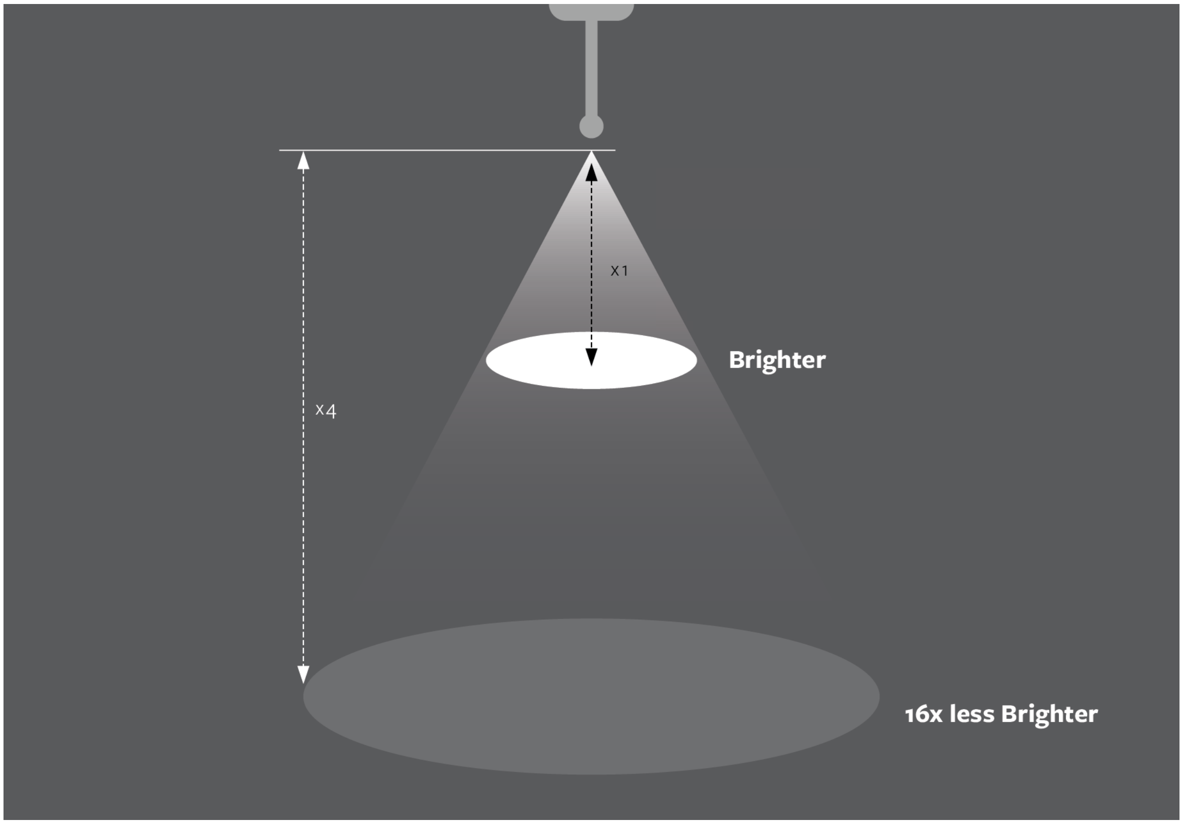
The physics of aerial connectivity

Before discussing the relative costs, benefits and capabilities of these platforms, it's important to understand the fundamental constraints we need to consider while working on aerial connectivity. These are not only issues of cost, efficiency and deployment, but also the basic laws of physics.

The most important constraint to consider is that as you increase altitude, assuming all else is equal, the signals emitted by aerial platforms cover a wider area and therefore become weaker. More specifically, the power of a radio signal weakens as a square of distance.

If you consider cell towers, they can provide really strong signals across relatively small areas. And stronger signals creates the ability to deliver higher capacity. A plane at an altitude of 20 kilometers will allow you to reach people more than 100 kilometers away, but the signal loss will be significantly higher than would occur for terrestrial networks. And if you send up a satellite that can beam internet across an entire continent, it might have wide reach across a large territory, but its signal will be a lot weaker than almost any other option for connecting.

Boosting the signal in order to achieve a high bandwidth capacity is also very impractical. Radio signals get weak very quickly, so they require a large amount of power to strengthen. Since satellites generally rely on solar power as their energy source, generating a lot of power (would need to square to make up the difference) would mean constructing either huge, unstable structures, which are impractical, or nuclear powered satellites, which are very expensive.



Physics of electromagnetic propagation

As radio waves or light propagate, everything else being equal, at a distance 4x from the source, a signal is 16 times weaker than at a distance 1x.

So physics creates a number of challenges for deploying aerial platforms for connectivity, and creates different costs and benefits for each platform. For lower population densities, where people are spread out across a large area, the higher up you go, the more cost effective it becomes to place trunk stations and to deliver the internet. But signal loss will also be higher, so satellite access is only really a way of providing a basic internet experience for remote communities. Likewise, for high population densities, only lower altitude platforms will be truly effective, and connection speeds will be faster and the experience better for a lot of people.

Given these challenges, Facebook is working on a range of technologies that will provide different options for connecting people.

Free space optics

Free space optical communication, or FSO, is a way of using light to transmit data through space. These are basically invisible laser beams in the infrared part of the spectrum.

FSO is a promising technology that potentially allows us to dramatically boost the speed of internet connections provided by any of the previously mentioned platforms. The lasers used in FSO systems provide extremely high bandwidths and capacity, on par with terrestrial fiber optic networks, but they also consume much less power than microwave systems. Because you can make the beam so much narrower, this allows you to focus all of your power exactly where you want it to go.

Using FSO technology could boost the signals being sent from Earth to orbit, and then between satellites in an orbital constellation. Potentially, the same system can also dramatically increase the speed of internet connections on the ground that are provided by satellite. If a laser receiver is mounted at a destination, a laser-equipped satellite can transmit data to it. Using FSO to connect people on the ground would dramatically increase the utility of satellites in providing internet access to larger segments of unconnected populations.

At the same time, FSO has a number of significant weaknesses. The narrow optical beams are hard to orient correctly and need to be pointed very precisely. The level of accuracy required is the equivalent of needing to hit a dime from 10 miles away, or hit the statue of liberty from California. Laser systems also require line of sight between both ends of the laser link, meaning that they don't work through clouds and are very vulnerable to bad weather conditions. As a result, backup radio systems are needed.

Despite these weaknesses, if we can overcome these problems, FSO can provide ways to connect people that are a lot better and more cost effective. We've already started hiring world experts on FSO, and we're going to invest in exploring the full potential of this technology over the coming years.

Drones and High Altitude Long Endurance systems

High altitude drones are one major area we're focused on developing. To understand the reasons for this, it is helpful to consider some of our technical constraints.

We want to:

- Fly as close to the ground as possible in order to maximize signal strength.

- Fly at a high enough altitude where the wind is not very strong in order to maximize endurance.

- Fly outside of regulated airspace for safety and quick deployment.

- Be able to precisely control the location of these aircraft, unlike balloons.

- Build the smallest structure possible so it requires minimal energy to stay aloft.

- Build a large enough structure that can effectively harvest all the energy it needs from the sun.

- Build the cheapest structure so we can cost effectively produce enough to span many areas.

- Build a re-usable structure to make it more cost effective as well.

Based on these constraints, drones operating at 65,000 feet are ideal. At this altitude, a drone can broadcast a powerful signal that covers a city-sized area of territory with a medium population density. This is also close to the lowest altitude for unregulated airspace, and a layer in the atmosphere that has very stable weather conditions and low wind speeds. This means an aircraft can easily cruise and conserve power, while generating power through its solar panels during the day to store in its batteries for overnight use.

With the efficiency and endurance of high altitude drones, it's even possible that aircraft could remain aloft for months or years. This means drones have more endurance than balloons, while also being able to have their location precisely controlled. And unlike satellites, drones won't burn up in the atmosphere when their mission is complete. Instead, they can be easily returned to Earth for maintenance and redeployment.

We're still finalizing the communication equipment payload, including FSO systems. If the technical hurdles can be overcome with free space optics, the value of this solution will only increase. But even equipped with microwave antennae, this system can potentially connect a lot more people to the internet in an efficient and cost effective way.

Our team is actively working on building our first aircraft now. We recently announced that key members from Ascenta, whose founders created early versions of Zephyr, which became the world's longest flying solar-powered unmanned aircraft, will be joining our Connectivity Lab to work on these aircraft. We expect to have an initial version of this system working in the near future.

Satellites and low population density areas

Despite the clear strengths of drone-based connectivity solutions, there will still be places where it remains uneconomical or impractical to deploy drones or to provide the internet connection to them. In these situations, satellites may prove a cheaper alternative for beaming internet access to communities.

There are two main types of orbits that Facebook is considering for deploying satellites: low Earth orbit (LEO) and geosynchronous Earth orbit (GEO).

Low Earth orbit
Low Earth orbit extends anywhere from 160 kilometers to 2,000 kilometers above the Earth. As a LEO satellite orbits, the Earth turns underneath. LEO is the simplest and easiest orbit to reach, and this is why the vast majority of satellites are deployed here.

LEO satellites have some clear strengths. Satellites in this orbit are close to Earth, so they can provide a usable signal while using less power. This means LEO satellites can be smaller and therefore cheaper to launch. There's also comparatively less signal latency at this orbit, so it's easier to use real-time services like the web or voice calling.

However, the signal is still weak and can only serve a small population density – probably less than 100 people per square kilometer. It also requires antennas to be installed at ground stations to track their movements. And because LEO satellites don't orbit at the same speed as the Earth spins, an entire constellation of satellites is necessary to maintain constant coverage. This drives up the cost considerably.

Geosynchronous Earth orbit
A geosynchronous orbit is an orbit around the Earth at the same speed that the planet is rotating at. To hold an orbit at this distance from the planet, a satellite holds steady at 35,786 kilometers above sea levels.

A satellite in this orbit can stay pointed at one region indefinitely. This means the base stations and trunk stations can be simpler and cheaper to configure since the beams don't need to be constantly tracking the moving constellations of satellites overhead.

As discussed earlier, with FSO technology it becomes possible to achieve much faster data speeds. With conventional microwave signals, it's much harder to deliver a high capacity signal as a geosynchronous satellite is 60-90 times further away. Since signals weaken as a square of distance, this becomes orders of magnitude worse.

This FSO approach is much harder for LEO because of satellite movement, but there are still considerable technical challenges to be solved here.

Satellites are expensive and slow to develop
Ultimately, space platforms are much more complex to develop and deploy than other competing technologies. Even if you can build satellites for relatively cheaply, transport to space can cost millions — or in some cases tens or hundreds of millions — of dollars.

Navigating the regulatory issues can be a slow and expensive process too. ITU licenses for regulated microwave spectrum can take 5-7 years to achieve, though FSO remains unregulated.

In spite of the challenges, satellites offer the potential to deliver connectivity solutions when all others fail. We're currently exploring both LEO and geosynchronous approaches.

Deployment

From our work examining the different technologies for offering aerial solutions for connectivity, it's clear that each platform has strengths and weaknesses. Some of these weaknesses will have to be fully solved in order to make the platforms viable and cost effective.

One major advantage of aerial connectivity, however, is that deployment to people's homes is relatively simple.

Relatively cheap devices already exist that can receive signals from the sky and broadcast wi-fi to mobile phones. These take the form of simple and durable boxes, and can become cheaper and capable of handling more kinds of signals over time. Even if everyone doesn't own one, someone in a village or community still may – a local store that wants to attract customers, a community hub or non-governmental organizations working in the area. Civil society organizations and governments would be ideal for disseminating these units throughout communities in developing countries.

This is a very different scenario from typical terrestrial network deployments. Installing traditional network infrastructure, like cell towers and fiber, requires digging. This means manual construction, modifying structures and building other physical infrastructure, and lots of regulatory approval. Having a network that depends on lots of facilities and hardware on the ground also makes your network subject to the insecurities of the ground – theft, looting, war and natural disasters.

By comparison, aerial connectivity is relatively plug-and-play. You can get an internet box and pick up signal from whatever is overhead.

Our approach

I hope this paper provides an interesting and useful overview of some of the technologies that can help bring internet access to everyone in the world.

Facebook's Connectivity Lab is building a team to develop these technologies, including areas such as drones, satellites, mesh networks, radios and free space optics, as well as other promising areas of research. We've hired some of the leading experts in these fields from NASA's Jet Propulsion Lab, Ames Research Center and other centers of aerospace research. If you're excited about working on this mission, we'd love to talk to you too.

Internet.org is a partnership between companies, non-profits and governments. No one company can do this work by itself, and Facebook will not deploy these technologies alone. We're looking forward to working with our partners and operators worldwide over the coming months and years. Together we can develop new solutions to these important problems, and deliver on the promise of a connected world.